ANALYSIS OF THE BEIJING GREENBELTS PLAN

USING GEOGRAPHIC INFORMATION SYSTEMS (GIS)

By

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To the Faculty of Washington State University:

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ABSTRACT

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Greenbelts are an important part of urban ecosystems and provide significant ecosystem benefits. Beijing, the capital city of China, started the Beijing Greenbelts Plan to achieve a sustainable ecosystem and ameliorate environmental problems including sandstorms and air pollution. As well, Beijing has the prospect of developing Beijing into an Eco-City for the Olympic Game in 2008.

This thesis explores the Beijing Greenbelts Plan and examines ecological services created by the Beijing Greenbelts Plan from qualitative and quantitative perspectives. Landscape ecological principles provide conceptual and qualitative explanations for examining the greenbelts. Two software packages, ARCGIS and CITYgreen, are applied to analyze the ecology aspects with quantitative evaluation of the greenbelt plan. Three scenarios are developed, analyzed, and compared to provide environmental statistics reports and approaches on improving the Beijing greenbelt plan.

The thesis concludes that the Beijing Greenbelts Plan almost reaches its goal on the percentage of tree canopy. As well, modifications are suggested to improve the Beijing Greenbelts Plan and increase the ecological benefits. The recommendations on the sustainable development of Beijing may be considered by planners and land-use decision makers.

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Chapter One: Introduction

In the twentieth century, many countries faced a growing urban pollution problem as urbanization and industrialization flourished. Urbanization has been a major historical trend for the past 150 years. It influences the urban environment in which people live, the air city dwellers breathe, the water they drink and bathe in, the indoor and outdoor noise they hear, and the geological and climate conditions they experience (Moore et al., 2003). Air pollution and noise exposure in the world increased steadily as urbanization progressed. Highways and streets pollute water through runoff and destroy green space. Urban buildings contribute to urban heat by increasing the temperature in cities (Lawrence, 1999).

A sufficient provision of green space such as greenbelts within urban areas is regarded as an effective way to mitigate environmental deterioration, which is associated with rapid urbanization. Urban green space improves the urban environment by purifying air and water, regulating micro-climate, reducing noise, protecting soil and water, and maintaining biodiversity. Green space contributes to public health, increases the quality of life of urban citizens and has recreational, cultural, and social values (Bound & Hunhammar, 1999).

Background of Study

Beijing, the capital city of China, has more than 3,000 years of history. It is located in the north of China within a temperate climatic zone. It has a total area of 16,800 km^2 and a population of about 13.8 million with an average population density of 821 persons/km^2 (Beijing Municipal Statistical Bureau, 2002). The rapid urbanization and the growing population continue to influence the urban environment in Beijing. The air quality in the city is getting worse. Sandstorms have frequently happened in spring in the last five years.

To develop Beijing towards an “Eco-City” and achieve the aim of “Green Olympic City 2008,” Beijing is planning to build up greenbelts. The Beijing Greenbelts Plan was proposed in 2003. The project is expected to improve air quality, hamper sandstorms, provide green space to local people, and subsequently promote sustainable development of Beijing (Li et al., 2004). According to the plan, three greenbelts will be constructed before 2007. The first greenbelt will be located between Beijing's third and fourth ringroads. The second greenbelt will be located in the suburb area, between the fifth and sixth ringroads. The third greenbelt will be developed in the mountain areas. The implementation of the Beijing Greenbelts Plan is expected to increase forest coverage to 50% of the city area and significantly decrease air pollution levels including SO_2, CO and NO_2 concentrations in the air.

Purpose of Study

The purpose of this study is to examine ecological services created by the Beijing Greenbelts Plan and attempt to make improvements. These are the major objectives of this study: 1. to review pertinent literature on key concepts and principles in landscape ecology and introduce technical tools for ecological analysis; 2. to analyze the impact of greenbelts on Beijing ecology, specifically on tree canopy creation and air pollution removals; and 3. to improve the Plan by providing suggestions and recommendations based on landscape ecology principles as well as Beijing’s specific situation.

To analyze the impact of urban green space on the urban ecosystem, two software packages, ArcGis (ESRI, 2004a) and CITYgreen (American Forests, 2003) are applied to statistically analyze the change in forest coverage and air pollutant removal brought by implementing the Beijing Greenbelts Plan. ArcGis offers spatial analysis tools to analyze landcover and to develop three scenarios. CITYgreen offers a statistical tool to calculate tree canopy and environment indicators based on air quality improvement. Additionally, CITYgreen provides a basic spatial structure that can directly link social and economic data to local environmental data, thus creating a more effective tool for sustainable urban planning (American Forests, 2003).

Due to limitations on information sources and time, this research does not take into account the issues of policy, real estate, and the influence of the city periphery. However, the approaches applied in the research will provide methods of analyzing ecological aspects of green space planning in Beijing. In addition, the recommendations for the Beijing Greenbelts Plan may be useful and could be considered by planners and land-use decision makers.

Outline of Thesis

This thesis contains six chapters.

Chapter 1, Introduction, begins with an historical background of Beijing, introduces the Beijing Greenbelts Plan and presents research objectives.

Chapter 2, Literature Review, provides an overview of green space and greenbelts including their definitions, history and development, and illustrates landscape design principles and designing strategies by presenting a series of case studies.

Chapter 3, Study Area, provides a general background on Beijing. It summarizes Beijing environmental problems, describes the Beijing Greenbelts Plan, and states the necessity for conducting the research.

Chapter 4, Methodology, lays out strategies and tactics that are applied through the study of greenbelts. It presents the spatial analysis techniques and the general steps in creating spatial model.

Chapter 5, Analysis, explicates three spatial geographic scenarios, which were the existing green space of Beijing in 1999, the Beijing Greenbelts Plan and an improved greenbelts scenario. The three scenarios would be simulated, analyzed, and compared in order to provide statistical reports and further insights on improving the Beijing Greenbelts Plan.

Chapter 6, Conclusion and Recommendation, takes a macro-view of the completed work and synthesizes the methods to improve the Beijing Greenbelts Plan. Limitations of this study and suggestions for future work are also presented.

Chapter Two: Literature Review

The purpose of this Literature Review is to provide background and principles on green space planning in the urban region. It starts with the definitions and history of green space, including greenbelts and greenways, which are the two main types of green space. Furthermore, it interprets the benefits of green space to ecology, recreation, and culture. Several landscape ecology principles and theoretical alternatives for distribution of green space are presented. Discussed next are the two software packages, ArcGis and CITYgreen, used to simulate and evaluate land-use planning from scientific perspective. Finally, three case studies are conducted to provide the strategies and guidelines for green space planning based on landscape ecology principles.

Green Space Definition and Benefits

Definition

Green space

The general term for green space is open space. Although a “standard” definition of green space keeps broad, there are specific characteristic features that set green space apart from other types of space. Green space in urban areas exists mainly as semi-natural areas and is essential for urban sustainability and the people's quality of life (Smith & Hellmund, 1993).

All land units regarded as green space may be viewed as ecosystems, which are defined as areas containing organisms, a physical environment, and the interactions and exchanges among the organisms and the environment (Thompson, 2002). Green space is an important part of complex urban ecosystems that provides significant ecosystem benefits. The history of green space planning began with the idea of the Garden City advocated by Ebenezer Howard. After Frederick Law Olmsted expounded the large urban park idea in the US, public green space have been increasingly designated in cities (Little, 1990).

Greenbelts, greenways, and urban parks are three main types of urban green space, which have significant ecological, social, and recreational functions (Shafer, 1999). They benefit urban communities environmentally, esthetically, recreationally, and economically.

Greenbelts

The notion of green space encircling a central city has been translated into the planning instrument of the greenbelt to confine unbridled urban sprawl (Wilson, 1989). A greenbelt is a ring of countryside where urbanization will be resisted for the foreseeable future, maintaining an area where agriculture, forestry, and outdoor leisure can be expected to prevail (Howard, 1898).

The purposes of greenbelts are to check the unrestricted sprawl of large built-up areas and safeguard the surrounding countryside from further encroachment, to protect the natural environment and improve air quality in urban areas, to ensure that urban dwellers have easy access to the countryside, with consequent educational and recreational opportunities, and to protect the unique character of rural communities, which might otherwise be absorbed by expanding suburbs (Thompson, 2002).

The protection of greenbelts was pioneered in the United Kingdom, where there are fourteen greenbelt areas, covering 13% of England (Thompson, 2002). Greenbelts were introduced around London following the Second World War. The notion was included in an advisory Greater London Plan prepared in 1944. Local councils were strongly urged to follow this detailed advice when considering whether to permit additional buildings in the greenbelt or assent to new uses being made of existing premises (Wikipedia, 2004).

Greenbelts were used in America in the design of several new planned communities, and towns (Teal et al., 1998). Benton MacKaye proposed systems of wooded open space that “would form a linear area, or belt around and through the locality” (Anderson, 2002, p. 33). His intent was more than just to surround cities with green space as a means of blocking urban sprawl.

In recent years, greenbelts have captured the attention and imaginations of land managers, landscape architects and planners interested in open space conservation. Greenbelts were implemented in different regions of the world, such as Canada and Germany, as well as in Asia (Sousa, 2003).

Greenways

A concept similar to a greenbelt is the greenway which has a linear character and may run through an urban area instead of around it. ‘Greenway’ is a more general term in the U.S. The purposes of greenways are to link landscape elements to form a linear networks system, usually along terrain features such as natural (e.g. ridgelines or rivers) and artificial (e.g. roads, canals, and railways) features (Smith & Hellmund, 1993).

The definition and purposes of greenways suggest a variety of greenway types and a multiplicity of uses. The typology distinguishes the types of greenways according to their dominant purpose, yet there is potential for overlap between each greenway type (Wikipedia, 2004). Recreational greenways may follow waterways, becoming riparian greenways. They are distinguished from greenways established along natural corridors and across land developed for human purposes. Ecological greenways most commonly follow natural landscape features, while the other greenway types are commonly found on both natural landscapes and landscapes altered by people for various purposes (Wikipedia, 2004).

As early as the 1860s, Frederick Law Olmsted recognized the great potential of linear open spaces for providing access to city parks and extending the benefits of parks into nearby neighborhoods. In 1866 and 1867, Frederick Law Olmsted and Calvert Vaux planned two connecting parkways for Central Park in New York City. They designed Central Park "to bring back a bit of nature" into the fast growing cities. Meanwhile, they anticipated that all major parks and open spaces would link together into comprehensive networks of greenways and green space (Smith & Hellmund, 1993, p. 8).

Benefits

Green space provides a large number of ecological, recreational and social benefits to communities. Although it would be a rather lengthy submission to list and identify every single benefit, the following is just a short list of the most important benefits that green space provides. The values and benefits of green space depend on their physical characteristics as well as the interests of those with a stake in their performance. Green space improves air quality and protects natural resources vital to people, plants, and wildlife. They can also preserve the biological diversity of plant and animal species by maintaining the connections between natural communities (Thompson, 2002). Some major ecological benefits of green space are air filtering, micro-climate regulation, noise reduction, and rainwater drainage. The social benefits of green space are to provide health benefits and quality of life to people.

Ecological Benefits

Green space has a host of important ecological benefits and maintains the ecological balance of regions. They protect natural areas and provide habitat for plants and animals. They cool down air and counteract excessive heat build up in cities through shading and vegetative evaporate transpiration. They also contribute to urban air quality by filtering out particulate matter, especially pollutants emanating from adjacent roadways. Moreover, they supply clean water to aquifers and maintain the quality of water resource by filtering excess nutrients in ground water (Lütz & Bastian, 2002). More details of the benefits are discussed below.

Air Filtering

Urbanization often produces large amounts of pollutants. Hazardous gaseous emissions, industrial effluents, and wastes adversely affect human health, vegetation, and property. As late as the mid-1990s, researchers estimated that urban air pollution contributed to 30,000–60,000 deaths per year in the U.S. (Leitão & Ahern, 2002).

It is clear that green space is an important and efficient way to attenuate air pollution. Green space abates the impact of pollutants by vegetation filtering pollution and particulates from the air (Jo, 2002). Vegetation is important for its ability to filter the air. Previous research indicates that up to 85% of air pollution in a park can be filtered out, and in a street with trees, up to 70%. In general, vegetation is much better than water or non-vegetated open spaces for filtering the air (Jo, 2002). Therefore, green space can be applied as a pollution mitigation tool in an industrial, urban development or for an historical site/sensitive area protection plan.

Planting trees in green space is the most important and efficient way to attenuate air pollution. Trees are efficient air cleaning machines that sequester many pollutants from the atmosphere, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), and particulate matter (PM) with sizes of ten microns or less (Jo, 2002).

Noise Reduction

Noise from traffic and other sources creates health problems for people in urban areas. Noise exposure, a common urban problem, may contribute to hearing impairment, hypertension, and ischemic heart disease. Green space can be an effective way to reduce noise by causing noise diffraction. Increasing green areas with soft ground is an easy way to decrease these noise levels (Nijwening, 1997).

Micro-Climate Regulation

Green space plays an important role in influencing climatic factors such as precipitation, evaporation and direction of prevailing winds. Green space in the city can regulate temperature deviations during both summer and winter. In this way green space can lower summer temperatures of cities. Green space can also decrease energy use for heating and air conditioning substantially in urban areas by shading houses in summer and reducing wind speed in winter (Mao et al., 1993).

Many cities benefit from green space by reducing heating costs. A study of Chicago found that the value of long-term benefits from trees was more than twice the present value of costs (Mao et al., 1993). Green space can also reduce wind velocity and increase atmospheric and soil moisture (Quam et al., 2005).

Rainwater Drainage

Green space contributes to solving problems of rainwater drainage. The soft ground of vegetated areas allows water to seep through, and the vegetation takes up water and releases it into the air through transpiration. Rainwater runoff is less in vegetated areas than vegetation-free areas. This benefits both the local climate and increases groundwater levels (Jo, 2002).

Cities can benefit economically from improved rainwater drainage through pervious and vegetated ground as the building and maintenance of storm water drainage systems involve large costs. Using this ecosystem service could lower these costs. The benefits of green space also include inhibition of erosion and increased nutrient recycling (Schrijnen, 2000).

Social Benefits

Green space provides social benefits including recreational, economic, aesthetic, and cultural benefits. It is essential to achieve the quality of life that creates a great city and that makes it possible for people to live a reasonable life within an urban environment (Davey, 1993). According to the Swedish economist Nils Lundgren, a good urban environment is an important argument for regions when trying to attract a highly qualified workforce (Kühn, 2003). Specific social benefits are discussed below.

Recreational and Health Benefits

Of all the benefits green space provides, recreation has received the most popular attention. With the increase of leisure time, people like to engage in more outside activities. Green space provides an attractive physical environment and a source of enjoyment for people to go jogging, biking, hiking, and so on (Francis & Paxson, 1984).

A city can be a stressful environment for its citizens. The overall speed and number of pressures cause hectic lifestyles with little room for rest and contemplation. Green space helps people escape from the asphalt world. Green space is also psychologically very important. A study of recovery of patients in a hospital showed that patients with rooms facing vegetation had 10% faster recovery and needed 50% less pain-relieving medication compared to patients in rooms facing a building wall (Ulrich, 1984). Such studies imply that green space can increase the physical and psychological well-being of urban citizens.

Aesthetic and Cultural Benefits

Green space has other social benefits that are less tangible than recreation but equally important. For instance, green space can add to the aesthetic appeal of landscapes. Visibility and legibility of green space is important to citizens. According to Lynch (1960), a legible landscape is important to provide a "sense of place" to its inhabitants.

Greenways can also provide nature education and routes for non-consumptive transportation modes, such as walking and cycling (Baschak & Brown, 1995). Combined with aesthetic enhancement, this significance adds to the sense of history and culture that is important to people's experience of a landscape and their overall sense of place. Greenways can also tie communities together by linking features such as parks, historic sites, residential areas, and shopping districts without the noise and rush of automobiles (Baschak & Brown, 1995).

Economic Benefits

Although green space is planned to control development and protect scenery (Cook & Lier, 1994), they can also increase property values, enhance tourism, and create employment and commercial opportunities. As green space benefits the health of urban citizens, they provide billions of dollars in saved costs of health expenses, making them a truly invaluable asset.

Therefore, green space provides combination of "economic, health, scenic and cultural benefits. Together, green space may function as an air/water purifier, a temperature modulator or energy saver, a soil stabilizer, a wildlife habitat, a noise barrier, a landscape beautifier, a real estate value booster, and even a psychological comforter" (Cook & Lier, 1994, pp. 1-4).

Landscape Ecological Principles and Design Scheme

Landscape ecology is the science and art of studying the spatial pattern of landscapes and its ecological consequences. The "art" of landscape ecology reflects the humanistic perspectives necessary for integrating biophysical and socioeconomic and cultural components within landscape design and planning. The "science" of landscape ecology provides the theoretical basis for understanding the formation, dynamics, and ecological effects of spatial heterogeneity, and the relationship between landscape pattern and ecological processes over different scales in space and time (Forman, 1996).

Landscape Ecology Principles

Landscape ecological principles are the essential principles guiding landscape planning and urban green space design. Three elements in landscape ecology that handle the development of general principles are patches, corridors, and matrix (Dramstad et al., 1996) demonstrates the key attributes of patches as large or small, round or elongated, smooth or convoluted, few or numerous, dispersed or clustered, and so forth, while corridors appear narrow or wide, straight or curvy, continuous or disconnected, and so on. As well, he presents the matrix combines to form the variety of land mosaics on earth (Dramstad et al., 1996). Several landscape ecological principles are simply stated with a diagram below.

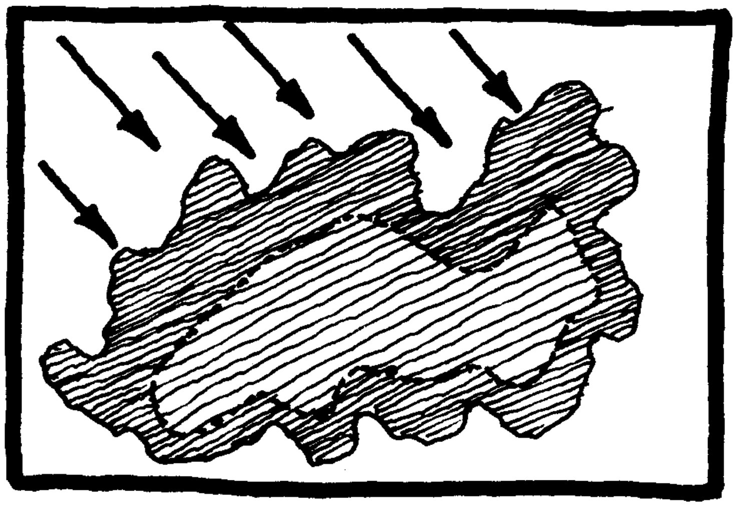
Edge width

An edge is described as the outer portion of a patch where the environment differs significantly from the interior of the patch. Edge width differs around a patch, with wider edges on sides facing the predominant wind direction and solar exposure (Figure 1).

Network connectivity and circuitry

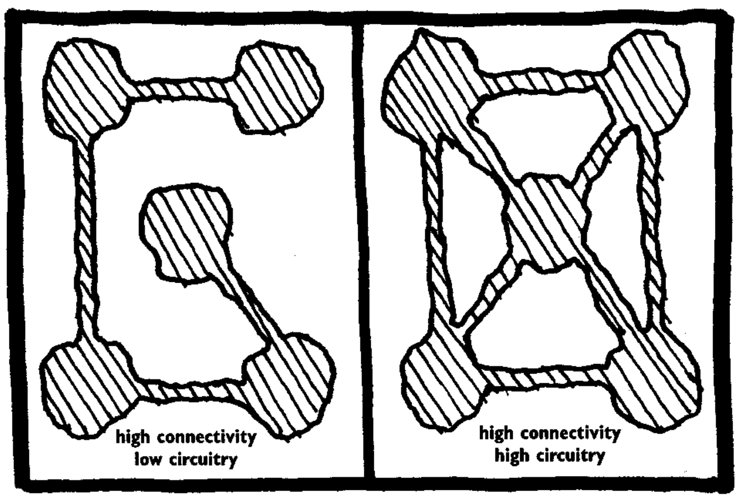
Networks exhibit connectivity, circuitry, and mesh size. Network connectivity is the degree at which all corridors are connected, and network circuitry is the degree to which loops or circuits are present in the net (Forman & Godron, 1986). Network connectivity combined with network circuitry provides an overall index of the effectiveness of linkages for species movement. In Figure 2, the diagram on left shows the high connectivity with low circuitry. The diagram on right shows the high connectivity with high circuitry.

Figure 1: Edge Width



Source: Dramstad et al. 1996

Figure 2: Network Connectivity And Circuitry

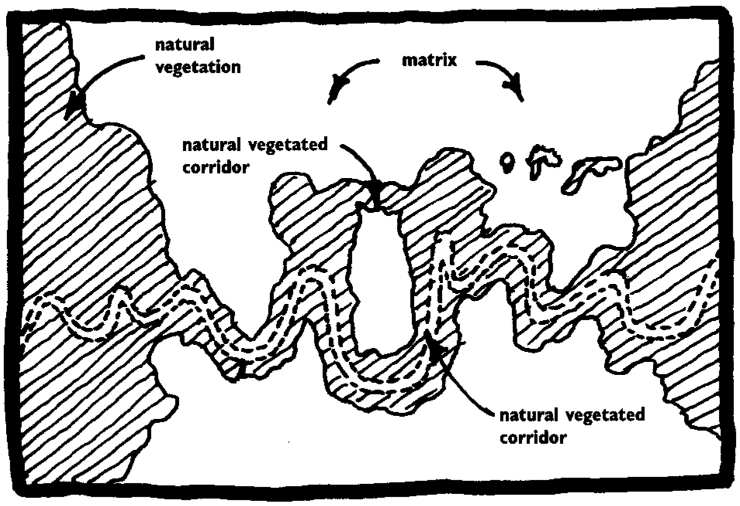


Source: Dramstad et al., 1996

Corridors

Corridors (Figure 3) provide landscape connectivity and maintain the ecological integrity in the face of intense human use. They act as barriers and filters to species movement. Corridors in a network reduce the negative effects of gaps and disturbances, thus increasing efficiency of movement (Dramstad et al., 1996).

Figure 3: Corridors

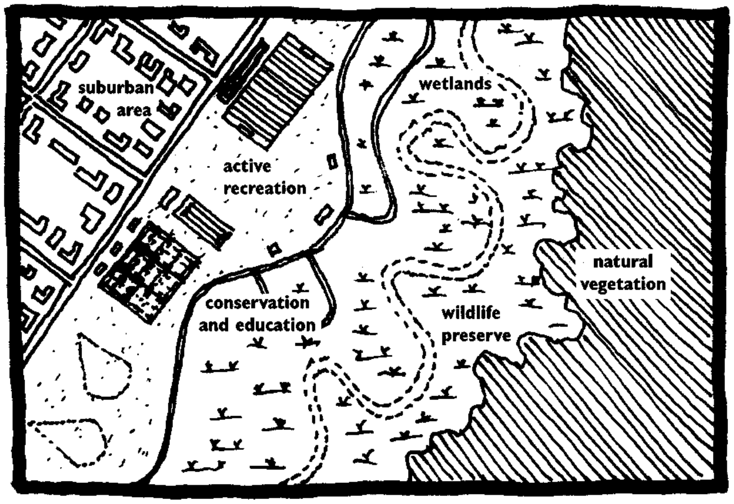


Source: Dramstad et al., 1996

Transition

In landscapes undergoing suburbanization, a transition (Figure 4) between the city and nature area protects nature area and provides education and recreation for the citizens. The transition includes education, recreation, bicycling, and hiking. Thus, community and cultural cohesion may be enhanced in the transition area (Dramstad et al., 1996).

Figure 4: Transition



Source: Dramstad et al.,1996

Design Schemes

Landscape ecology provides many useful concepts and principles for urban planning and designing in general and urban green space in particular. Several theories may be used as design schemes to guide the planning, managing, and design of urban green space and eco-cities (Forman, 1996). These theories are presented below.

Hierarchy theory

In hierarchical systems, higher levels are characterized by slower and larger entities, or low-frequency events, whereas lower levels by faster and smaller entities, or high-frequency events. Urban green space often forms a hierarchy of patches from isolated individuals to networks of corridors and to relatively large and contiguous patches (Burch & Grove, 1993).

The hierarchical view attempts to conceptualize a large, connected system of green space. Hierarchical approaches help manage ecological complexity by organizing it into discrete functional components operating at different scales. The three main components—regional patches, urban green space, and greenways—set a fitting spatial framework that is useful for planning. The hierarchical view suggests that an understanding and appreciation of urban green space can be gained by considering them at multiple scales and hierarchical linkages among green space (Burch & Grove, 1993).

Landscape connectivity

Landscape connectivity refers to the degree of connectedness among landscape elements (patch, corridor and matrix) of the same or similar type (e.g., forest habitats, lakes or rivers). Buffers and corridors are linear landscape elements that may function as habitats, conduits, filters/barriers, sources, or sinks (Forman 1995). A network of patches and corridors can provide connectivity between natural elements and help to preserve linkages between different ecosystems. Corridors of the same or similar types interconnect to form a network whose functionality is determined by network density, network connectivity, and network circuitry (Forman & Godron 1986).

Heterogeneity

The green space in urban areas may be most appropriate to treat as a landscape that consists of a variety of dynamic, interacting patch ecosystems of different shape, size, and history. It is considered that the urban environment is extremely heterogeneous in space and dynamic in time (Forman 1995). The heterogeneity concept acknowledges that ecological heterogeneity, which is crucial to the functioning and maintenance of natural systems, provides environmental benefits. Heterogeneity, diversity, and connectivity within the components of green space contribute powerfully to the features and process for which people and institutions value them (Forman & Godron. 1986).

Biodiversity

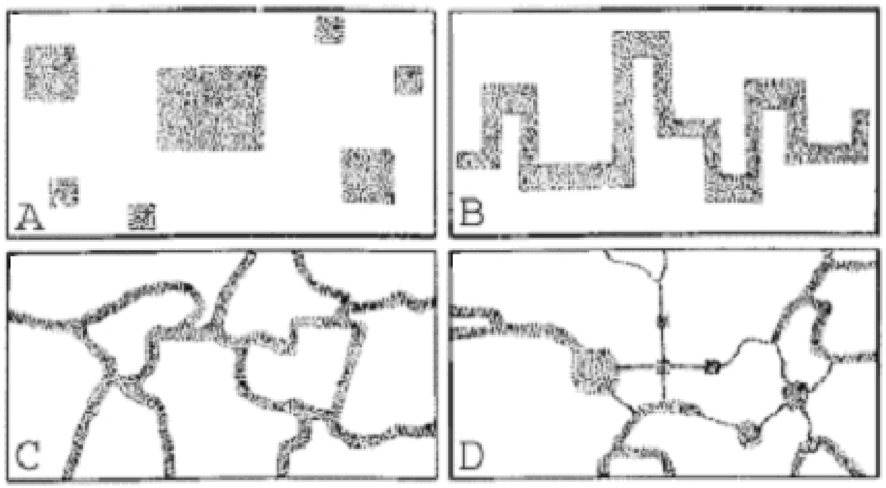
Landscape units and green space combine several ecological functions rather than a mono-function. Appropriate ecosystem services have high green space quality and diversity. Biodiversity improves specific conditions for endangered species by reducing negative effects on their habitat (e.g. linkage of fragmented habitats). Buffer zones are efficient green space to protect biodiversity and natural reserves (Forman, 1996).

In essence, landscape ecology is a highly interdisciplinary field that focuses on spatial patterning of landscape elements and its relationships to ecological processes on different scales. Landscape ecological principles and design schemes provide a variety of useful concepts and principles for urban planning and designing and can be applied in specific situations.

Theoretical Alternatives of Distributions of Green Space at City Level

Turner (1995) generalized a series of theoretical alternatives for distribution of open space through the history of London's greenbelts plans. These theoretical alternatives provide the methods to build green networks linked by greenways and green buffers in cities. It provides a diversity of greenways patterns and advantages of each pattern. The theoretical alternatives of distributions of green space are showed in Figure 5.

Figure 5: Theoretical Alternatives For The Distribution Of Open Space



Source: Turner, 1995

Diagram A represents a hierarchy of parks of different sizes which were first proposed in the Greater London Council's 1976 proposal. The plan was based on careful and extensive social science research. The findings led to the conclusion that London should be provided with more parks, arranged in a hierarchy of different sizes: Metropolitan Parks, District Parks, and Local Parks

Diagram B represents a typical greenway in an urban area, which is short of connection. It does not provide either a useful route or useful recreational space.

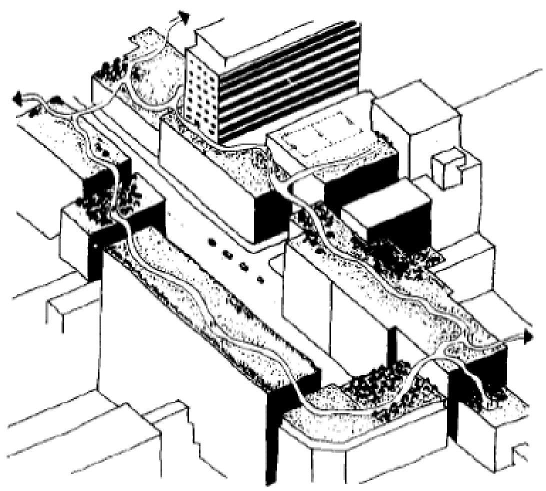
Diagram C represents an interconnected park system which was mentioned in London's 1944 proposal. The plan carried forward the idea that introduced a visionary proposal for creating an immense network of greenways to interlink green space in central areas with those on the periphery of Greater London.

Diagram D represents a series of overlapping networks as the green strategy. The idea is to create a "green web" which would function as a citywide pedestrian zone, combining paved and vegetated space. Overlapping networks are composed of different layers as a pedestrian layer and ecological corridors linked by greenways and green buffers within the surrounding landscape matrix (Turner, 1995).

Further, Turner proposed that greenways may be the best single marketing concept in a green space plan and can improve the quality of green space in urban areas. Greenway promotion and diversification can lead to the different types, including parkway, blueway, glazeway, cycleway, skyway, and ecoway, which are becoming as familiar components of the urban environment. Each type should be recognized as an archetype for environmentally sound places, and each should be subject to further diversification.

Turner illustrated six greenways from which urban areas can build networks and links. 1). The parkway is designed for providing the active recreation which the residents may use for their everyday life. 2). The cycleways link roads and paths to improve physical fitness and benefit people's health. 3).The blueway is designed for citizens to access to water, pools and streams. 4). The glazeway links pedestrian malls to afford protection from the elements. 5). The skyways link roof gardens so that urban areas become a circulating system. Meanwhile the skyways are capable of providing quiet space in dense urban areas (Figure 6). 6). The ecoways establish networks of ecological space in cities. They can provide a variety of benefits for plants and animals, as well as people.

Figure 6: Skyways And Roof Gardens



Source: Turner, 1987

In summary, the theoretical alternatives provide the methods to build green networks linked by greenways and green buffers in cities. It presents a diversity of greenways patterns and advantages on building urban-green space.

GIS and CITYgreen Application

GIS

The understanding of green space plans and ecological processes are based on a great variety of geographical data collected at many spatial scales. Geographic Information Systems (GIS) are spatial tools useful for evaluating land-use plans and land-use suitability by integrating topography, vegetation cover, and land-use types (Lavely, 1989).

GIS provides a variety of tools for mapping and manipulating spatial data. The characteristics of GIS not only facilitate a better understanding of green space plans and ecological processes but can also improve decision-making efficiency (Clarke & Gaydos, 1998). Some useful functions provided by GIS include the following:

Manipulating spatial data

GIS provides the abilities to input, store, analyze, display, and handle geographical data and spatial information. GIS allows one to store data from various origins and facilitates the design of maps meeting specific needs (ERIS, 2004).

Modeling ecological changes and simulate evolution

GIS can simulate impacts on environmental diversity and predict potential changes so that the implementation of management strategies may avoid or reduce some negative impacts. Also, space-time modeling from the information stored in a database can be helpful in making an accurate evaluation on ecosystems (Clarke & Gaydos, 1998).

Detecting change

GIS can provide visual information and detect change over time. The ability to detect change is crucial for efficient land management. It is fundamental for administrators to quickly know change affecting an area in order to take action (Lavely, 1989).

Making efficient decisions

The database held in the GIS offers the potential for many more analyses to be carried out. By providing accurate spatial data and predicting future change, GIS can lead to the development of suitable management decisions and a better understanding of an ecosystem. GIS is a tool for decision support provided that time is invested in data collection (ERIS, 2004).

CITYgreen

CITYgreen is a software extension for the ArcGis package. It provides an effective tool for measuring ecological services of green space and facilitates an assessment of environmental impacts based on landcover and air quality. Also, it provides model-basic estimates that could directly link social and economic data to local environmental data.

Background

CITYgreen is a software extension developed by American Forests. When the first version of CITYgreen was released in 1996, it represented a groundbreaking collaboration between cities and conservation groups to both calculate the economic and environmental benefits provided by trees and other vegetation. With each release based on the most up-to-date, peer-reviewed science, CITYgreen analysis has increasingly became an important decision-making tool for local and regional planners (CITYgreen Manual, 2004).

Operation procedures

CITYgreen uses aerial imagery for an analysis of a study area. The first step of operating CITYgreen is usually creating shape files of the study boundary and landcover data, followed by converting vector data to raster data. Then CITYgreen conducts an analysis by converting input raster landcover values to its own specific categories. Finally, a statistics report is created to show basic ecological services, including air pollution removal, carbon capture and sequestration estimates, storm-water runoff and detention statistics. Table 1 provides the categories for reclassifying the specific data for CITYgreen.

Table 1: Landcover Categories In CITYgreen

Code	Landcover categories
1	Arid & Semi-Arid Rangeland
2	Cropland
3	Farmsteads (Buildings, lanes, driveways and surrounding lots)
4	Impervious Surfaces
5	Meadow (Continuous grass, generally mowed, not grazed)
6	Open Space - Grass/Scattered Trees
7	Pasture/Range (Continuous forage for grazing)
8	Shrub
9	Trees

10	Tropical
11	Unclassified
12	Urban
13	Water Area

Source: Author, 2005

Models.

CITYgreen performs basic ecological services analysis functions based on the four models. The models are demonstrated below.

Air Pollution Removal

The Air Pollution Removal model estimates the amount of pollution being deposited within cities based on pollution data from the nearest city, and then estimates the removal rate based on the area of tree and/or forest canopy coverage on the site. Dr. David Nowak of the U.S. Forest Service conducted the research and developed models in 55 different cities across USA. Dollar values for pollutants come from the median value of the avoided externality costs, which are expenses to society such as public health care costs. The public avoids these externality costs because the trees remove pollutants. CITYgreen applies the research to calculate the value of trees to urban environments. Table 2 lists pounds of pollutants removed annually by trees and annual value of trees with respect to air pollution in some cities. CITYgreen can determine the Air Quality city nearest the site, or the user can manually identify a city that better represents their air quality, and the results from that city are used (CITYgreen Manual, 2004, p.51).

Table 2: Trees And Air Quality In American Cities

City	Pounds of pollutants removed annually by trees	Annual value of trees with respect to air pollution
Washington, DC	878,000	$2.1 million
Atlanta, GA Metro Area	19,000,000	$47 million
Portland, OR Metro Area	2,000,000	$4.8 million
Denver, CO Metro Area	1,100,000	$2.6 million

Source: American Forest, 2004

Carbon Storage and Sequestration

The carbon model estimates annual sequestration, or the rate at which carbon is removed, and the current storage in existing trees. The carbon model multiplies a per unit value of carbon storage by the area of canopy coverage. Economic benefits can also be associated with carbon sequestration rates using whatever valuation method the user feels appropriate. In estimating urban carbon storage and sequestration, the study area (in acres) and the percentage of crown cover are required (CITYgreen Manual, 2004, p.81).

Stormwater Runoff Reduction

The CITYgreen stormwater runoff analysis estimates the amount of stormwater that runs off a land area during a major storm, as well as the time of concentration and peak flow. The program determines runoff volume based on the percentage of tree canopy, and other landcover features, as digitized by the user in the CITYgreen view or as reported in a raster data set. The Stormwater Runoff program incorporates procedures and formulas developed by the Natural Conservation Service (NRCS). In addition, the program estimates the additional volume of water in cubic feet, which can be associated with an economic value since planners generally know the cost per cubic foot to build a retention pond in their municipality (CITYgreen Manual, 2004, p.82).

Water Quality Model

The water quality model calculates the effect of landcover on the amount of pollutants and suspended solids in surface water runoff. The model is based on a storm event calculation; that is how landcover affects the runoff from a typical 2-year, 24- hour storm. The relationship between the landcover and water quality is predicted using the L-THIA spread sheet model, which was developed by Purdue University an the U.S. Environmental Protection Agency (EPA) (CITYgreen Manual, 2004, p.86).

Application of CITYgreen

The application of CITYgreen is expounded by a project, which applied CITYgreen software and analyzed ecological insights at two “regional” and “local” scales, surrounding Clemson and within the city. The project built ecologically improved versions of developments at region and local levels. Three scenarios were created to compare the change of tree canopy and identified additional ecological services. The statistical reports produced by CITYgreen emphasized the benefits of trees, and recommendations were presented to the city of Clemson. The processing is presented below. (Brooks et al., 1999)

At Regional Level

The project employed multi-date Thematic Mapper satellite imagery to detect vegetative changes over a ten-year period (1988-1998) for the Clemson region. By applying zoning and development regulations to the vacant parcels, the analysis estimated the amount of vegetation remaining after development. Additionally, it assessed the proposed overall zoning and land-use changes in terms of urban trees and a number of their related benefits. Consequently, the section concludes with recommendations to the city of Clemson on ecological insight.

At Local Level

In this section, the project developed and compared three development scenarios, including a baseline scenario, a conventional scenario, and an environmental scenario. The baseline scenario served as a control which compared the alternative designs. The conventional scenario was a representation of a scheme allowable under current city regulations. The environmental scenario delineated the best ecological development practices applied to the site. Linking CITYgreen results, the project compared three scenario models based on the ecological services, including storm-water run-off and detention statistics, carbon capture and sequestration estimates, pollution removals and energy savings. Results included development regulation recommendations for the City of Clemson and demonstrated the benefits of sensitive design to the city and to development of the community.

Case Studies

To provide the guidelines and methodology on the modern ecological framework, two case studies have been chosen to explain green space planning in the historic metropolitan regions. The first case study shows how well-designed greenbelts in Canada can hamper sandstorms and reduce wind speed. The second case is the green space system for New York

City. It summarizes the green space network by presenting five key ecological principles. The two case studies provide the guidelines and methodology on the modern ecological framework for further study and are presented below.

Properly Designed Greenbelts in Canada

The research on greenbelts in Canada presents the primary benefit of greenbelts being to reduce wind speed. Moreover, it describes the methods of properly designed greenbelts and choice of tree species. Tests of wind speed were conducted on four greenbelts surrounding the Regina, Alberta plains area. By correlating with wind speed, the effect of differences in greenbelt density could be detected. It was found that the denser greenbelts on the north side reduced wind speeds by 83%, and the moderate density greenbelts on the east and west sides reduced wind speed by an average of 70%. For the light density belt on the south side wind speed was reduced by 52% (Agriculture and Agri-Food Canada, 2003).

The research reports that the best design for greenbelts in Canada is with the maximum protection on the northwest due to the prevailing winds that come from the northwest in most of Canada. It pointed out that "a five-row shelterbelt on these two sides consisting of an outside row of shrubs, a double row of deciduous trees and a double inner row of conifers with staggered spaces is the ideal design for protection from both wind and blowing snow" (Agriculture and Agri-Food Canada, 2003, np).

The second aspect of a properly designed greenbelt in Canada is leaving more openness in the south. Because south and east winds are generally warmer than north and west winds, it is desirable to leave the south open and restricted to rows of deciduous trees and shrubs. The benefit of more openness to the south is to gain maximum solar light in the winter and allow more ventilation of the farmyard or living area in the summer (Agriculture and Agri-Food Canada, 2003).

In addition, the study proposes that the wind is deflected up and over the greenbelts, creating a well protected zone in the lee of the greenbelts. By testing, the research found that "the zone of maximum protection extends outward five times the height of the trees" (Agriculture and Agri-Food Canada, 2003, np). The study also found that the use of conifers and other densely branched species is essential for winter protection (Agriculture and Agri-Food Canada, 2003).

Furthermore, the research presented other details that should be noticed when a greenbelt plan is created. Openings in greenbelts should be designed to avoid creating a wind tunnel effect. Because of the cold weather in Canada, the research proposes that the belt should be continuous on the north and west. "Any openings on these sides should be perpendicular to prevailing winds so that wind is not allowed direct access. Trees and shrubs can also be planted around the openings to baffle the winds and keep the snow from piling up in laneways" (Agriculture and Agri-Food Canada, 2003, np). The distance between buildings and belts was also studied. It is found that buildings should be about 30 meters away from the inner row of trees to avoid the accumulation of snow occurring immediately inside the belt. Specimen plants can be planted closer to the buildings for addition of protection and attractiveness.

In summary, the research conducted tests to examine different percentages of reducing wind speeds in greenbelts with different densities. It presents methods to design a greenbelt plan according to the climate and location of the site. The results of this study provide useful methods on design and improvement of existing greenbelts.

Green Space System for New York City

To preserve natural areas and improve environmental quality, New York City developed the green space plan, called Metropolitan Greensward Plan. In addition, the city developed approaches on green space to assist communities in implementing effective land development in neighborhoods. The approaches on green space aim to preserve natural area and rehabilitate urban green space to build the long-term livability of urban areas.

The Metropolitan Greensward Plan is an attempt to address these overall concerns through green space planning and improved natural resource management. To protect and restore environmental systems, green space with large-scale regional natural reserves is linked into a single green space system. Flores summarizes this framework by presenting five key ecological principles: content, context, dynamics, heterogeneity, and hierarchies (Flores et al., 1998).

The ecological content principle is based on the concept of the ecosystem. All ecosystems have structure and function, which cannot be separated. Structure refers to the physical arrangement of biological and non-biological components of the system, whereas function refers to the way the components interact with one another.

The context principle states that ecosystems often are strongly affected by the external landscape providing a specific context to each site. The size and shape of land units play a key role in the way ecosystem function is influenced by external interactions.

The dynamics principle states that the structure and function of ecosystems are in constant flux. Ecosystem dynamics result from two major ecological concepts, succession and disturbance. The more dynamic view of green space within the modern framework has important implications for both planning and management.

The heterogeneity principle acknowledges that ecological heterogeneity is crucial to the functioning and maintenance of natural systems. Heterogeneity, diversity, and connectivity contribute powerfully to green space.

The hierarchical principle helps manage ecological complexity by organizing it into discrete functional components operating at different scales. Three main components—the regional reserves, urban green space, and greenways—set a fitting spatial framework that is useful for land development.

Furthermore, New York City developed approaches on green space which emphasizes a dynamic view of a rich urban environment and interactions among multiple sites in urban area. Those approaches are listed below.

Green space provides benefits for physical health and often reduces stress. It is also good for spiritual revitalization. Community parks in New York create a more livable environment but also enhance property values (Flores et al., 1998). Parks are also sites for athletic recreation which is so important to residents. The qualities of communities can be greatly improved, and living environments become more beautiful and enjoyable if more parks are established (Flores et al., 1998).

Buffer zones between natural vegetation and settlement provide the benefit of biodiversity as well as provide spaces for recreation and environmental education. Interpretive walks and classes conducted in buffer zones can increase one's appreciation for the environment.

Public access offers visual hints of access to natural or cultural resources. Communities are more pleasant places to visit when their residents can have visual and direct access to diverse views.

A number of historic districts in New York City have historic or aesthetic interest as part of the cultural, political, and economic history of the state and nation. Protecting and rehabilitating historic sites is an important commitment in a green space plan. New York State municipalities have enacted some form of historic preservation regulations, and most of these municipalities have established historic preservation commissions.

The green space plan protects and restores environmental and life-supported systems for the region's cities, suburbs, and rural communities. The plan explores explicitly the connection between ecological process and quality of life. Also, the approaches on green space presented can be used to rehabilitate urban green space and reach specific planning goals.

Overview

Two examples of green space planning in different regions offer insight to the green space planning in metropolitan areas. The case of greenbelts in Canada offers the way of reducing wind speed by employing wider edges on sides facing the predominant wind direction. Also, it indicates that leaving more openness in the south can gain maximum solar light and more ventilation. Moreover, the case specifies parameters for properly designed greenbelts and species selection. The study aids in the improvement of existing greenbelts to provide maximum protection from wind.

The case study of New York applies the landscape ecological principles and analyzes the green space plan strategies by using five ecological principles: content, context, dynamics, heterogeneity, and hierarchy. Additionally, it represents the approaches on enriching green space to rehabilitate environmental quality of urban areas.

Summary

The literature review identifies several key issues associated with green space planning in urban areas. The illustration of landscape ecology and case studies provides general principles for analyzing the Beijing Greenbelts Plan. In addition, the interpretation on GIS and CITYgreen presents that the two software packages offer analysis tools to the greenbelts plan from quantitative perspective.

How to develop a proper greenbelts plan to improve a sustainable ecosystem and hamper sandstorms? According to landscape ecology and the case studies, the principles and strategies of developing greenbelts plans are as below:

At the regional level, widening edges on sides facing the predominant wind direction offers a way of reducing wind speed. Also, leaving more openness in the south can gain maximum solar light and more ventilation. At city level, building green networks and green buffers can enhance the connectivity of green space in cities. At neighborhood level, developing more community parks is the approach on enhancing green space to build sustainable and livable place environment in compacted urban areas.

Furthermore, how to apply the software package to analyze greenbelts from a quantitative perspective? The Clemson study presents a method for application of CITYgreen, which is creating three scenarios to analyze ecological services at the local scale and by using the Landsat image to detect the landcover change at the regional and district scales.

Chapter Three: Study Area

This chapter introduces the general background of Beijing, and provides an overview of the history of greenbelts in Beijing. It also illustrates the details of the Beijing Greenbelts Plan proposed in 2003.

The General Background of Beijing

Beijing is situated at the northwest end of the North China Plain. The region of Beijing spreads over a total area of 16,800 square kilometers (4,151,000 acres), of mountain land accounts for approximately one third (Figure 7). The city core covers an area of 62 square kilometers (15,320 acres). Beijing has more than 3000 years of history with a multitude of national cultural and historic sites (Mann, 1984).

Topography and Geology

The topography of the Beijing region comprises both mountains and plains. Beijing is bordered by the Mongolian Plateau to the north and the Yanshan Mountain range to the northeast. The Xishan Mountains rise up on the west of Beijing, a residual range of the Taihang Mountains. The mountains are located in the northwest of Beijing Region and account for 38% of the surface area. The Beijing Plain, in the southeast, covers 62% of Beijing Region and serves as the main scene of urban extension (Institute of Geography 1990). A number of rivers including the Wenyu River and Yongding River run from the northwest to the southeast through the city (Figure 8) (Chinese Academy of Forestry, 1996).

Figure 7: Location Of Beijing

Source: Beijing Municipal Environmental Protection Bureau, 2004

Figure 8: The Topography Of Beijing Region

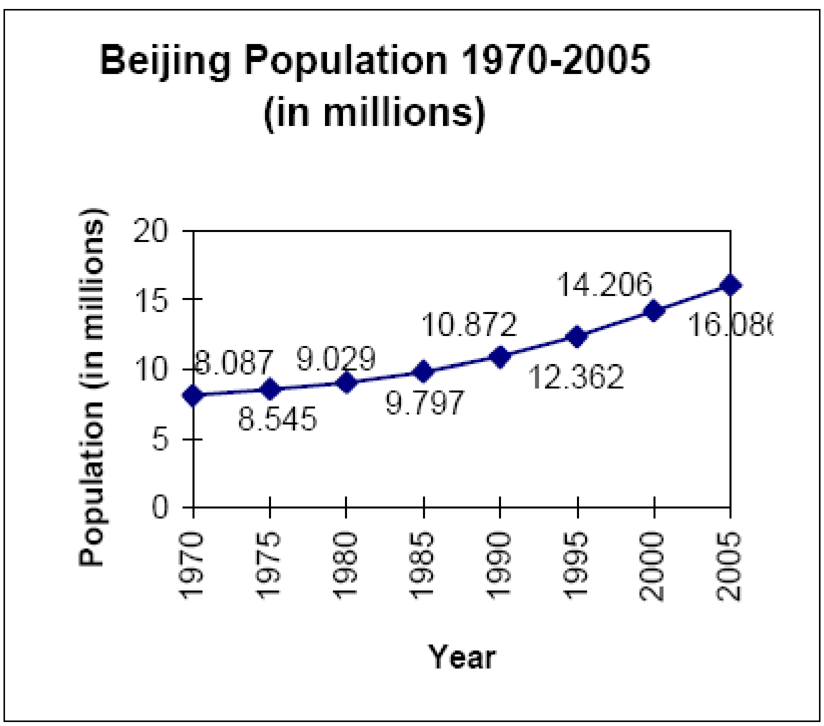
Source: Chinese Academy of Forestry, 1996

Population

Beijing has a population of about 13.8 million with an average population density of 821 persons/km^2. The urban and suburban regions are very heavily populated with 11 million residents on one fourth of Beijing's total landmass. The remaining people are spread over the eight rural counties. In addition, it has a transient population of 3.295 million (Beijing Municipal Statistical Bureau, 2002).

Although Beijing's rate of population growth is stabilizing at around 2.5% annually due to government policies to restrict fertility and movement, growth in absolute numbers continues to soar. Figure 9 shows that Beijing had a population of approximately 8 million in 1970. By the year 2005, that number is anticipated to have doubled to 16 million (Population Division of United Nations, 1995).

Figure 9: Beijing's Population 1970-2005



Source: Beijing Municipal Statistical Bureau, 1996

Vegetation and Wildlife

The original natural vegetation of the Beijing Region was deciduous broadleaf and evergreen coniferous forest. Due to human influence, most of the original natural vegetation has disappeared. The native vegetation on the peripheral Beijing Region is coniferous forest on the upper elevations of the mountains. Originally, the low mountain zone was covered by the predominant native vegetation of cork oak, oak trees, pitch pine, and arborvitae. At elevations of 1900 meters above sea level, vegetation is a mountaintop meadow community (He, 1992).

The national parks surrounding Beijing provide at least some protection for wildlife. There are more than 400 species of vertebrates living in the mountainous region and plain in the Beijing Region, such as tigers, snow leopard, crested ibis, and red-crowned crane (Wang, 2001).

Climate

Beijing is in the north of China and located at 39°38′–41°05′N in the semiarid continental monsoon climatic zone with a mean annual temperature of 12 °C. Beijing's climate is characterized by four distinctive seasons. The seasons are characterized by hot and rainy summers contrasted by cold and dry winters with spring and autumn being very short. Spring becomes dry and windy, the season when Beijing is most likely to be hit by smothering sandstorms from the northern desert plains of Mongolia (Mann, 1984).

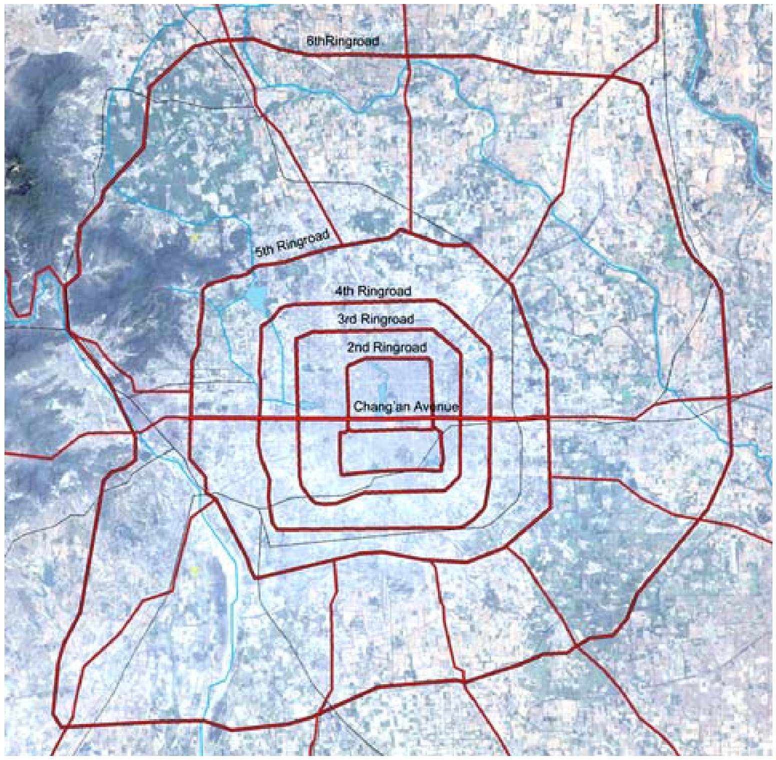
Beijing is located in the hydrogeological district of the northern semihumid climatical zone. The main source of water in the Beijing area is precipitation. Precipitation is extremely varied from year to year and varies in a cycle of several consecutive wet years followed by several consecutive dry years. Beijing's rainfall is not evenly distributed throughout the year. Eighty-five percent of rainfall falls between July and September and in some instances between 40-70% of rainfall falls within 3 days (Mann, 1984).

History and Features

Beijing became the capital in the 12th century during the Jin Dynasty. Its urban form shares its heritage with the Yuan Dynasty (1206-1341), the Ming Dynasty (1368-1644), the Qing Dynasty (1644-1911), and has remained intact until present. The urban pattern and architectural features are remarkable and unique. Ever since Marco Polo's visit to China, Beijing has been the object of high praise from planners around the world (He, 2003).

The Walled City of Beijing was composed of the Inner City (neicheng) and the Outer City (waicheng). Its plan is characterized by its central axis emphasizing hierarchy, regularity, and symmetry. Beijing's road system can be described briefly as a network, with ringroads and radial roads as its arteries (Figure 10). The road around the Forbidden City is named the first ring, and the ringroads beyond are the second, third, fourth, and fifth ringroads in order of the radial distance from the center of the city (Mann, 1984).

Figure 10: Beijing Ringroads Map



Source: Author, 2005

Eco-Environmental Problems

At present, Beijing is undergoing a fast urbanization period characterized by fast transition, high density, and significant environmental and ecological impacts. With the increase in the number of urban areas and in the total urban population, environmental problems have become more and more serious in terms of mass destruction of natural landscapes, CO_2 emission, loss of biodiversity, water source pollution, and so forth. The most severe environmental problems in Beijing are sandstorms and air pollution (Beijing Local Website, 2004).

Air Pollution

The air pollution of Beijing comes mainly from three sources: dust pollution, traffic pollution and sulfur dioxide pollution, which are caused by urbanization and industrialization. An important air pollutant source is coal burning. The consumption of coal in Beijing in 2000 was about 27 million tons. In addition, according to the Beijing Environmental Protection Bureau (BEPB), around 10-15% of the inner city's 6 million residents still heat their homes with coal-burning stoves in the winter (Beijing Academy of Environmental Sciences, 1998).

Heavy traffic also contributes to air pollution, and motor vehicle ownership is increasing. The concentration of nitrogen oxides, suspended particulates, and photochemical pollution on major traffic arteries has a severe impact on the physical and mental health of the inhabitants. In addition, the air quality of Beijing is greatly affected by factories. More than one hundred polluting factories exist in the urban area of Beijing (Cernet, 1997). The increased number of motor vehicles in the city is responsible for the increase in ambient levels of NO_2. The dominant sources of SO_2 in Beijing are heavy industries and power plants, which make up 72% per cent of total SO_2 emissions.

The plans for the 2008 Beijing Olympics have catalyzed efforts to improve Beijing's environment. Beijing has adopted strict emission standards since 1999, which require a reduction of emissions by 80%, and even stricter standards are planned to further reduce emissions by 60% from 2004 to 2007 (Asian Development Bank, 2002). Consequently, the air quality is expected to meet the National Grade II Standard which sets limit values for concentrations of SO_2, NO_2, CO and particulate matter (PM). The regulated values and the calculated total emissions are shown in Table 3. The actual pollutant concentrations and total emissions are given as well to make comparison. From this table, it can be seen CO is the only pollutant that has reached the requirement. SO_2 and NO_2 exceeded standard values by two times and four times respectively.

Table 3: Air pollutant Concentrations In National Grade II Standard And Actual Values in 1999

Pollutant	Regulated Concentration	Total Emission Allowed (ton/year)	Actual Concentration in 1999	Actual Total Emission in 1999 (ton/year)
SO_2	150 μg/m3	100,000	300 $\mu g/m^3$	200,000
NO_2	80 μg/m3	60,000	300 μg/m3	225,000
CO	4 mg/m3	3,000,000	2.4 mg/m3	1,800,000
PM	150 μg/m3	94,000	170 μg/m3	106,500

Source: Guo and Teng, 2003

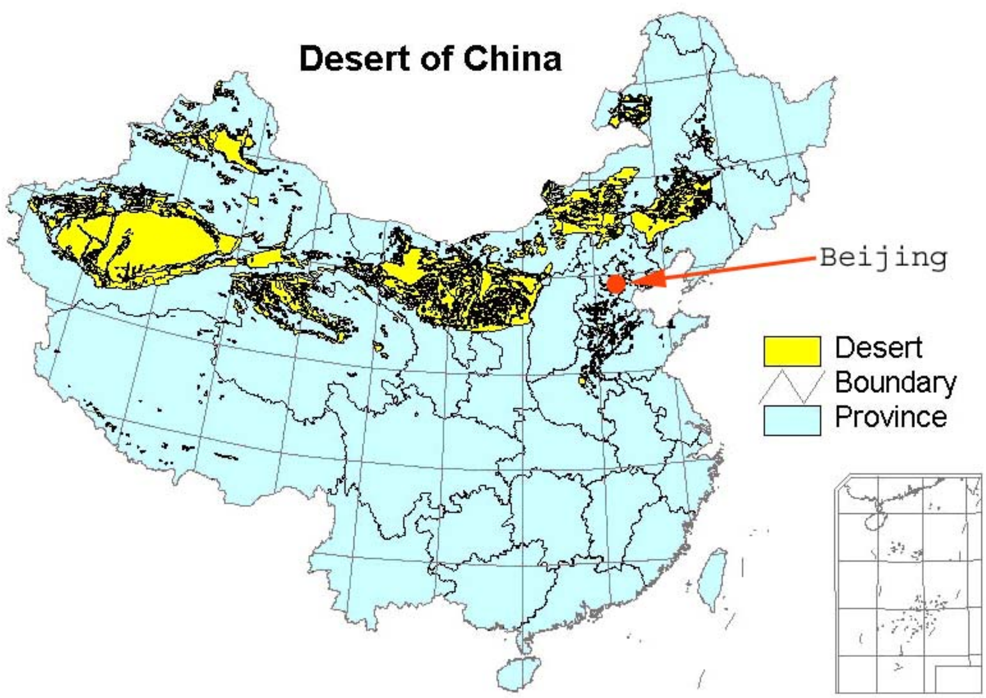
The Beijing Municipal Government has made plans to abate air pollution, mainly by regulating mobile sources of pollution (Asian Development Bank, 2002). Measures were proposed, including reducing coal consumption, lowering vehicle emissions and preventing industrial pollutants. Besides, an important measure is to expand green space in urban area to absorb pollutants (Asian Development Bank, 2002).

Sandstorms and Desertification

Beijing is situated next to a desert (Figure 11), and strong winds blow in from the north year round. These winds are more severe in April and serve to aggravate the already critical air pollution problem in Beijing (Mann, 1984). Beijing suffers from severe sandstorms, which blanket the city with sandy dust each spring. Huge dust clouds regularly travel hundreds of miles to Beijing and other cities in northeastern China. As they move over urban centers they pick up particles from industrial pollution. Sand and dirt become swept up by the wind from the many construction grounds. Sandstorms reduce visibilities to near zero, making ground transportation all but impossible. Residents caulk windows with old rags to keep out the dust, and municipal crews have to clean public structures repeatedly during the sandstorm season (Beijing Local Website, 2004). The main causes of sandstorms are overgrazing and deforestation which damage the fragile ecosystem and increase the desert environment. Beijing is now less than 250-kilometres from the encroaching desert, heightening the environmental concern of the region.

Sandstorms are frequent in Beijing and are rapidly increasing in intensity and scope. Records indicate that severe sandstorms occurred 8 times in 1960s, 13 times in the 1970s, 14 times in the 1980s and 23 times in the 1990s. The frequency of sandstorms has evidently increased with 15 sandstorms occurring in the year of 2000 alone and 18 sandstorms in 2001. The sandstorm has become a sensitive environmental problem and a hotspot attracting social attention (UNCCD, 2002, p. 49).

Figure 11: The map Of Chinese Desert

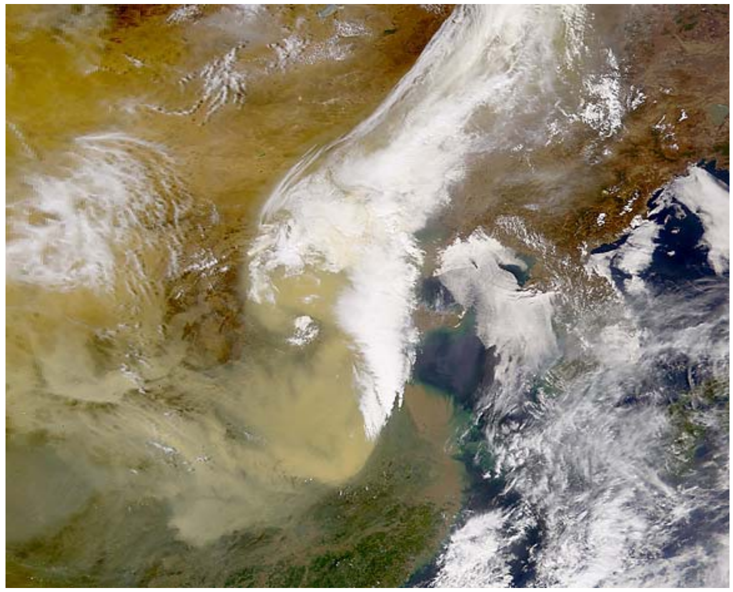


Source: Beijing Forestry Bureau, 2003

During a sandstorm, the concentration of suspended particles rapidly increases. Sand (dust) transported by the air currents from the source areas, such as the desert edges, degraded grassland, and bare fields in Mongolia and Inner Mongolia, become the dominant air pollutant in Beijing. In Beijing, suspended particles are the dominant pollutants on most days of a year, the majority is fine particle pollutants dominantly less than 2 μm made up ions of sulfate and nitrate, in the ranges of 0.5–1.8 μm. PM (i.e. respirable particulate matter) mostly falls in this range. When a sandstorm occurs, wind carries larger particles with 2-20 μm in size and flushes into Beijing city. The big size particles tend to precipitate when wind speed slows down. With an average of 30,000 tons sand (dust) brought into Beijing for each sandstorm, at an average of 5 times a year, there are approximately 150,000 tons sand (dust) precipitated annually in Beijing due to sandstorms.

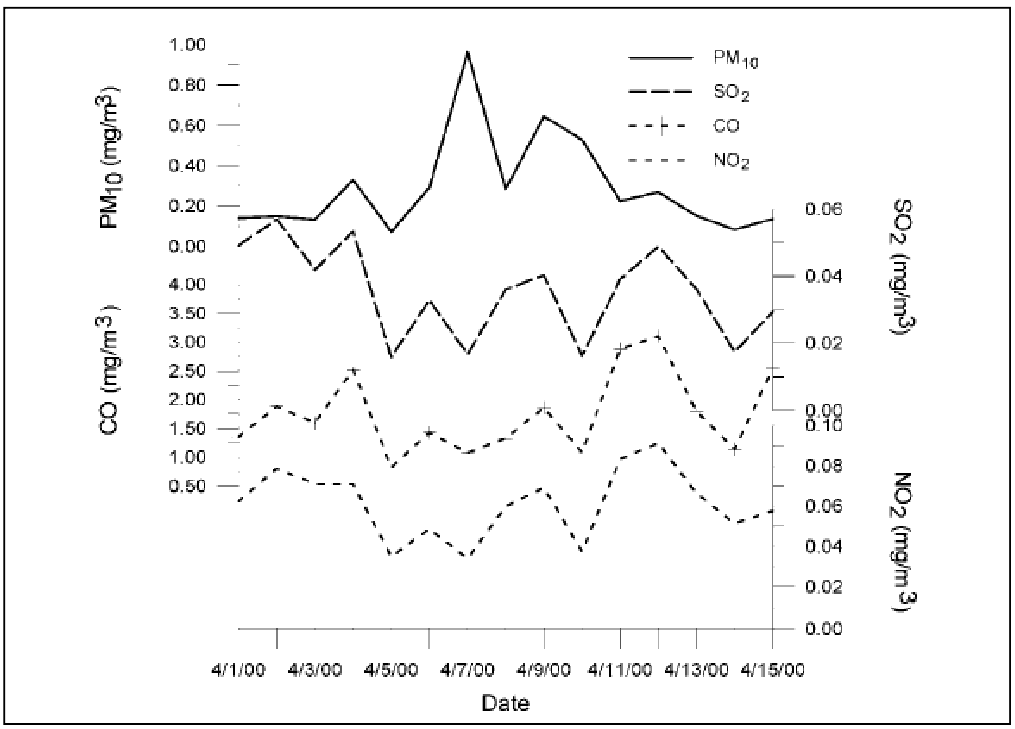
Figure 12 shows an aerial image for a sandstorm that occurred in 2002. The large dust cloud even drifted across the continental United States and lingered over Denver and other areas, at times obscuring views of the Rocky Mountains. During the sandstorms, the wind speed increases from an average of 3-4 m/s to more than 10 m/s. The concentration of respirable particulate matter (PM) was observed to increase and the atmospheric visibility decreased. Figure 13 shows the effect of the sandstorm that occurred on April 3rd-9th, 2000 on different pollutant concentrations. It shows that PM increased sharply from normally around 0.2 mg/m^3 to 1 mg/m^3 (Fan et al., 2002). In addition, this sandstorm precipitated about 50,000 tons of sand in the Beijing city area.

Figure 12: Aerial Image Of Sandstorm



Source: Beijing Municipal Environmental Protection Bureau, 2004

Figure 13: Effects Of Beijing Sandstorm On Pollutants



Source: Fan et al. 2002

Sandstorms pollute the air, disrupt traffic, harm health and may even cause the death of both human beings and animals. Experts have warned that sandstorms could be a major problem for Beijing when it hosts the 2008 Olympics (National Bureau of Statistic of China, 2001). A number of measures have been suggested to stave off dust storms, including improving the vegetation and environment in the areas of origin, establishing greenbelts in key areas, and long-term cooperation with Mongolia on dust storm prevention.

"Three-North" Protective Forest System and Development of Beijing Greenbelts

Various efforts have been mounted to halt increasing sandstorms and air pollution. The establishment of "Three-north" protective forest system in the north of China was an important measure to ameliorate desertification and sandstorms. In Beijing, greenbelts were built up from as early as the 1950's to increase green space as well as inhibit the invasion of sandstorms and the deterioration of air quality.

"Three-North" Protective Forest System

During the late 1970s and early 1980s, the government initiated the "Three-north" protective forest system project aiming to ameliorate the desertification and sand storms besetting northern cities in China. The "Three-north" protective forest system is located in Northeast China, North China, and Northwest China (Figure 14). It is the largest ecological project in the world and is sometimes aptly called the "Green Great Wall **."** As a part of this project, Beijing focused on forestation in its northern and western mountainous areas (Cai, 2003).

Figure 14: Three-North Forest

Source: Maps.com, 2002

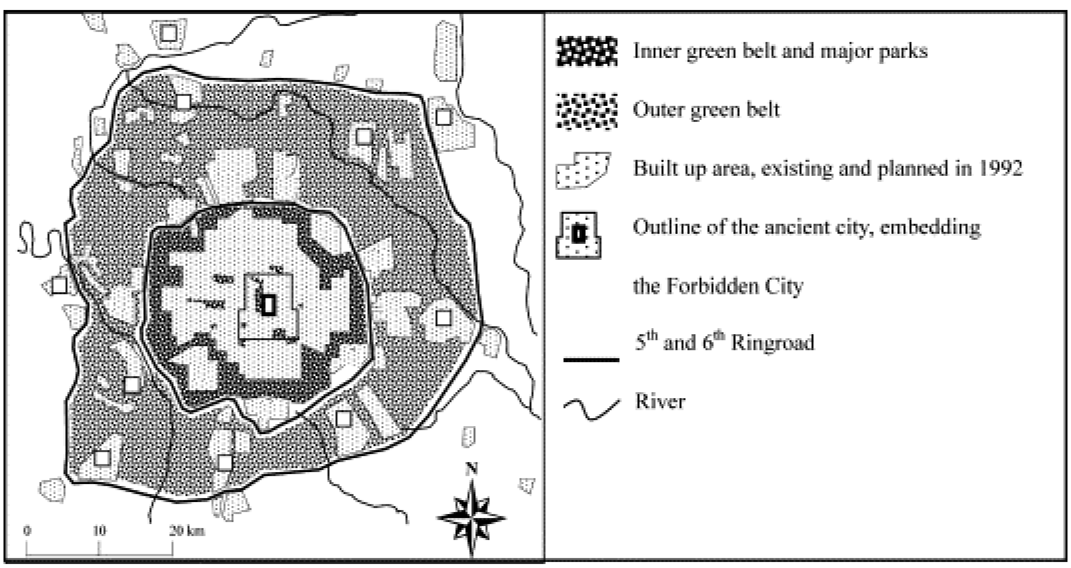
Since the augmentation of the system, the build up of sand dunes in North China has been reduced by as much as 64%. Nationwide the total forest cover increased by 14% in 1995 as a result of intensive planting (Xiao, 1997). The problem of sandstorms has been noticeably ameliorated, and more green space is seen (Zhou, 2000).

Development of Beijing Greenbelts

At the beginning of the 1950s, some Chinese scholars advocated establishing forests in the areas around Beijing with the purpose of improving air quality and conserving water. Starting in 1958, the Beijing government launched a movement of massive afforestation in areas near the city, as well as in remote areas (Zhao, 2003). The 1958 Master Plan of Beijing proposed two greenbelts; the inner greenbelt and the outer greenbelt (Figure 15). The inner greenbelt was planned to be located at the transition between the urban area and suburbs. The proposed outer greenbelt was planned to be located at the transition between the city and the rural area (Beijing Annals Editorial Board, 2000).

In the early 1980s, green space development in Beijing was transformed from government-oriented to a market-oriented policy after the economic reform, and the opening-up policy has been occurred. The greenbelt area was opened to private commercial development (Beijing Forestry Bureau, 2003). As a result, the greenbelt areas created in the previous planning were fragmented by urban development and industrialization. The existing greenbelt was fragmented by overwhelming urbanization (Zhu & Wu, 1995). For example, the total area of the inner greenbelt was 314 km^2 in the 1958 Master Plan, but it had shrunk to 241.37 km^2 by 1999 (Li, 2002).

Figure 15: 1958 Master Plan



Source: Beijing Annals Editorial Board, 2000

The Beijing Greenbelts Plan

To promote a sustainable ecosystem, as well as control the expansion of the urban area on the basis of existing planning, the Beijing Greenbelts Plan was developed by the Beijing Municipal Institute of City Planning and Design in 2003. The plan focuses on alleviating the sandstorms and improving air quality by developing greenbelts. With Beijing hosting the Olympic Game in 2008, the plan is expected to create an attractive environment for the games (Chen et, 1998). According to the plan, three greenbelts will be established in urban, suburb (plain), and mountain areas respectively (Li, 2002). An annual investment of 600 million Yuan (US$72.3 million) will be allocated to the project from the municipal government (Beijing Forestry Bureau, 2003).

The major goal of the Beijing Greenbelts Plan is to build a sound ecological basis for the city by developing more forested areas, hampering sandstorms and preventing air pollution. The three greenbelts will be completed by 2007. The construction of the greenbelts is expected to increase forest coverage by 50% in the city area, and to reduce PM, SO_2, NO_2 and CO concentrations in the air. The air quality is expected to meet the National Grade II Standard that sets limit values for concentrations of SO2, NO2, CO and particulate matter (PM).

Figure 16. The First Greenbelt Plan

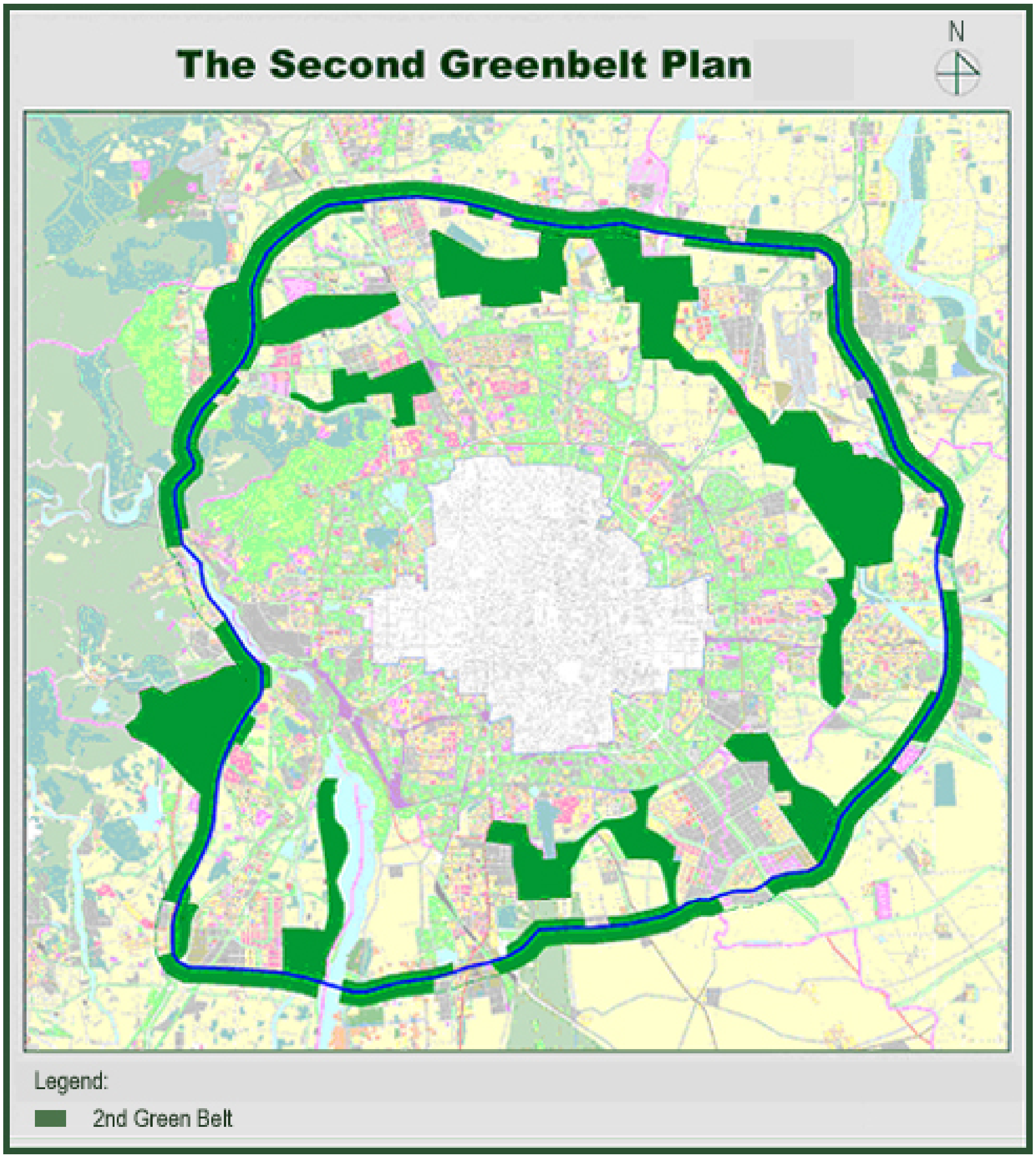
Source: Beijing Municipal Institute of City Planning and Design, 2003

The First Greenbelt

The first greenbelt will be located between Beijing's third and fourth ringroads, immediately adjacent to the core of Beijing (Li, 2002). It will cover some 240 square kilometers in the urban area (Figure 16). Because the compact urban core of Beijing features high-density settlement with crowded communities, the first greenbelt faces the largest challenge related to planning, implementation and maintenance (Zhang, 2001).

The Second Greenbelt

Figure 17: The Second Greenbelt Plan

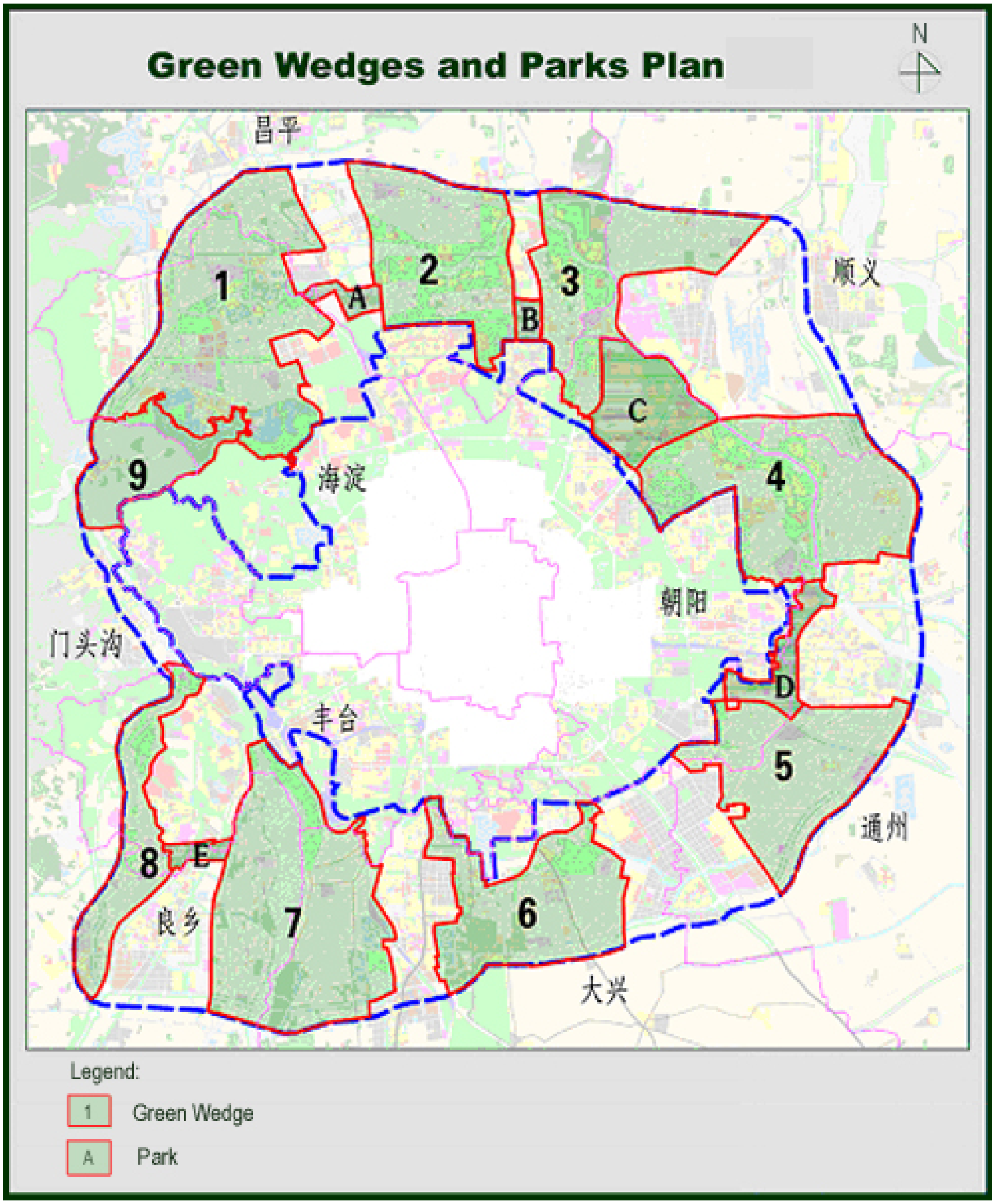


Source: Beijing Municipal Institute of City Planning and Design, 2003

The second green belt will be located in the plains area, between the fifth and sixth ringroads and cover a total area of 1,650 square kilometers (Figure 17). It will function to not only improve urban environmental quality but also limit future urban expansion. Arbor trees will be planted along a 200-meter stretch on both sides of city roads. The second greenbelt is composed of the green circle, greenways, nine green wedges, and five community parks. The greenways are linear networks along two major rivers (the WenYu River and the Yongding River), and will serve to create corridors that link the surrounding green space (Zhao, 2003).

The nine green wedges and community parks are proposed in both suburbs and urban areas. The green wedges are composed of parks, gardens, forest patches, farmlands, rivers, and wetlands. These green wedges and green corridors form an integrated ecological network by connecting the urban center, mountain forest and outer regional green space. The green wedges and community parks proposed at the city scale are shown in Figure 18.

Figure 18: Plan For Green Wedge And Parks

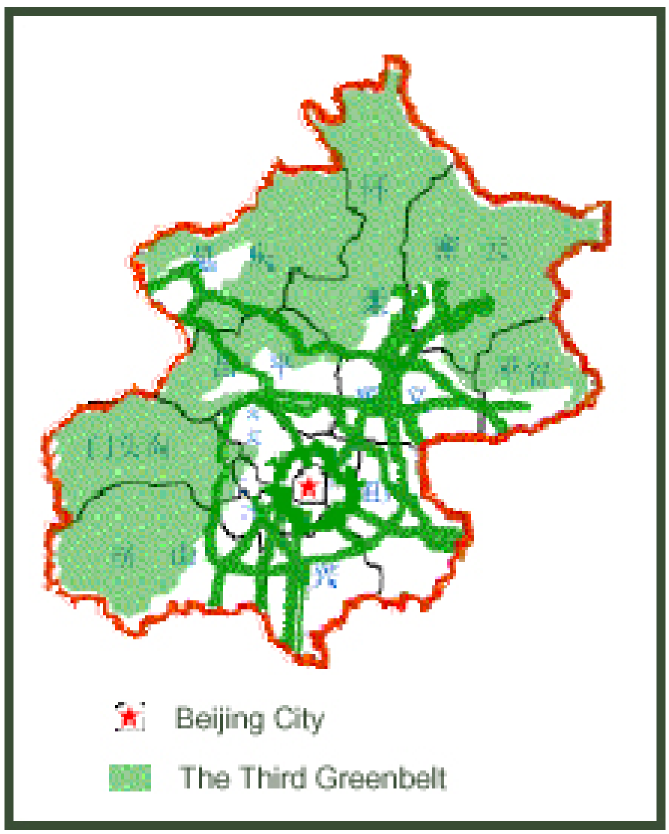


Source: Beijing Municipal Institute of City Planning and Design, 2003

The Third Greenbelt

The third greenbelt will be developed in the western and northern mountain areas. The mountains cover an area of 10,418 km^2 and have a length of 700 km from southwest to northeast of Beijing (Figure 19). The third greenbelt aims to transform desert areas and prevent soil erosion, thus eliminating sandstorms originating in local areas by controlling the sand storm sources. The third greenbelt will be planned and managed as a large, natural and self-sustaining ecosystem. At present, the large forest area in the mountains covers 4057 km^2, which accounts for 38.9% of the mountain area.

Figure 19: The Third Greenbelt Map



Source: Beijing Qianlong Website, 2005

Issues

Beijing has been working hard in recent years to improve air quality and the environment in the city. As a major project aiming to increase Beijing's green space and improve the ecological system, the Beijing Greenbelts Plan is receiving significant attention. It is an enormous project with great capital input, and it will generate remarkable influence on Beijing's future ecosystem development. It is meaningful to inspect the plan carefully to ensure the greenbelts provide the best ecological services. However, due to lack of scientific methods, there has been no research conducted to quantitatively examine the greenbelts' impact.

On the other hand, the greenbelts plan gives a general idea on developing green space. A more detailed study is still necessary. For example, the spatial arrangement of the greenbelts could be adjusted to more effectively hamper frequently invading sandstorms. The plan also emphasizes the number of trees and canopies, while little attention is paid to the recreational function of greenbelts. Therefore, this study will use modern modeling software, ArcGis and CITYgreen, to examine the effect of the Beijing Greenbelts Plan on the tree canopy and air pollution removal, and to explore the plan in depth and attempt to provide modification recommendations according to landscape ecological principles.

Figure 20: Beijing Comprehensive Master Plan

Source: Beijing Municipal Institute of City Planning and Design, 2003

So far, the detailed plan for the first and second greenbelt has been released, while the planning for the third greenbelt in the mountain area is still in process. Therefore, the emphasis of this study will be put on the first and second greenbelt. These two greenbelts cover the city area, including the urban area of Beijing with its suburbs, as well as the surrounding peri-urban zone (Figure 20).

In addition, in support of greenbelts project, Beijing has proposed some other greening projects to provide more green space (Zhang, 2001). For instance, the City Street Green Project proposes a green ring along the internal side of the second ringroad. The Olympic Green Park aims to build up a large scale park near the site of athlete village. Because the official information is very limited, the latter green space will not be included during the analysis. This is reasonable considering the predominant role the greenbelts will play in Beijing’s green space system.

Summary

Due to desertification and urbanization, Beijing is facing serious environmental problems such as sandstorms and air pollution. To improve the environment, the Beijing Greenbelts Plan was developed. Three greenbelts will be built- up by 2007 in urban, suburb (plain), and mountain areas. The construction of the greenbelts will improve air quality and hamper the sandstorms and contribute to a successful “Green Olympic” event in 2008. In-depth study is needed to improve the plan for providing the best ecological service. Modern modeling tools such as GIS and CITYgreen are necessary to simulate the mechanism and anticipate its impact on air quality.

Chapter Four: Methodology

This chapter describes the methodology and the procedures employed in the research. The research was conducted in three steps: The first step was to prepare data. Secondly, three scenarios were created and analysis was conducted with CITYgreen software. In the final step the three scenarios were compared and the analysis results were discussed. In this chapter, the first section introduces the method of modeling three scenarios. The second section introduces the data preparation methods. The third section presents the procedures employed in CITYgreen. A flow chart presents information in the fourth section to provide an overview of the analysis.

Modeling Scenario and Analysis

Three spatial scenarios providing descriptive and visual information of greenbelts were created to analyze the impact of urban green space. The three scenarios include EXISTING GREEN SPACE IN 1999, THE BEIJING GREENBELTS PLAN, and IMPROVED GREENBELTS.

The First Scenario: THE EXISTING GREEN SPACE OF BEIJING IN 1999

The first scenario was to analyze the existing green space of Beijing in 1999. The study area of Beijing were defined according to the boundary in the map of Beijing Comprehensive Plan. By clipping the original raster data, the city raster data were obtained for CITYgreen analysis. CITYgreen software can convert the raster data to their own identifying categories and calculate the environmental indicators, including tree canopy, air pollution removal, carbon storage and sequestration values. These environmental indicators for Beijing in 1999 are the baseline before the Beijing Greenbelts Plan.

The Second Scenario: THE BEIJING GREENBELTS PLAN

The second scenario was created to analyze the impact of the Beijing Greenbelts Plan. Because CITYgreen software can only identify its own categories, appropriate raster data was created for CITYgreen analysis. The strategy of preparing the appropriate raster data was to convert city raster data to a polygon and then edit its attributes. The purpose of editing the attributes was to create a new category for raster conversion. The raster data of greenbelts was created using Arc Map. By using CITYgreen, a statistic report on the area of tree canopy and the amount of air pollution removal were generated.

The Third Scenario: IMPROVED GREENBELTS

To improve the Beijing Greenbelts Plan, the third scenario was developed based on the landscape ecology principles and strategies applied in the case studies presented in Literature Review. The scenario development and analysis was conducted at three different levels: region level, city level, and neighborhood level.

At the region level, two approaches were proposed to improve the Beijing Greenbelts Plan: widening edges on the sides facing the predominant wind direction and leaving the south side open.

At the city level, two methods were suggested: creating green network connectivity and build up buffer zones along roads and rivers. 100-meter-wide tree buffers along rivers and roads and a 50-meter wide tree buffer along the city central axis were developed.

At the neighborhood level, the analysis included two sections: Section 1 was to study an example site (a basic unit cell) in the urban core. Section 2 was to analyze the whole urban core area according to the results found in Section 1. By manipulating ArcGis and CITYgreen, the amount of tree canopy and air pollution removal in each unit cell zone were estimated.

Data Preparation

This study used Landsat image data to detect the spatial patterns of the land use and landcover. The Landsat image of Beijing was taken in the summer of 1999. It was multi-spectral satellite imagery with high resolution in order to provide detailed and reliable information about the region's landcover features, especially tree canopy.

The Landsat image was processed by using unsupervised reclassification in PCI Image Processing software, ISO_ Cluster Program. Landcover was grouped into categories based on the landcover categories system used by the U.S. Geological Survey (USGS) in the U.S. national landcover data. Eight landcover types were classified to represent the feature of Beijing's landcover.

According to the Beijing Greenbelts Plan, a unionized layer of greenbelts was created by individually digitizing the three greenbelts in ArcGis. To provide descriptive and visual information of Beijing, the key features of major roads, rivers, lakes, and parks were also digitized.

CITYgreen Processing

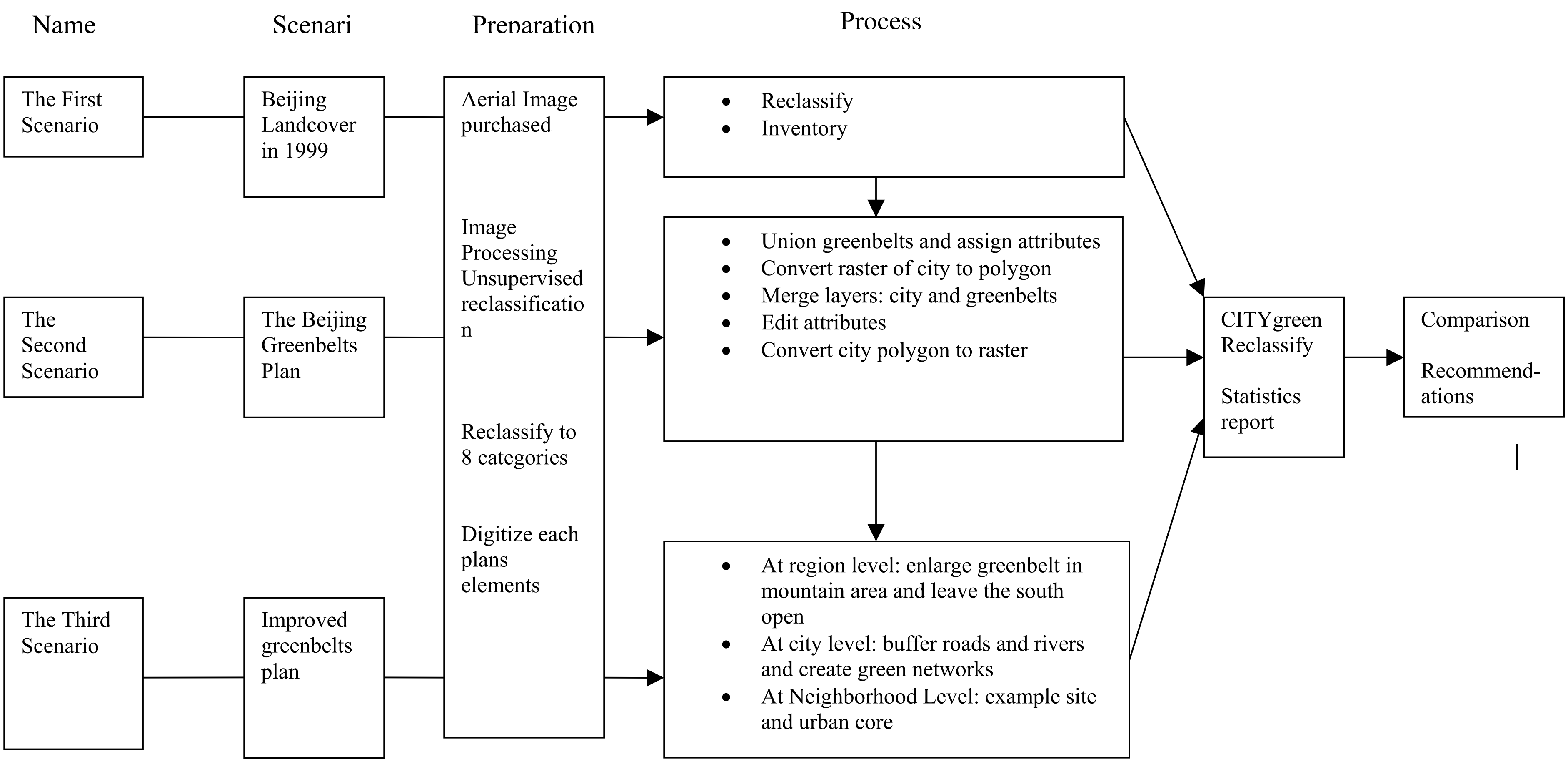
CITYgreen software converts input landcover data to its identifying categories and generates the statistics report of the landcover and environmental indicators. In CITYgreen report, the landcover section summarizes the percentage of different landcover categories by showing a pie chart of the landcover composition. In addition, the report shows the environmental indicators including air pollution removal, carbon storage, and sequestration (CITYgreen User Manual, 2004).

In CITYgreen, Washington, D.C. was used as the reference city to calculate dollar values. The reason is that Washington, D.C. and Beijing have similar features in geography and climate. They are both adjacent to oceans and have continental monsoon climate.

Overview of Procedures

Data preparation was the first stage of the study. Then three scenarios were created, and statistics reports were generated by CITYgreen. The final stage of the research was to compare three scenarios from a quantitative, and other considerations were presented based on landscape ecological principles. Figure 21 is the analysis flow chart for this study.

Figure 21: Analysis Flow Chart



Chapter Five: Analysis

The purpose of this chapter is to implement analysis, as set forth in the methodology, which includes creation and analysis of three scenario models and comparisons among the scenarios. This chapter contains three sections: data preparation, modeling scenarios and discussion. Data preparation presents the process of data collection, image processing and landcover digitizing. For each scenario, the processing methods are described, and the results of the statistics report are presented. The analysis results of three scenarios are compared qualitatively and quantitatively.

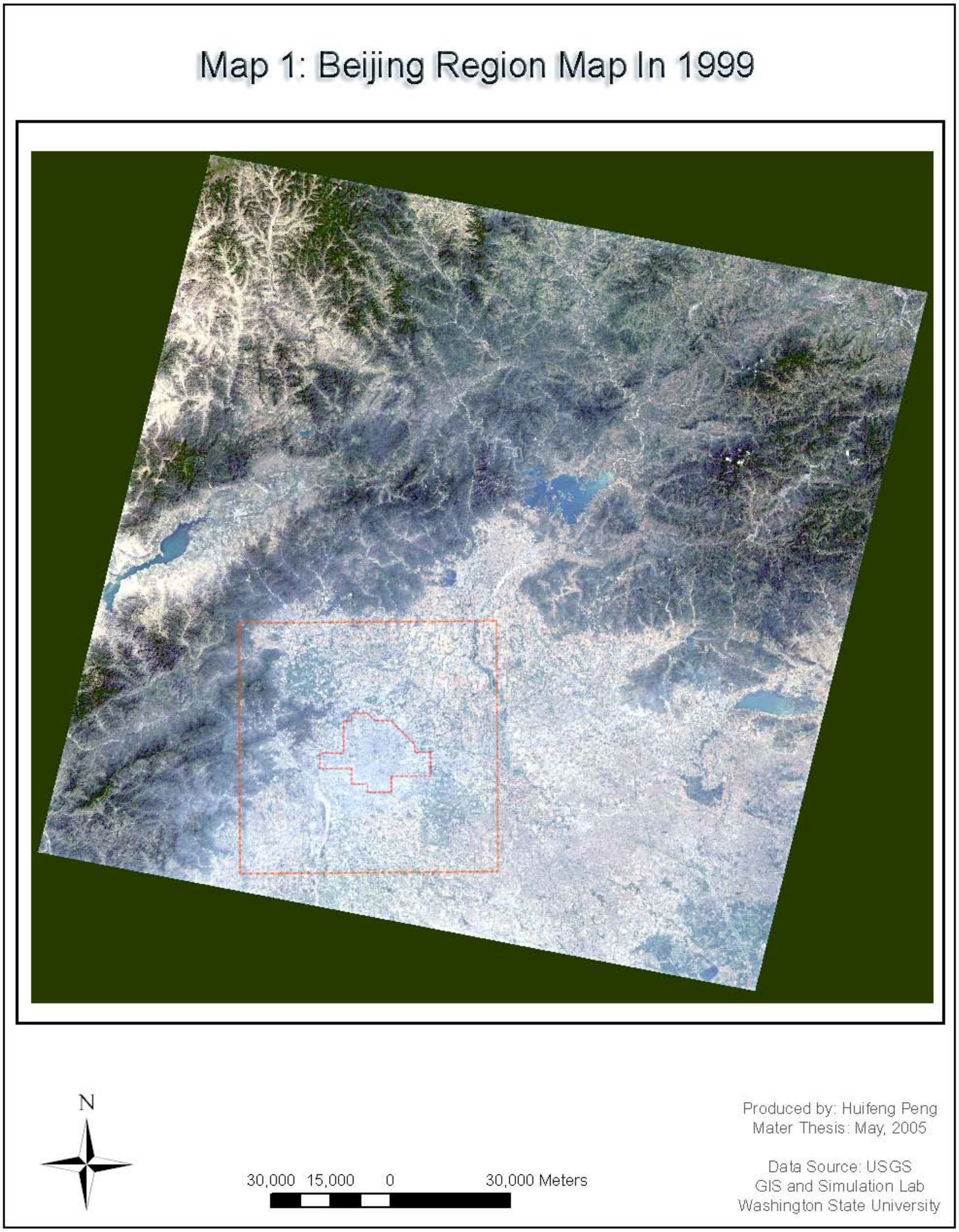
Data Preparation

Data Collection

Data collection is the first step of the research that provides basic information. Numerical satellite imagery and aerial remote-sensing have provided environmental studies with a genuine investigation power. The integration of remote-sensing into GIS can quickly detect the spatial patterns and monitor the dynamics of large-scale environment on a period time-scale (Campbell, 1987).

The study used Landsat Thematic Mapper (TM) data to detect the palatial patterns of the land use and landcover in Beijing (Map1). The coverage area of the Landsat data includes the urban core of Beijing, part of peripheral counties and the northwest mountain area. To detect space changes in the area, data-acquisition and analysis scales must be in high resolution with multi-spectral satellite imagery (Peccol, 1994).

Map 1: Beijing Region Map In 1999



To reflect typical land use and landcover patterns for the broad range of sites, the process of aerial image selection is very important. The aerial image was selected based on the data quality, cloud cover, and time of the year. The satellite imagery used in study was taken in the summer of 1999. An important reason for using the image taken in the summer is that trees are actively photosynthesizing. Thus can gain detailed and reliable information.

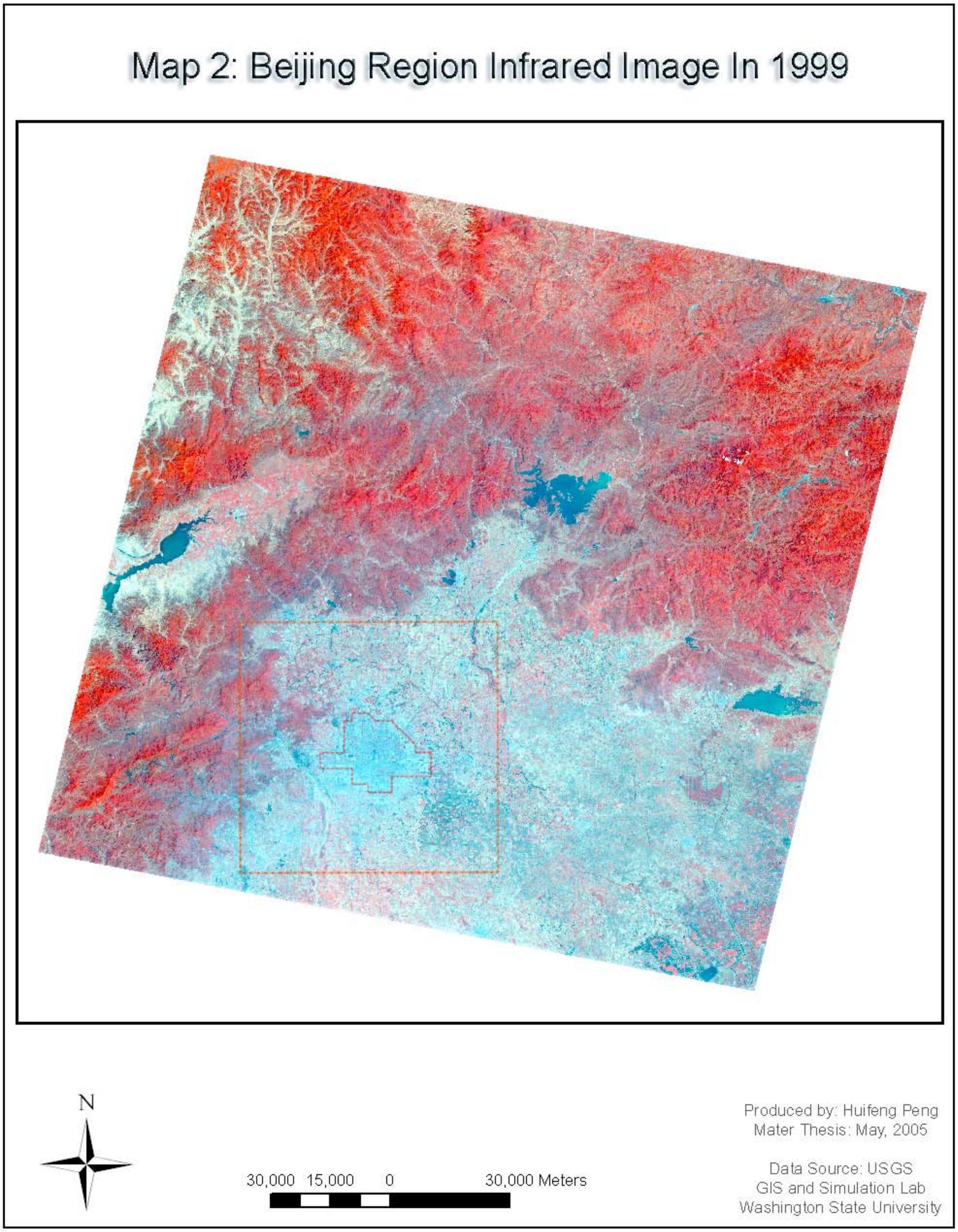
The Landsat data were taken for path 123 and row 32, and the spatial resolution is 30 × 30 m. The covered area enclosed within 39°35'52''–41°17'30'' N and 114°50'05''–117°59'09'' and is nearly 5100 km^2. Some counties that are left out of the study are all distributed in the outskirts of the Beijing region.

Image Processing and Unsupervised Reclassification

The Landsat image was processed by using unsupervised reclassification in the ARCGIS and Simulation Lab at Washington State University. Raw raster satellite data contain widely fluctuating reflectance values for each pixel in the image. According to different albedo values of features, the image was classified into categories associated with reflectance values (Verbyla, 1995). The Landsat image was firstly classified into fifty spectral clusters to represent details of the landcover in Beijing (Verbyla, 1995). The spectral clusters, as discussed below, were then assigned to landcover information categories. The result was a fully classified scene with pixels accurately assigned to buildings, street, grass, water, and trees.

An infrared image provides an effective way to detect landcover and is very helpful in land-use planning. Map 2 shows an infrared image of Beijing region by using TM Bands 2, 3, and 4. The red color in the map shows the vegetations of Beijing.

Map 2: Beijing Region Infrared Image In 1999



Land Categories

The landover classification was based on the system used by the U.S. Geological Survey (USGS) in the US Landcover National Map. The classification system used for the National Landcover Map is divided by categories, such as water, developed area, and etc, with definitions and legends (USGS web, 2005).

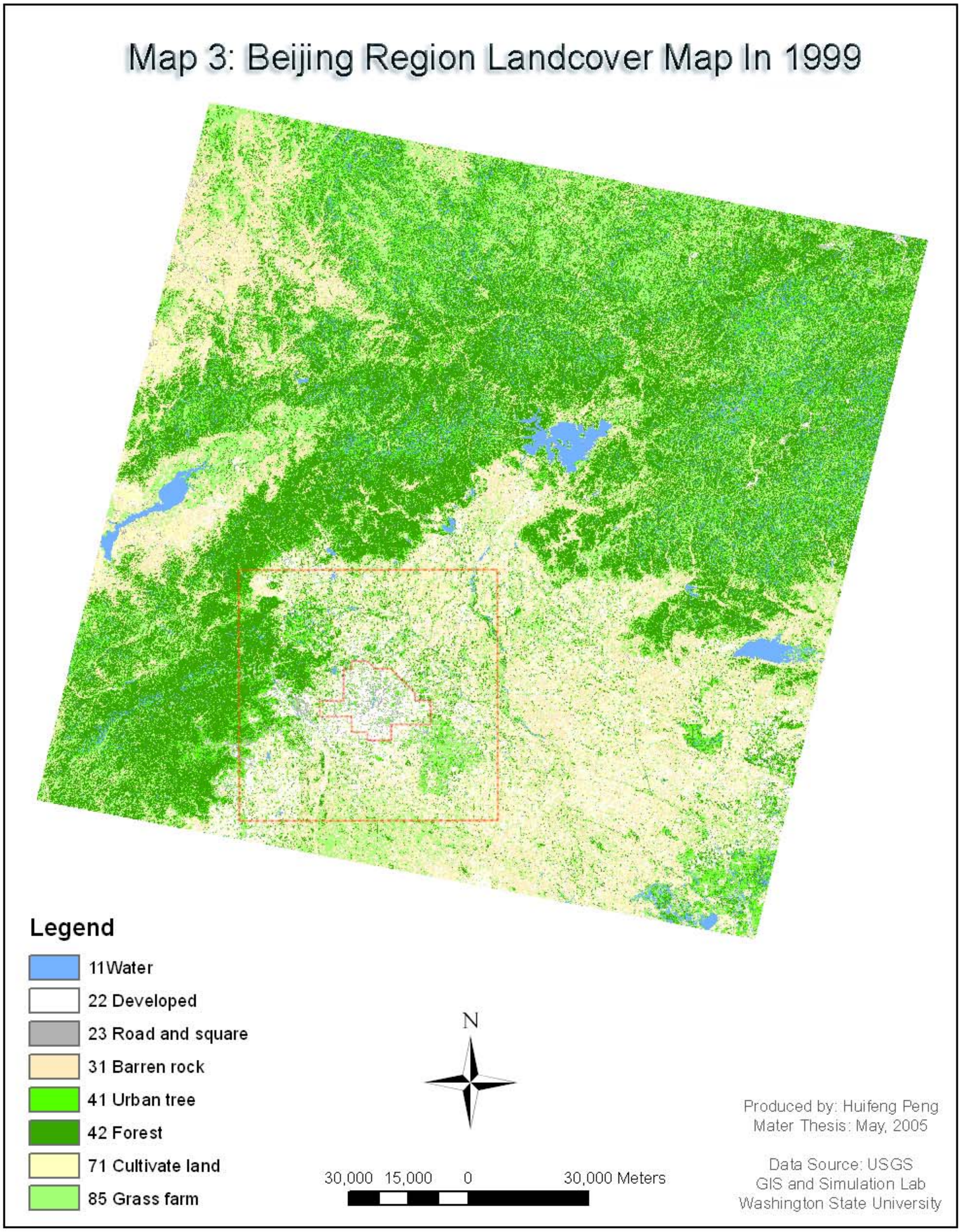
For the Beijing area, eight landcover types were identified from the fifty spectral categories by manual interpretation. The resulting map is shown on Map 3. In the urban area, landcover was divided into six categories: urban developed areas (including commercial, office and residential areas), road and square areas, urban tree area, water (including canals and fish ponds), grass and farmland, and cultivated land with row crops. In the mountain area, landcover was divided into two categories: forest, and barren and rocky areas (Table 4).

Table 4: Categories In Beijing Landcover Reclassify Map

Area	Code	Landcover
Urban Area	11	Water (including canals and fish ponds)
	22	Urban developed area (commercial, official and residential area)
	23	Road and square area
	41	Urban tree area
	71	Cultivated land with row crops
	85	Grass and farmland
Mountain Area	31	Barren and rocky area
	42	Forest

Source: Author, 2005

Map 3: Beijing Region Landcover Map In 1999



Digitizing Beijing Greenbelts Plan

To provide descriptive and visual information of overall the Beijing Greenbelts Plan, a unified layer of greenbelts was created. The three greenbelts were individually digitized in ArcGis. As the maps of the greenbelts plan obtained from the web do not contain spatial reference information, image versions of the maps were aligned to the Landsat image. By using the ArcGis Georeference command and adding control points, the greenbelts maps were approximately aligned to proper positions.

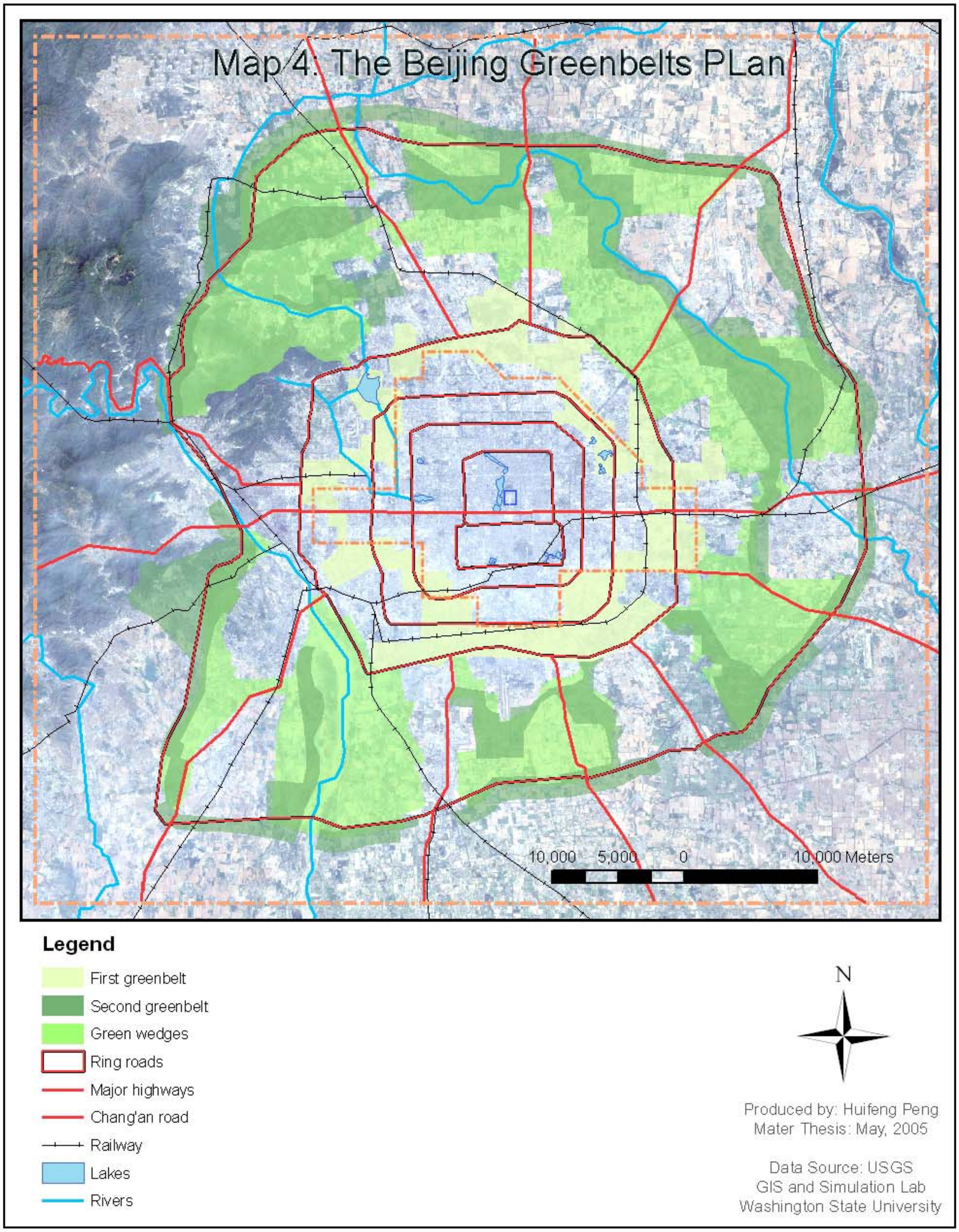
In ArcCatalog, a shape file of each greenbelt was created and then moved into ArcMap. Then by using the Editor Tool and tracing the edge of each greenbelt, a digital version of the greenbelts was developed. By applying a Union command, the three greenbelt layers were combined and are called Union Greenbelts. Map 4 shows the three greenbelts in Beijing.

Digitizing Features of Landcover

Key features of Beijing landcover were digitized for further study. The key features are listed below:

- Roads and Railways: Beijing is characterized by the circling ringroads and radiating highways which connect with other cities.
- Rivers and Reservoirs: Major rivers and reservoirs are selected for the overlay based on the Beijing topology map.
- City Axis: The Beijing plan is featured with symmetry and a north-south city central axis.
- Parks and Lakes: Beijing as a historic city has several imperial parks and community parks.

Map 4: The Beijing Greenbelts Plan



The First Scenario: The Existing Green Space of Beijing in 1999

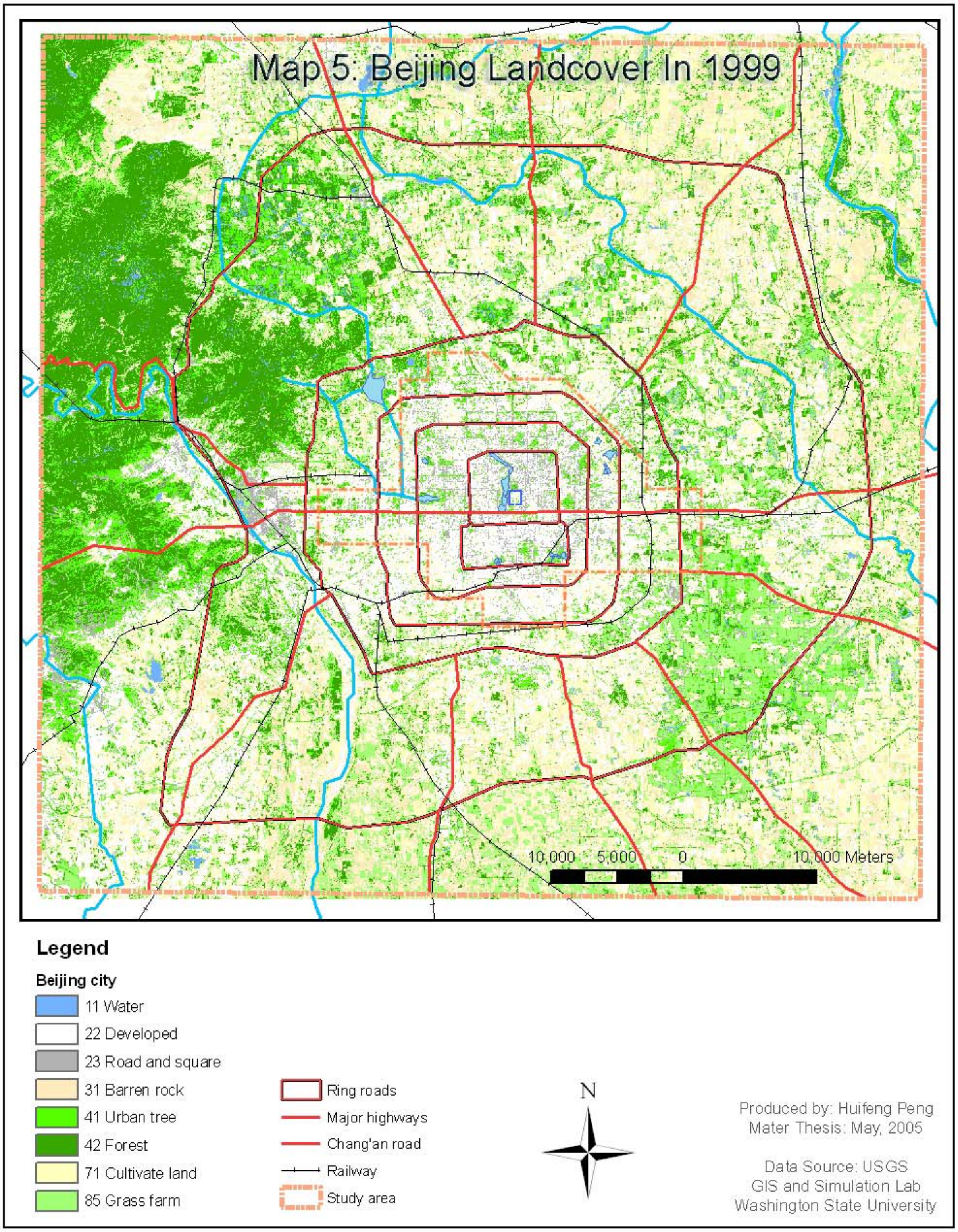
The first scenario was developed based on the existing landcover in 1999. The purpose of creating the first scenario was to analyze green space that existed before 2003, when the Beijing Greenbelts Plan was released. In the first scenario, the study area of Beijing was defined according to a boundary in the map of the Beijing Comprehensive Plan. Once data preparations were finished, the raster data with eight categories were in an appropriate format and ready for CITYgreen to analyze. The following steps were operated in ARCGIS and CITYgreen .

Data Processing

Landcover of city.

At first, the appropriate geoprocessing environment was set up, and cell size was assigned 30 which was to be used by all geoprocessing tools. The landcover for the city was created by clipping the regional landcover data. Map 5 shows the landcover in the city of Beijing.

Map 5: Beijing Landcover In 1999



Configuring landcover map

Instead of analyzing the existing landcover data, CITYgreen software converted the previous categories to its own identifying categories. Table 5 shows each category in Beijing Landcover Reclassify Map and CITYgreen.

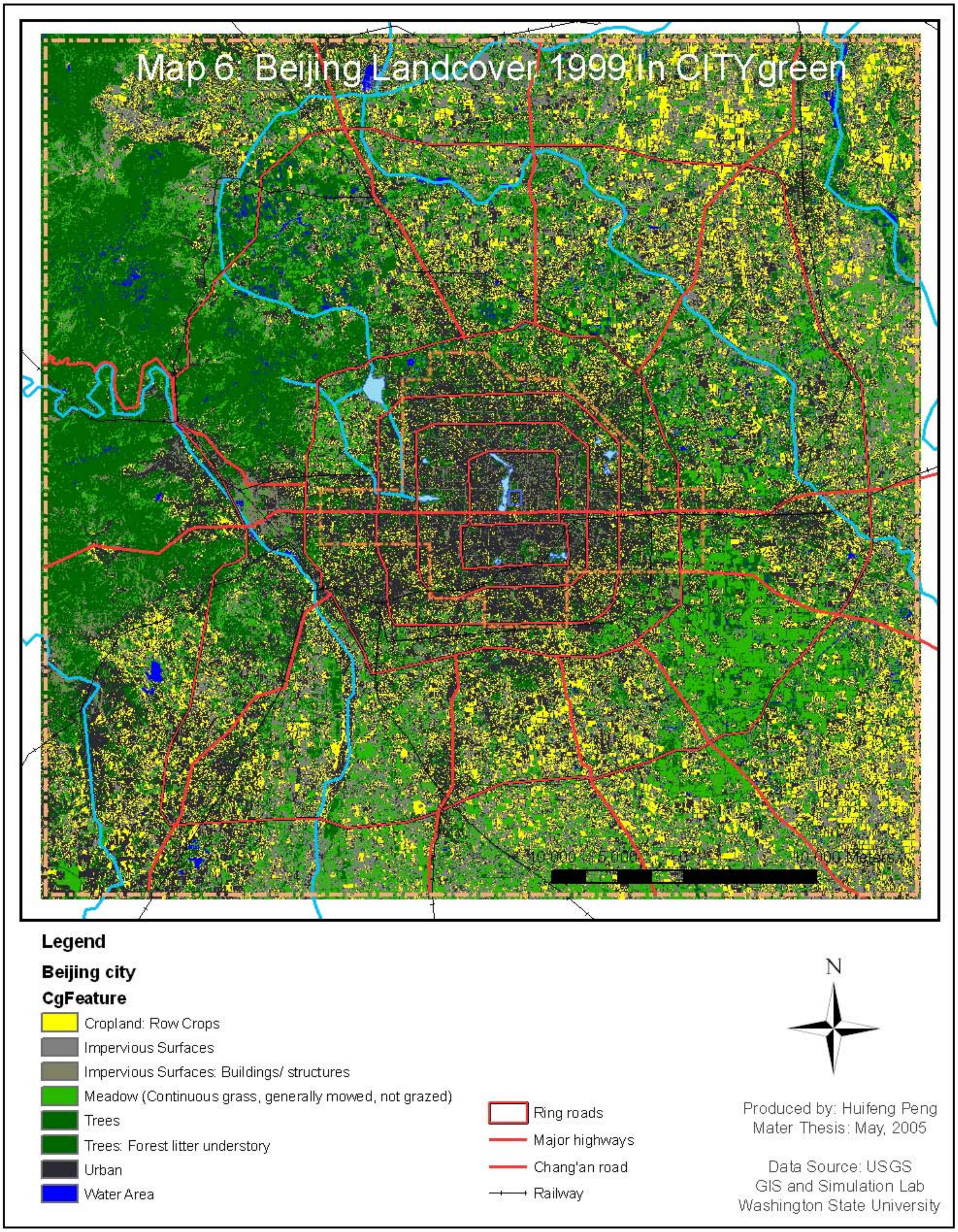
Table 5: Categories in Beijing landcover Reclassify Map and CITYgreen

Categories	Code	Landcover in Beijing Maps	Landcover in CITYgreen
1	11	Water (including canals and fish ponds)	water area
2	22	Urban developed area (includes commercial, official and residential area)	urban
3	23	Road and square area	impervious surface(buildings and structures)
4	31	Barren and rocky area	impervious surface
5	41	Urban tree area	trees
6	42	Forest	trees with forest
7	71	Cultivated land with row crops	cropland(row crops)
8	85	Grass and farmland	meadow(continuous grass, generally mowed)

Source: Author, 2005

After converting the eight categories, CITYgreen applied the original data to a new landcover data. Map 6 shows the categories obtained by converting into CITYgreen's categories.

Map 6: Beijing Landcover 1999 In CITYgreen



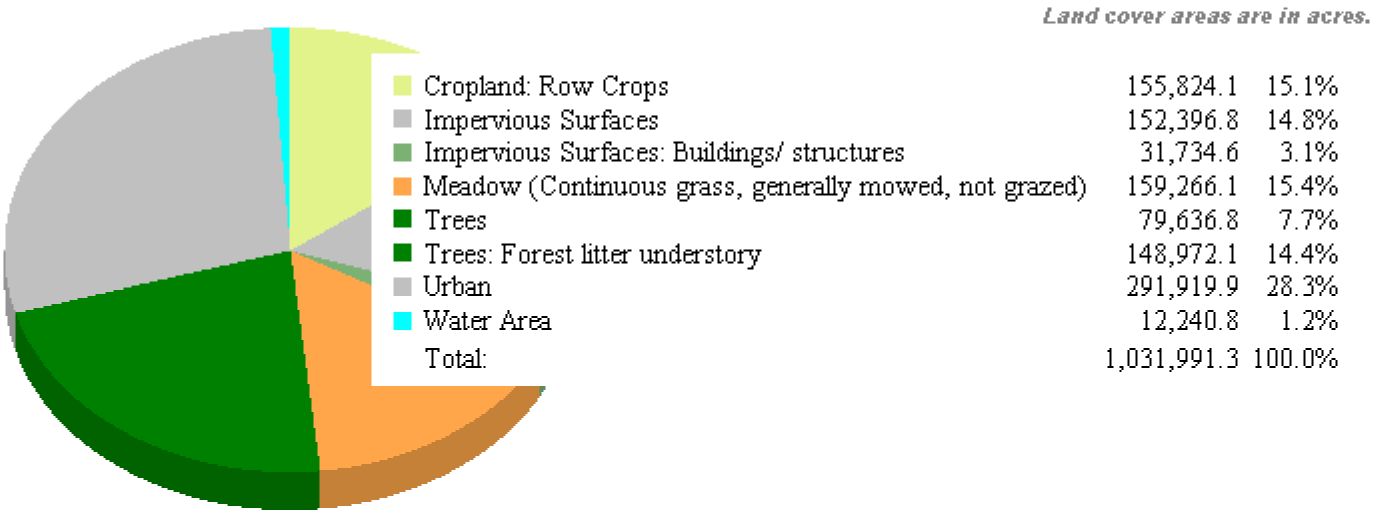
Result: The CITYgreen Report

By running the “CITYgreen Analysis” command, the software calculated the environmental indicators and then exported results to Crystal Reports, a powerful database-reporting program. In the CITYgreen report (Figure 22), the landcover section summarizes the percentage of different types of landcover in the study area by showing a pie chart of the landcover composition. In addition, the report shows the air pollution removal, carbon storage and carbon sequestration (CITYgreen User Manual, 2004).

On the left of the report, the pie chart shows graphically the composition of the landcover. On the right of the report is the landcover section. In the first column, the section summarizes the area of eight categories and the total number in Beijing region. In the second column, the report shows each category’s percent coverage in the area. From the report, it can be seen that the total tree canopy of Beijing in 1999 was 228,608.8 acres, and the percentage was 22.2%.

Under the landcover section, the Air Pollution removal result is shown. Air pollution removal includes carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), particulate matter, and sulfur dioxide. The left column of the table shows the pollutants that trees remove per year, which is 23,027,608 lbs. The right column indicates the removal of the pollutants to be a $53,613,718 dollar value. The amount of particulate matter removal is 6,724,877 lbs. per year and the dollar value of saving expense is $13,793,879.

The last section of the report shows carbon storage and sequestration values. It shows that the total amount of carbon storage is 9,837,377.50 tons, and the amount of total carbon sequestration is annually 76,586.60 tons.



Total Tree Canopy: 228,608.8 acres (22.2%)

Air Pollution Removal

By absorbing and filtering out nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), carbon monoxide (CO), and particulate matter less than 10 microns (PM10) in their leaves, urban trees perform a vital air cleaning service that directly affects the well-being of urban dwellers. CITYgreen estimates the annual air pollution removal rate of trees within a defined study area for the pollutants listed below. To calculate the dollar value of these pollutants, economists use "externality" costs, or indirect costs borne by society such as rising health care expenditures and reduced tourism revenue. The actual externality costs used in CITYgreen of each air pollutant is set by the each state, Public Services Commission.

Nearest Air Quality Reference City: **Washington DC**

	Lbs. Removed/yr	Dollar Value
Carbon Monoxide:	1,018,921	$434,835
Ozone:	7,947,581	$24,416,703
Nitrogen Dioxide:	4,075,683	$12,521,386
Particulate Matter:	6,724,877	$13,793,879
Sulfur Dioxide:	3,260,546	$2,446,916
Totals:	**23,027,608**	**$53,613,718**

Carbon Storage and Sequestration

Trees remove carbon dioxide from the air through their leaves and store carbon in their biomass. Approximately half of a tree's dry weight, in fact, is carbon. For this reason, large-scale tree planting projects are recognized as a legitimate tool in many national carbon-reduction programs. CITYgreen estimates the carbon storage capacity and carbon sequestration rates of trees within a defined study area.

Total Tons Stored: 9,837,377.50

Total Tons Sequestered (Annually): 76,586.60

Figure 22: Analysis Report For Beijing In 1999

The Second Scenario: The Beijing Greenbelts Plan

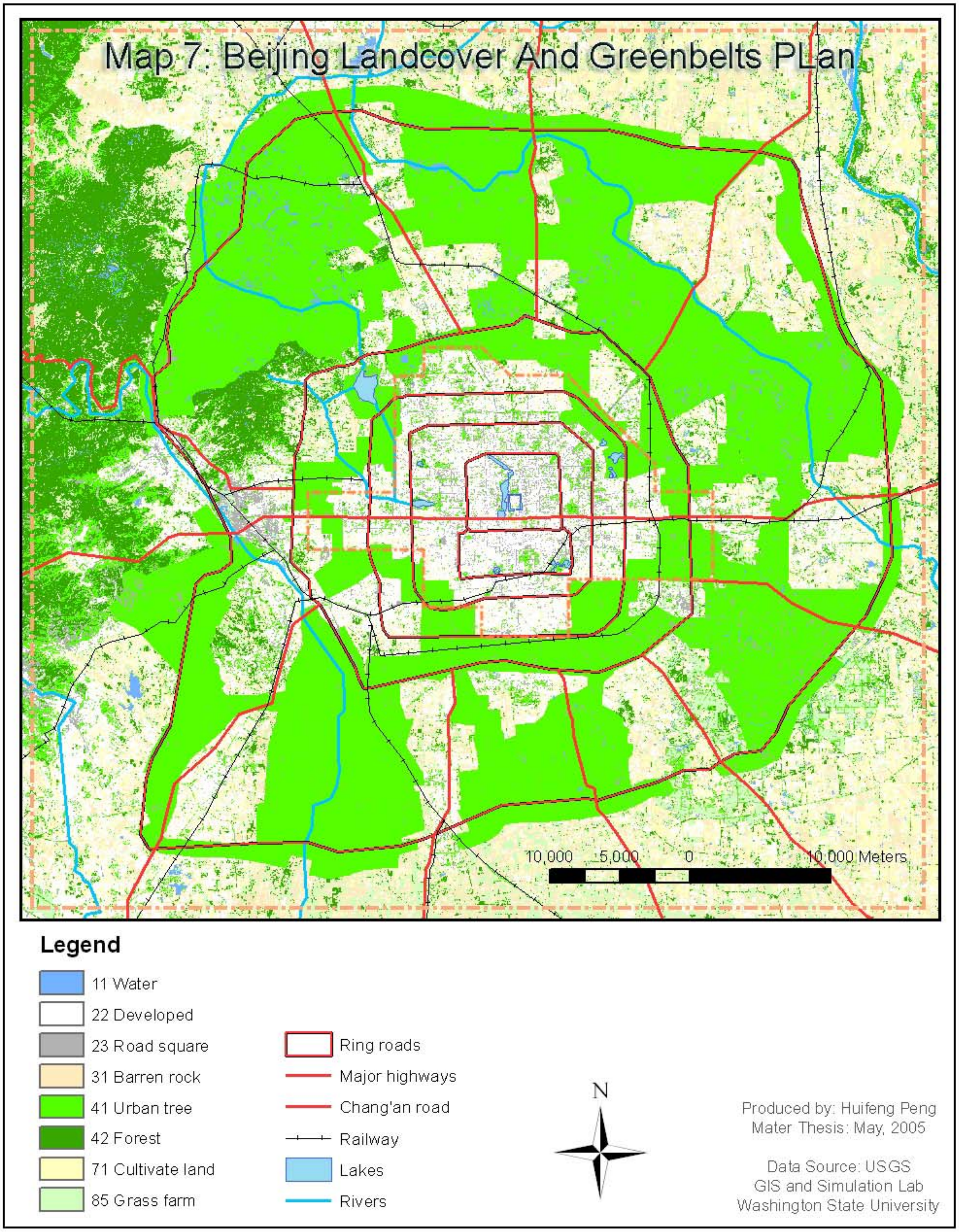
The second scenario was created to analyze the impact of the Beijing Greenbelts Plan proposed in 2003. The Second Scenario used the landcover created in the first scenario. The landcover was merged into the coverage of the Beijing Greenbelts Plan. By applying CITYgreen , a statistic report on tree canopy and air pollution removal was generated.

Data Processing

Creating landcover raster data with greenbelts.

As CITYgreen software can only identify its own categories, an appropriate raster is needed for CITYgreen analysis. To prepare the specific raster data, the attributes table of Union Greenbelts was edited by assigning the code "41 urban tree areas" to all greenbelts. Then, the raster data of the city were converted to the polygon using Conversion Tools. By using Union Tools again, the polygon of city and union greenbelts were merged into a same layer. The attributes of the union layer were edited to modify tree coverage. Data of water and roads were maintained and other data changed to tree coverage. The final step was using Conversion Tools to convert the new city polygon with greenbelts back to the raster data corresponding to the new category (Map 7).

Map 7: Beijing Landcover And Greenbelts Plan



Configuring landcover map.

The new raster data created were suitable for CITYgreen analysis. The step of reclassifying categories was the same as the one performed in the first scenario. By running "Configuring Raster Data" in CITYgreen , the eight categories were reclassified, and new landcover data were generated (Map 8).

Result: The CITYgreen Report

By replacing the first scenario model with the second one and performing analysis, CITYgreen generated the statistical report (Figure 23) for the Beijing Greenbelts Plan. The report shows the percentage of landcover, air pollution removal, carbon storage, and the dollar value of tree canopy.

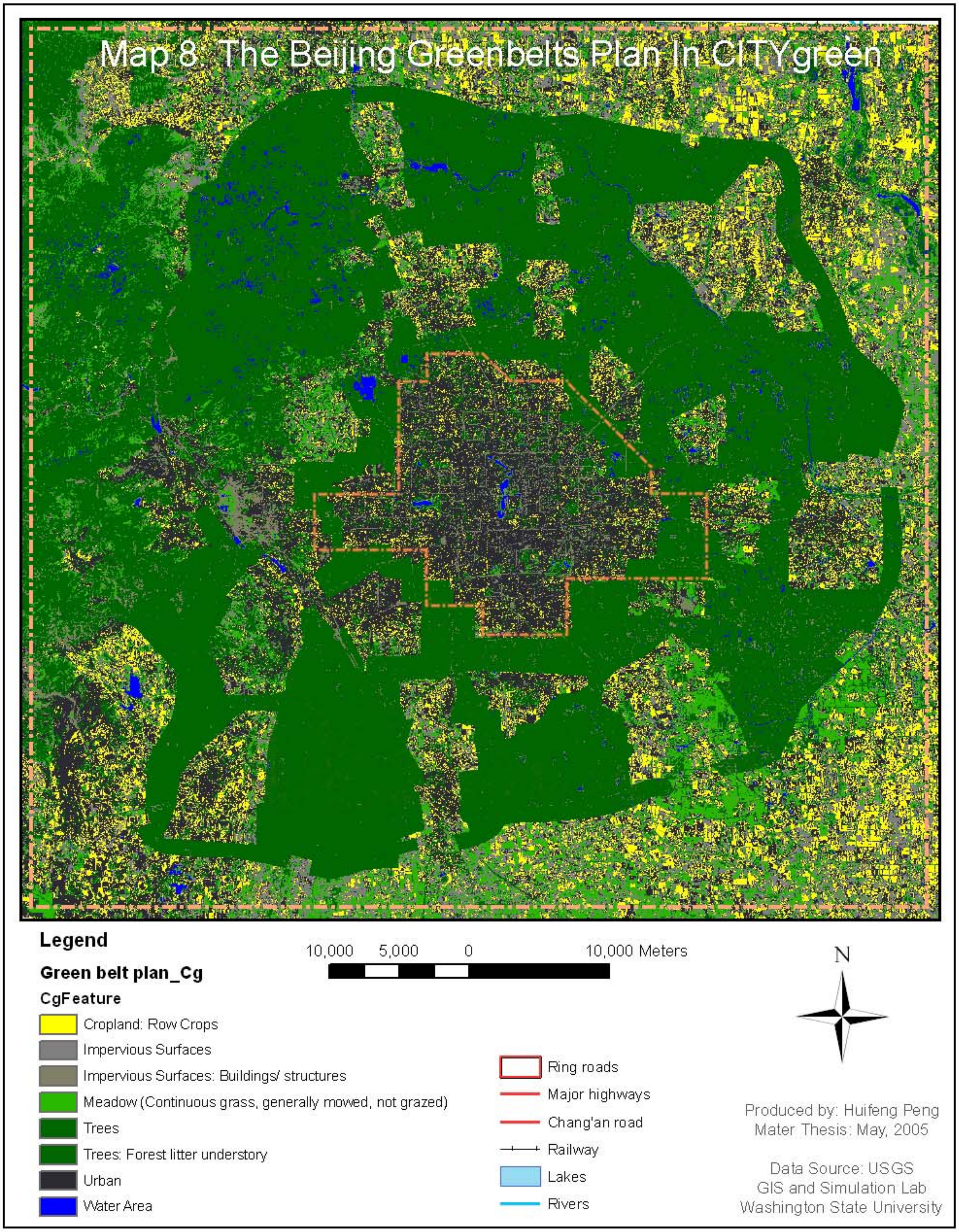
Figure 23 shows the area of tree coverage is 495,601.7 acres, and the percentage of canopy is 48.0%. The total of air pollution removals is 49,921,608 lbs. per year, and the dollar value of saving expense is $116,229,312. The amount of particulate matter removal is 14,578,877 lbs. per year, corresponding to $29,903,784 dollar value.

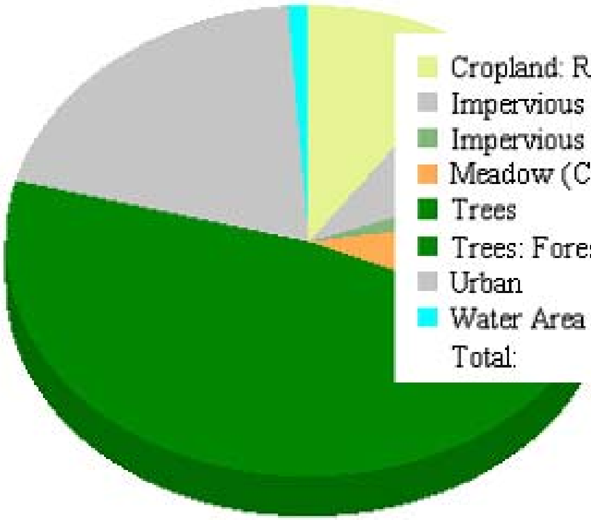
As mentioned in Chapter 3, a major goal of the Beijing Greenbelts Plan is to realize 50% of tree canopy in the city area. The canopy of 48% in the CITYgreen report indicates that Beijing can almost reach its goal if the greenbelts are developed successfully as the plan proposed.

Comparing the report of The Beijing Greenbelts Plan (Figure 23) with Beijing in 1999 (Figure 22), it can be seen after implementation of the Beijing Greenbelts Plan in the city area, the PM removal will increase by 7.85×10^6 lbs. per year. According to Guo and Teng (2003), PM is the dominant pollutant affecting Beijing air quality. As seen in Table 4, the total PM emissions allowed in Beijing urban area is 94,000 ton/year (2.10×10^8 lbs./year), while the actual PM emissions in 1999 was 106,500 ton/year (2.40×10^8 lbs./year). This results with 3.0×10^7 lbs. PM amount needed to be removed, which is four times of the capability of the greenbelts. Moreover, Figures 20 and 21 show the removal of SO_2, and NO_2 will increase by 3.81×10^6, 4.76×10^6 lbs./yr respectively by implementing the Beijing Greenbelts Plan, while Table 4 shows that the removal amounts of SO_2, NO_2 need to increase 100,000 ton (2.22×10^8 lbs.) and 165,000 ton (3.67×10^8 lbs.) per year respectively to reach National Grade II Standard, which are much larger than the capability of the greenbelts. Therefore, the construction of the greenbelts will not improve Beijing air quality to reach the regulations in National Grade II Standard. The third greenbelt to be constructed in the mountain area is expected to produce more profound effect due to its location, direction and by being the largest canopy area among the three greenbelts. In addition, other measures are to be taken by Beijing authority that will contribute to realize the goal, such as reducing the proportion of high pollution industries, moving industry out of the core urban area, using clean coal and natural gas to replace the low quality coal, limiting motor vehicles and strengthening emission control systems (Asian Development Bank, 2002).

During sandstorms, greenbelts will function to decrease sand volume transported by reducing wind speed. It was found that greenbelts could reduce wind speeds by 52% to 83% depending on canopy density (Agriculture and Agri-Food Canada, 2003). Another study shows as density of the canopy increases from 20.8 to 55.5%, the wind reduction factor rises from approximately 30 to 40% (Tran & Pyree, 1999). On the other hand, the overall volume of sand moved has an exponential relationship with wind velocity, i.e. as wind speeds increase, the downwind rate of sand movement increases exponentially (Mangimeli, 1981). Figure 20 and 21 shows the tree canopy will increase from 22.2% in 1999 to 48% after implementation of the Beijing Greenbelts Plan. As a rough estimate, there will be a 10% wind reduction on the basis of the 1999 sandstorm conditions. Subsequently, the sand volume carried by the wind will be greatly decreased. Therefore, the construction of the greenbelts may significantly inhibit the severity of sandstorms in terms of reducing sand volume transported into Beijing city.

Map 8: The Beijing Greenbelts Plan In CITYgreen





Land cover areas are in acres.

Cropland: Row Crops	100,412.7	9.7%
Impervious Surfaces	99,898.7	9.7%
Impervious Surfaces: Buildings/ structures	30,667	3.0%
Meadow (Continuous grass, generally mowed, not grazed)	91,633.3	8.9%
Trees	390,093.2	37.8%
Trees: Forest litter understory	105,263.3	10.2%
Urban	201,991.6	19.6%
Water Area	11,787.6	1.1%
Total:	1,031,992.7	100.0%

Total Tree Canopy: 495,601.7 acres (48.0%)

Air Pollution Removal

By absorbing and filtering out nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), carbon monoxide (CO), and particulate matter less than 10 microns (PM10) in their leaves, urban trees perform a vital air cleaning service that directly affects the well-being of urban dwellers. CITYgreen estimates the annual air pollution removal rate of trees within a defined study area for the pollutants listed below. To calculate the dollar value of these pollutants, economists use "externality" costs, or indirect costs borne by society such as rising health care expenditures and reduced tourism revenue. The actual externality costs used in CITYgreen of each air pollutant is set by the each state, Public Services Commission.

Nearest Air Quality Reference City: **Washington DC**

	Lbs. Removed/yr	Dollar Value
Carbon Monoxide:	2,208,921	$942,679
Ozone:	17,229,581	$52,933,030
Nitrogen Dioxide:	8,835,683	$27,145,144
Particulate Matter:	14,578,877	$29,903,784
Sulfur Dioxide:	7,068,546	$5,304,675
Totals:	**49,921,608**	**$116,229,312**

Carbon Storage and Sequestration

Trees remove carbon dioxide from the air through their leaves and store carbon in their biomass. Approximately half of a tree's dry weight, in fact, is carbon. For this reason, large-scale tree planting projects are recognized as a legitimate tool in many national carbon-reduction programs. CITYgreen estimates the carbon storage capacity and carbon sequestration rates of trees within a defined study area.

Total Tons Stored: 21,326,474.91

Total Tons Sequestered (Annually): 166,032.28

Figure 23: Analysis Report For The Beijing Greenbelts Plan

The Third Scenario: Improved Greenbelts

To improve the Beijing Greenbelts Plan, the third scenario was developed based on Beijing's specific situation and combined with landscape ecology principles. The scenario development and analysis were conducted at three different levels: region level, city level, and neighborhood level. For each level, approaches were proposed to improve the effect of the greenbelts on ecological system in the study area.

Data Processing

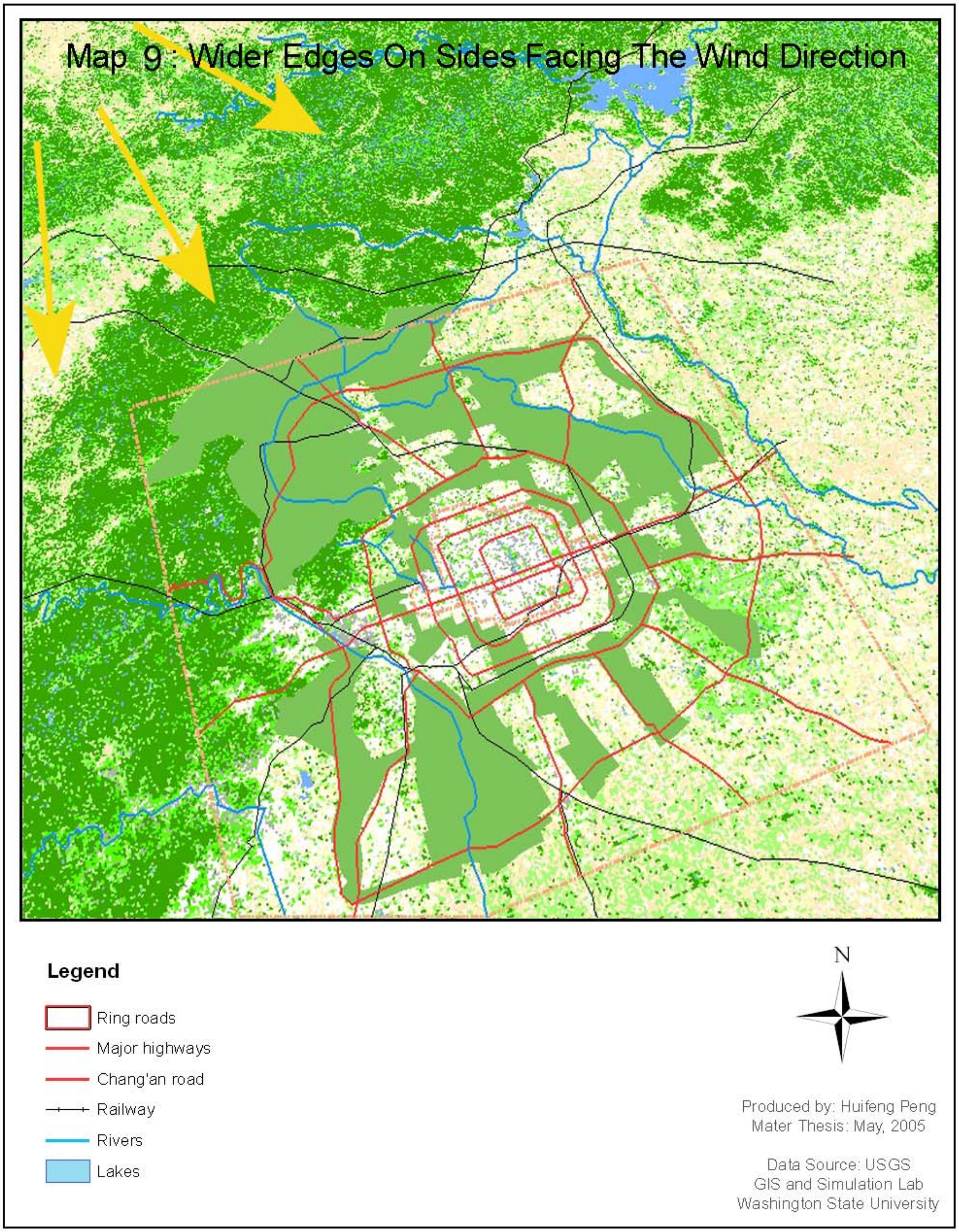
At region level

Widen Edges on the Sides Facing the Predominant Wind Direction

One of the major purposes of the greenbelts is to prevent sandstorms from the northwest. The greenbelts in Beijing should always target the original goals. According to the methods illustrated in the case study of the Canadian greenbelts in Chapter 2, the greenbelt on the northwest of Beijing could be enlarged to maximize the capability of resisting sandstorms. More trees should be planted in northwest instead of evenly distributed across the city.

Furthermore, the prevailing winds in the winter bring snow and cold air from the northwest. If the area of the greenbelt increases in the northwest, it can not only strengthen the ability to hamper the sandstorms but also prevent cold winds in the winter. Map 9 shows that the green area is enlarged in the northwest of Beijing. The continuous greenbelts ranging from suburb to mountain area form a natural solid barrier to hamper the sandstorm and cold winds.

Map 9: Wider Edges On Sides Facing The Wind Direction



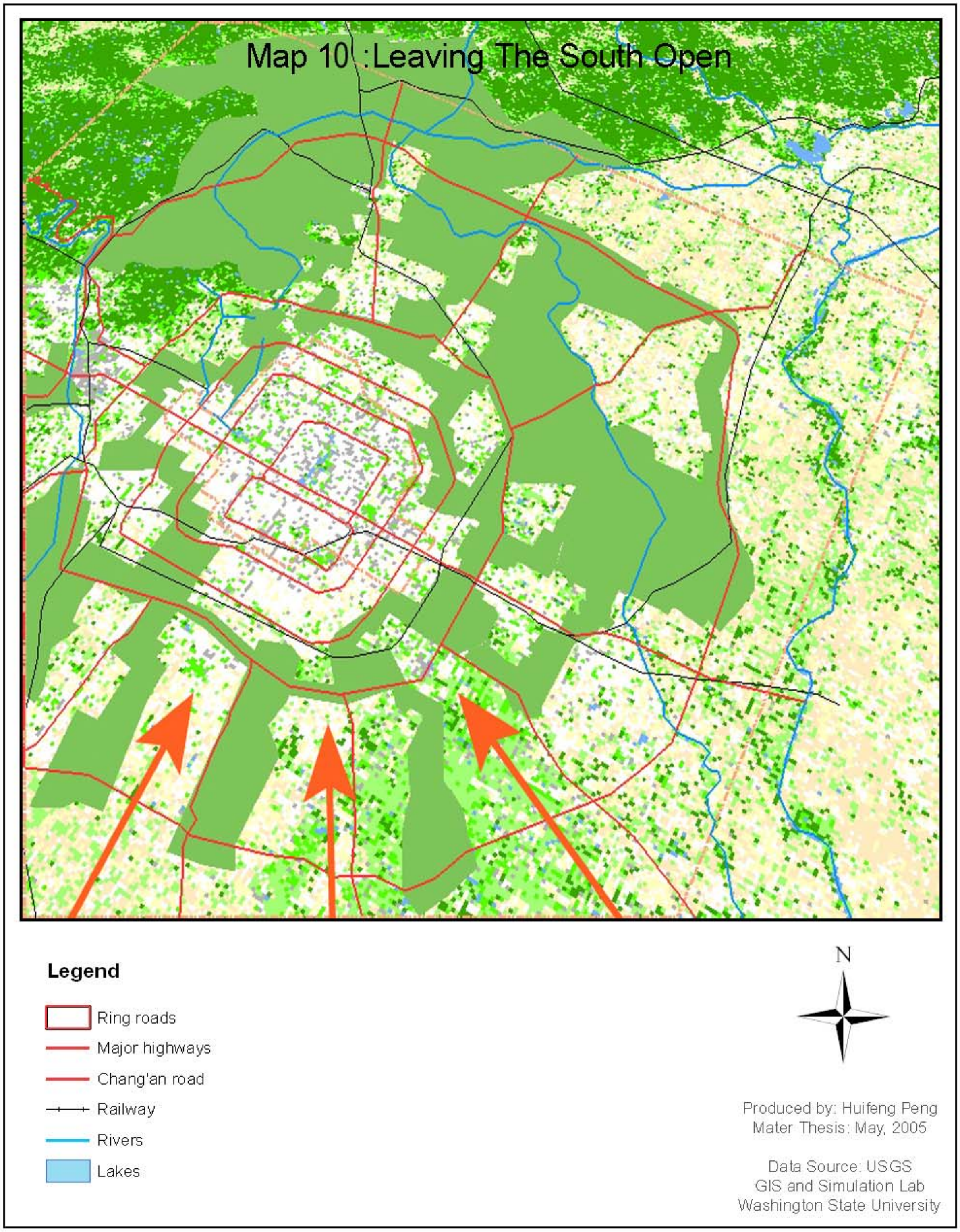
Leaving the South Open

Beijing lies in the semiarid continental monsoon climatic zone and receives the majority of precipitation in summer. The monsoon comes from the southeast of Beijing and brings the moisture and precipitation from the ocean.

According to the case study of Canadian greenbelts, it is preferred to leave the south open and let the moist monsoon enter easily into the mass of urban area. Thus the city is capable of gaining maximum solar energy in the winter and enjoying enough ventilation of living area in the summer. In GIS Arc Map, the planned greenbelt in the south is reduced, and some parts of green wedges are cut off (Map 10).

In addition, it is recommended to create more moderate density of the greenbelt on the southeast than the northwest. Fewer tall arbor trees should be planted in the southeast; high-rise buildings should be restricted from situating in the southeast of the city.

Map 10: Leaving The South Open



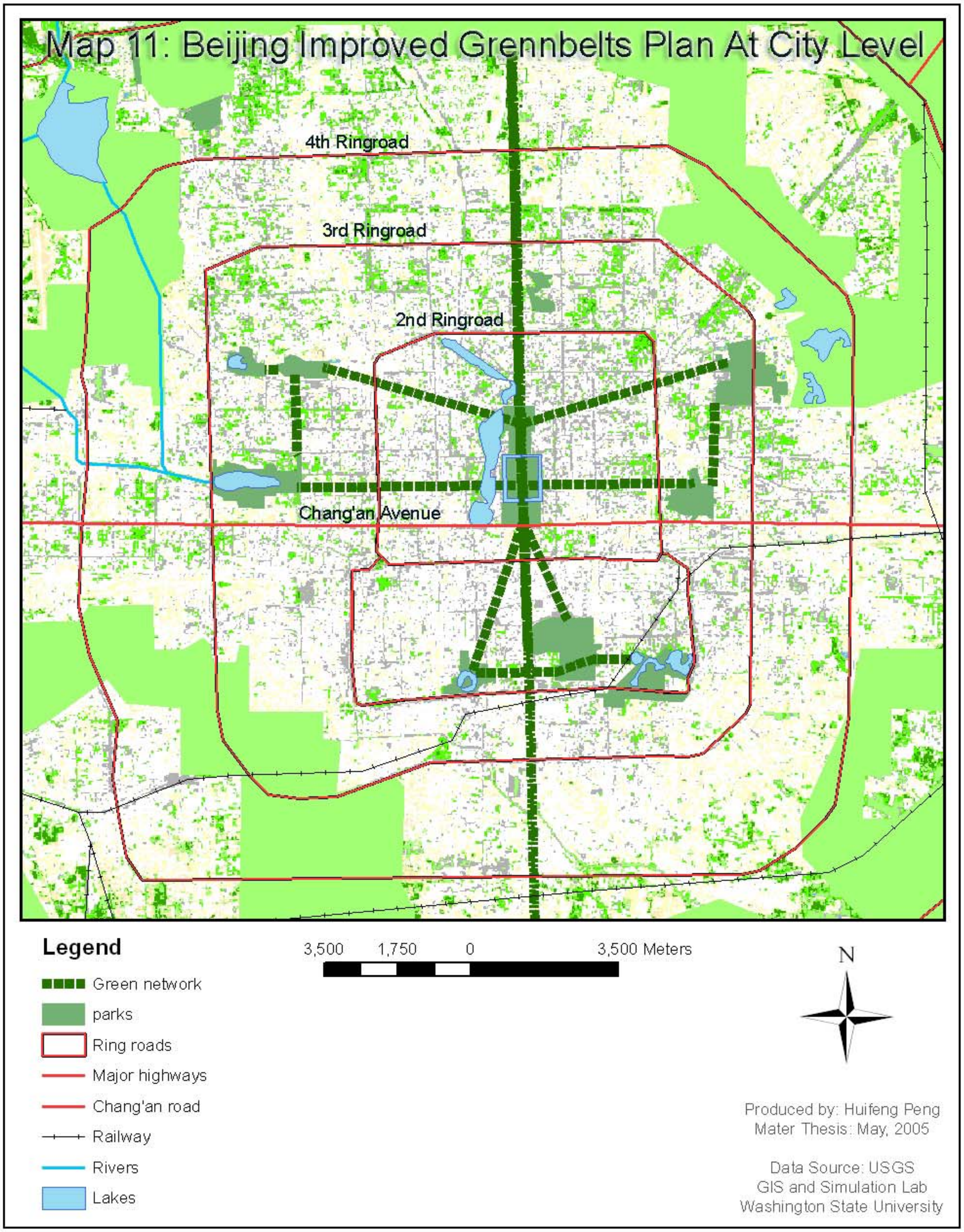
At city level

<u>Create Green Network Connectivity</u>

Several major parks including imperial parks and large community parks are separately situated in Beijing. The connection among parks is weak and inadequate as what Turner presented in Diagram A (in the second case study of Chapter 2). According to London's 1944 proposal (Diagram C) and the method on creating green web (Diagram D), the representative succession of green space should be planned to continue the availability of environmental benefits. In other words, an interconnected park system should be considered to create network connectivity. This principle is also adopted in Frederick Law Olmsted's greenways plan for New York City, where the major parks and open spaces were linked together into comprehensive networks of green space by greenways (Map 11).

Parkways generalized by Turner are designed for the network system to establish an effective linkage. Meanwhile, parkways provide active recreation for citizens' everyday life. Clustering is arranged between large parks which maintain an overall linearly-oriented array. Clustering could be a small park located in community.

Map 11: Beijing Improved Greenbelts At City Level



Buffer Roads and Rivers

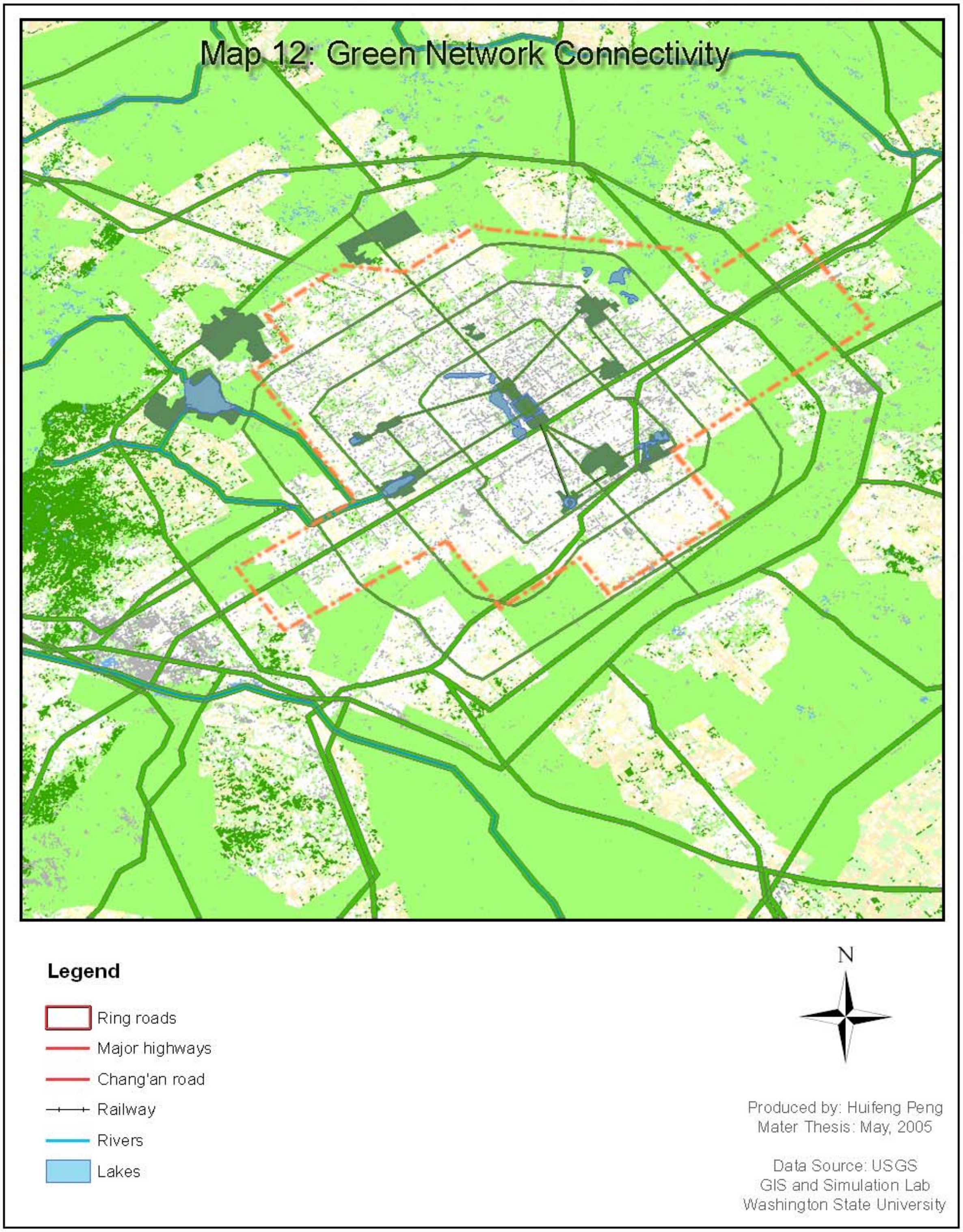
The Beijing Greenbelts Plan proposed to plant trees along the 5th and 6th Ringroads; most of the roads and rivers in the urban area are not covered. According to the recommendations in Turner's Green Strategy, 100-meter wide-tree buffer along rivers and roads should be developed. Buffers of roads and rivers provide the connectivity of green space. As well, they could be networks of "scenic urban roads," which are a pleasure to drive along, as well as networks of accessible water space. Moreover, buffer zones provide the benefit of biodiversity as well as spaces for recreation and environmental education.

Besides, the city planning of Beijing is characterized by its central axis emphasizing hierarchy, regularity and symmetry. A 50-meter-wide buffer along the axis could strengthen this feature of Beijing. The buffers would also assist in protecting land of the highest visual quality (Map 12).

A 100-meter width assigned to buffers along roads and rivers is a common width for natural green space. It is effective in providing diversity and a higher survival rate for species, being compacted with high-density settlement. As space in urban core area is limited, 50-meter width is assigned to the buffers along the city axis as a compromise.

Overall, a park network system consisting of buffers of roads, rivers, and city central axis forms overlapping green networks in the city area. The dynamic green network with buffers helps maintain the city's ecosystems and provides environmental benefits.

Map 12: Green Network Connectivity



At neighborhood level

As the distribution of green space in the urban area of Beijing is uneven, the scenario at the neighborhood level is to examine the percentage of tree coverage in the urban area. CITYgreen software is used to perform statistical assessment.

First, an example site in the urban core is selected to study. By applying CITYgreen, the formula between an acre of urban area and the amount of air-pollution removal is generated. Secondly, creation of a grid coverage fishnet divides the urban core area into 'pseudo-neighborhood' areas, as maps of actual neighborhood boundaries were not available. By manipulating Arc Map, the percentage of tree canopy in each zone is documented.

Additionally, the amount of tree canopy needed to reach 35%, the proposed value in Beijing Regulations, is calculated. The amount of air pollution removal and dollar values are also calculated using the generated formula. The details of this processing are described below.

<u>Example Site</u>

1. Prepare raster data

The selected example site is located between the Second and Third Ringroads. The location of the site is a representative community which lies between the modern city and the ancient city. The study boundary of this site is the center line of the surrounding roads. After executing the command Raster Clipping, the site raster data is generated (Map 13).

2. Existing model

By operating Configuring Raster Data, CITYgreen reclassifies eight categories as it did in the previous scenarios. Then CITYgreen performs an analysis and generates a statistical report. The statistical report shows the total area is 249.5 acres, and the tree canopy is 19.3 acres equivalent to 7.8% of the site area. The amount of particulate matter removal is 569 lbs. per year and the dollar value of saving expense is $1,167. The total air pollution removal is 1,949 lbs per year and the dollar value of saving expense is $4,537(Figure 24).

3. Improved tree percentage model

According to Beijing Regulation of 35% tree canopy in the urban area, a new report is generated by running CITYgreen analysis and assigning a tree percentage of 35.7% (Figure 25). The area of canopy increases from 19.3 acres to 89 acres. The amount of air pollution removal increases from 1,949 Lbs per year to 8,970 lbs. per year. The amount of particulate matter removal increases from 569 lbs. per year to 2,620 lbs per year. As well, the dollar value rises from $4,537 to $20,884.

4. The comparison between existing and improved models

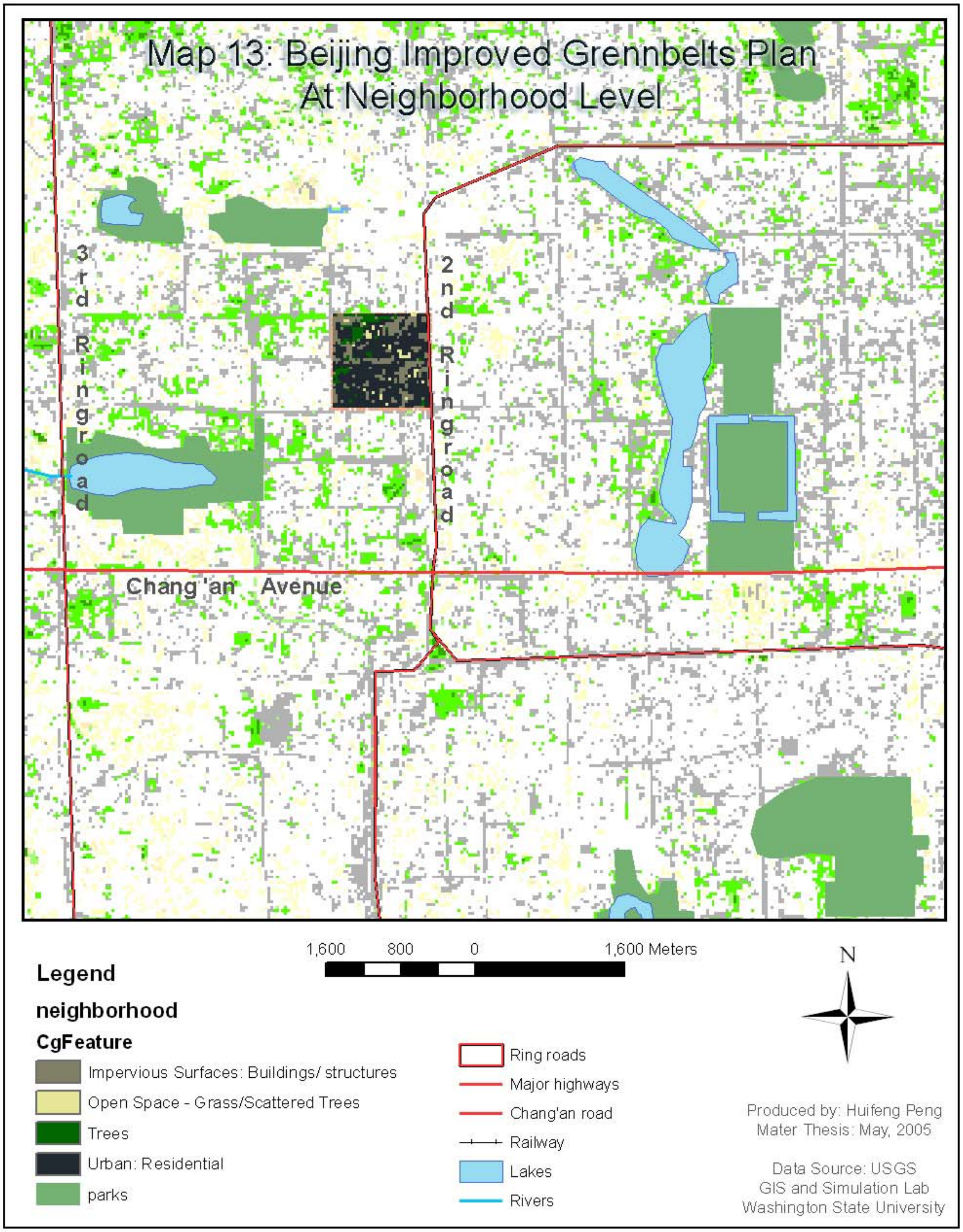
The amount of air pollution removal per acre is calculated and shown in Table 6. Table 6 shows that an acre of tree canopy removes 100.73 lbs of air pollution per year and 29.43 lbs of particulate matter per year. Also, the table indicates that an acre increase in tree canopy will bring about $234.53 saving by removing air pollutants. The result is in consistent with literature values (The City of Fairfax Rapid Ecosystem Analysis for 1992 and 2001, 2005).

Table 6: Comparison Between Existing And Improved Models

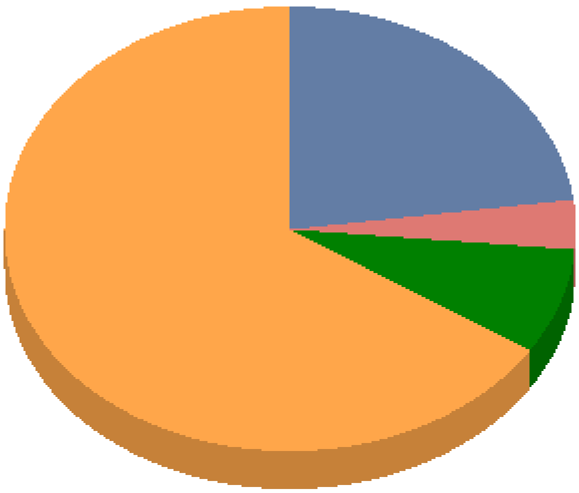
	Tree Acre	**Tree Percent**	**Air Pollution Removal(lbs/yr)**	**Particulate Matter(lbs/yr)**	**Carbon Storage (ton)**	**Carbon Sequestered (ton)**	**Dollar Value**
Existing	19.3	7.8	1949	569	832.56	6.48	4537
Improved	89	35.7	8970	2620	3831.93	29.83	20884
Increasing	69.7	27.9	7021	2051	2999.37	23.35	16347
Per acre			100.73	29.43	43.03	0.34	234.53

Source: Author, 2005

Map 13: Beijing Improved Greenbelts Plan At Neighborhood Level



Land cover areas are in acres.



Impervious Surfaces: Buildings/ structures	56.7	22.7%
Open Space - Grass/Scattered Trees	8.9	3.6%
Trees	19.3	7.8%
Urban: Residential	164.6	66.0%
Total:	249.5	100.0%

Total Tree Canopy: 19.3 acres (7.8%)

Air Pollution Removal

By absorbing and filtering out nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), carbon monoxide (CO), and particulate matter less than 10 microns (PM10) in their leaves, urban trees perform a vital air cleaning service that directly affects the well-being of urban dwellers. CITYgreen estimates the annual air pollution removal rate of trees within a defined study area for the pollutants listed below. To calculate the dollar value of these pollutants, economists use "externality" costs, or indirect costs borne by society such as rising health care expenditures and reduced tourism revenue. The actual externality costs used in CITYgreen of each air pollutant is set by the each state, Public Services Commission.

Nearest Air Quality Reference City: **Washington DC**

	Lbs. Removed/yr	Dollar Value
Carbon Monoxide:	86	$37
Ozone:	673	$2,066
Nitrogen Dioxide:	345	$1,060
Particulate Matter:	569	$1,167
Sulfur Dioxide:	276	$207
Totals:	**1,949**	**$4,537**

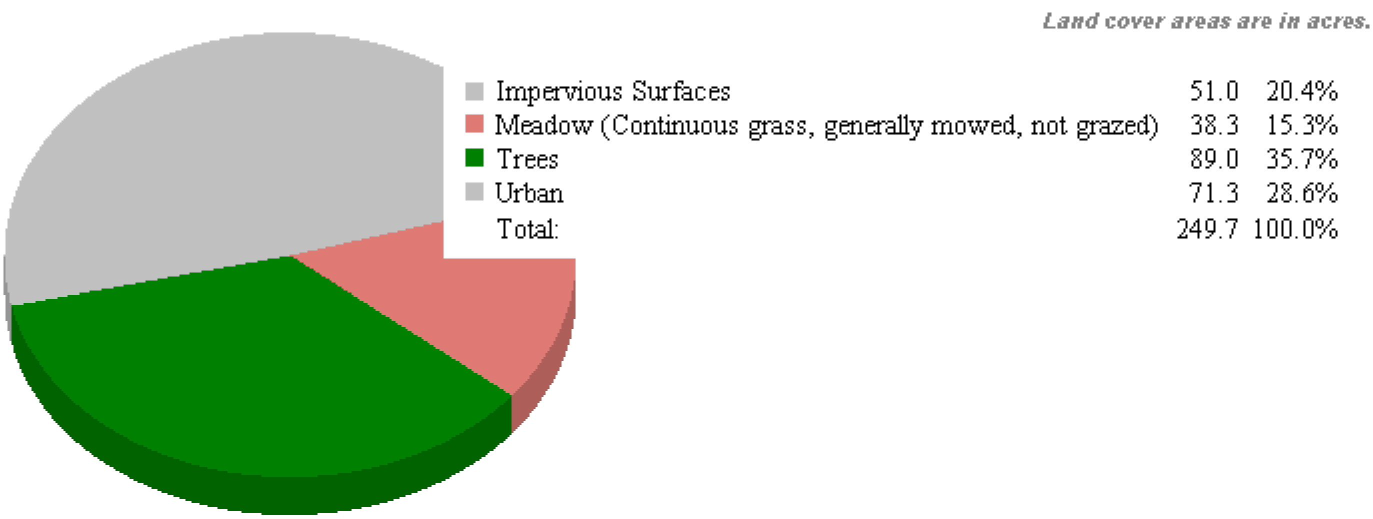
Carbon Storage and Sequestration

Trees remove carbon dioxide from the air through their leaves and store carbon in their biomass. Approximately half of a tree's dry weight, in fact, is carbon. For this reason, large-scale tree planting projects are recognized as a legitimate tool in many national carbon-reduction programs. CITYgreen estimates the carbon storage capacity and carbon sequestration rates of trees within a defined study area.

Total Tons Stored: 832.56

Total Tons Sequestered (Annually): 6.48

Figure 24: Analysis Report For Sample 1: Site Study



Total Tree Canopy: 89.0 acres (35.7%)

Air Pollution Removal

By absorbing and filtering out nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), carbon monoxide (CO), and particulate matter less than 10 microns (PM10) in their leaves, urban trees perform a vital air cleaning service that directly affects the well-being of urban dwellers. CITYgreen estimates the annual air pollution removal rate of trees within a defined study area for the pollutants listed below. To calculate the dollar value of these pollutants, economists use “externality” costs, or indirect costs borne by society such as rising health care expenditures and reduced tourism revenue. The actual externality costs used in CITYgreen of each air pollutant is set by the each state, Public Services Commission.

Nearest Air Quality Reference City: **Washington DC**

	Lbs. Removed/yr	Dollar Value
Carbon Monoxide:	397	$169
Ozone:	3,096	$9,511
Nitrogen Dioxide:	1,588	$4,877
Particulate Matter:	2,620	$5,373
Sulfur Dioxide:	1,270	$953
Totals:	**8,970**	**$20,884**

Carbon Storage and Sequestration

Trees remove carbon dioxide from the air through their leaves and store carbon in their biomass. Approximately half of a tree’s dry weight, in fact, is carbon. For this reason, large-scale tree planting projects are recognized as a legitimate tool in many national carbon-reduction programs. CITYgreen estimates the carbon storage capacity and carbon sequestration rates of trees within a defined study area.

Total Tons Stored: 3,831.93

Total Tons Sequestered (Annually): 29.83

Figure 25: Analysis Report For Sample 2: Improved Canopy

Urban Core

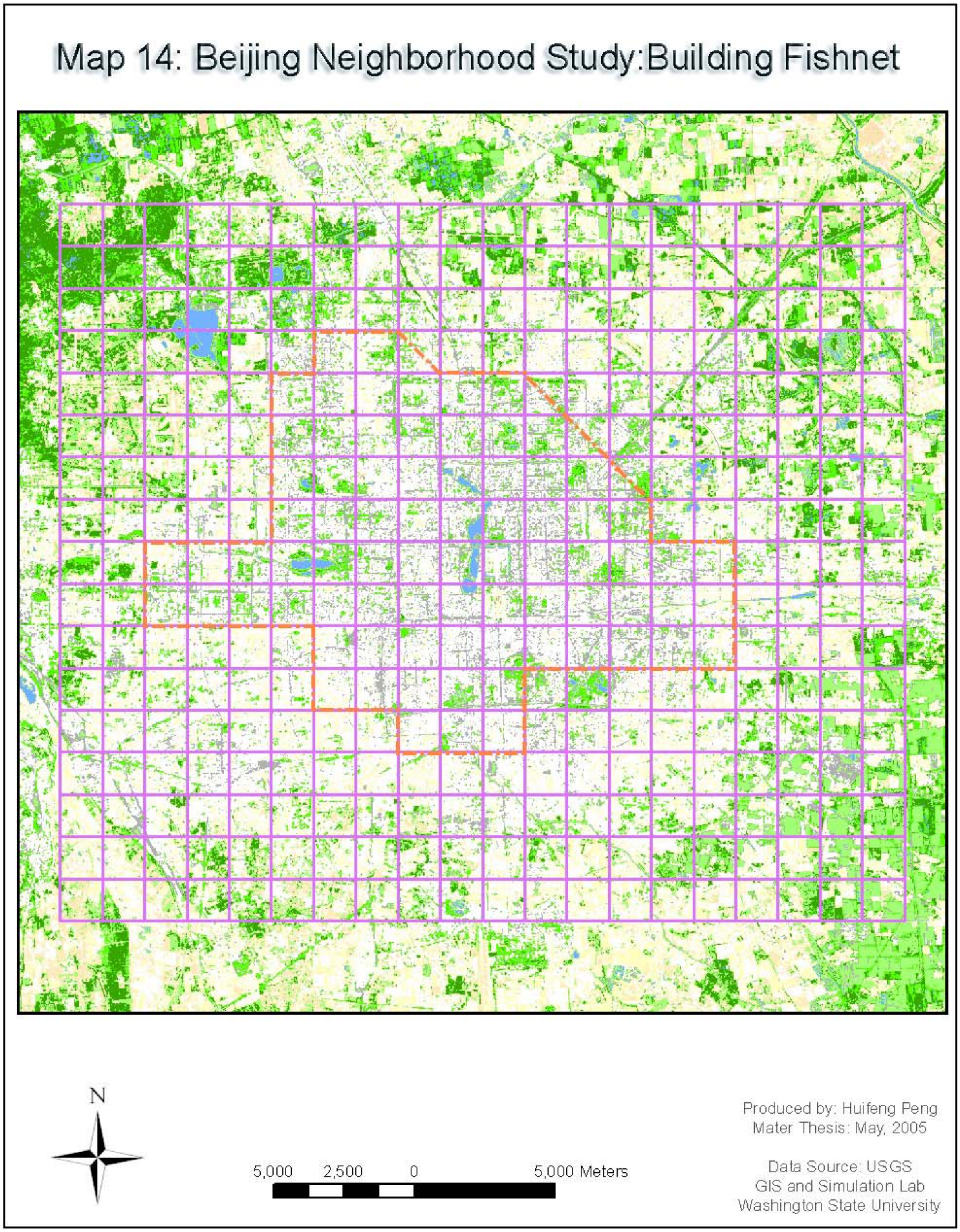
1. Fishnet coverage

To create a fishnet coverage, the command GENERATE is used in Arc Info Workstation. Cell size is 1500 m×1500 m. The number of rows and columns are selected as 17 and 20 to define the size of the fishnet (Arc Info Workstation Help, 2004). After running the command "BUILD," the fishnet coverage of Beijing was built up (Map 14).

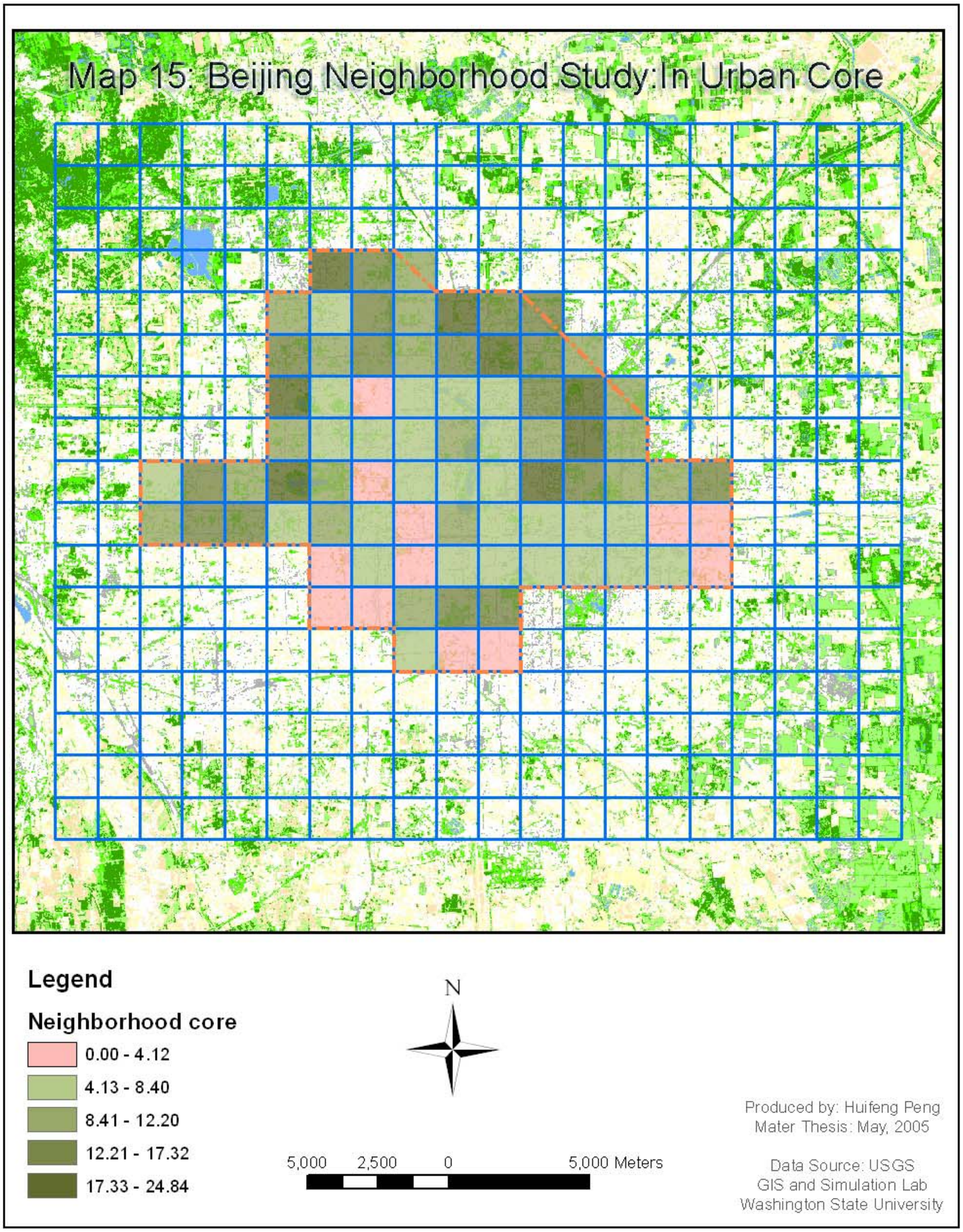
2. Canopy percentage in the urban core

To study the canopy percentage in the urban core, a new fishnet coverage was created by the urban core boundary resulting in a subset of the original fishnet grid that represents the urban core. In Spatial Analyst Tools, the tool "Zonal Statistics as Table" was used to summarize the amount of tree canopy area within each cell. To calculate tree canopy in each cell, two attributes tables were joined. Then, the percentage of tree canopy in each cell was calculated by running the command of CALCULATE VALUE as "Tree Area/Zone Area." Map 15 represents the quantitative value of existing tree canopy in each cell in graduated colors. The dark green color shows areas that contain higher amounts of tree canopy, while the red color represents areas with lower amounts of tree canopy.

Map 14: Beijing Neighborhood Study: Building Fishnet



Map 15: Beijing Neighborhood Study: Urban Core



3. Table of CITYgreen Indicators

Table 7 shows the canopy percentage in the existing model and the percentage needed to reach 35% for each parcel. In each parcel, air pollution removal, carbon storage and dollar value are calculated. From Table 7, the minimum tree percent for an area is 0.96%, and the maximum of tree percent is 19.88%. Thus, the tree canopy in the urban core is far below the 35% goal. In total, the areas need 11,626.77 acres to reach 35% of tree canopy in urban area. The increasing tree canopy will remove 1,171,164.70 lbs air pollution per year, including 342,175.89 lbs particulate matter. . It may save $2,726,826.74 from the pollutant removals. Table 7 indicates that green space offers benefits in many ways.

Table 7: Table Of CITYgreen Indicators For Each Parcel Of The Urban Area

ID	Tree Percent	Increasing Percent	Increasing (m2)	Increasing (acre)	Air Pollution Removal(lbs/yr)	Particulate Matter(lbs/yr)	Carbon Storage(ton)	Carbon Sequestered(ton)	Dollar Value
1	6.12	28.88	649800	160.57	16173.77	4725.45	6909.14	54.59	37657.45
2	18.00	17.00	382500	94.52	9520.57	2781.60	4067.01	32.14	22166.78
3	14.88	20.12	452700	111.86	11267.88	3292.10	4813.43	38.03	26235.03
4	10.36	24.64	554400	136.99	13799.23	4031.68	5894.78	46.58	32128.79
5	8.60	26.40	594000	146.78	14784.89	4319.66	6315.83	49.90	34423.70
6	7.80	27.20	612000	151.23	15232.91	4450.56	6507.22	51.42	35466.85
7	14.32	20.68	465300	114.98	11581.50	3383.73	4947.40	39.09	26965.23
8	9.84	25.16	566100	139.88	14090.45	4116.77	6019.18	47.56	32806.83
9	18.72	16.28	366300	90.51	9117.35	2663.79	3894.76	30.77	21227.95
10	13.84	21.16	476100	117.64	11850.31	3462.27	5062.23	40.00	27591.12
11	16.08	18.92	425700	105.19	10595.84	3095.76	4526.35	35.76	24670.32
12	14.48	20.52	461700	114.09	11491.89	3357.55	4909.12	38.79	26756.61
13	9.84	25.16	566100	139.88	14090.45	4116.77	6019.18	47.56	32806.83
14	14.16	20.84	468900	115.87	11671.10	3409.91	4985.68	39.39	27173.86
15	10.08	24.92	560700	138.55	13956.04	4077.50	5961.76	47.11	32493.89
16	14.04	20.96	471600	116.53	11738.30	3429.55	5014.39	39.62	27330.33
17	19.88	15.12	340200	84.06	8467.71	2473.99	3617.25	28.58	19715.39
18	12.68	22.32	502200	124.09	12499.95	3652.08	5339.75	42.19	29103.68
19	9.84	25.16	566100	139.88	14090.45	4116.77	6019.18	47.56	32806.83
20	18.48	16.52	371700	91.85	9251.76	2703.06	3952.18	31.23	21540.89
21	6.08	28.92	650700	160.79	16196.17	4731.99	6918.71	54.67	37709.60
22	3.68	31.32	704700	174.13	17540.25	5124.69	7492.87	59.20	40839.03
23	7.68	27.32	614700	151.89	15300.12	4470.19	6535.93	51.64	35623.32
24	6.24	28.76	647100	159.90	16106.57	4705.81	6880.43	54.37	37500.97

25	7.76	27.24	612900	151.45	15255.32	4457.10	6516.79	51.49	35519.00
26	16.16	18.84	423900	104.75	10551.03	3082.67	4507.21	35.61	24566.01
27	23.12	11.88	267300	66.05	6653.20	1943.85	2842.12	22.46	15490.67
28	10.52	24.48	550800	136.10	13709.62	4005.50	5856.50	46.27	31920.16
29	10.44	24.56	552600	136.55	13754.43	4018.59	5875.64	46.43	32024.48
30	8.16	26.84	603900	149.22	15031.30	4391.65	6421.10	50.74	34997.43
31	6.76	28.24	635400	157.01	15815.35	4620.73	6756.03	53.38	36822.93
32	7.56	27.44	617400	152.56	15367.32	4489.83	6564.64	51.87	35779.79
33	9.96	25.04	563400	139.22	14023.24	4097.13	5990.47	47.33	32650.36
34	5.48	29.52	664200	164.12	16532.19	4830.16	7062.25	55.80	38491.96
35	10.84	24.16	543600	134.32	13530.41	3953.14	5779.94	45.67	31502.90
36	21.64	13.36	300600	74.28	7482.05	2186.01	3196.19	25.25	17420.48
37	9.24	25.76	579600	143.22	14426.47	4214.94	6162.72	48.69	33589.19
38	7.12	27.88	627300	155.01	15613.74	4561.82	6669.90	52.70	36353.52
39	14.76	20.24	455400	112.53	11335.08	3311.74	4842.14	38.26	26391.51
40	10.88	24.12	542700	134.10	13508.01	3946.60	5770.37	45.59	31450.75
41	24.84	10.16	228600	56.49	5689.94	1662.41	2430.64	19.21	13247.91
42	11.60	23.40	526500	130.10	13104.79	3828.79	5598.12	44.23	30511.92
43	3.72	31.28	703800	173.91	17517.85	5118.14	7483.30	59.13	40786.87
44	7.12	27.88	627300	155.01	15613.74	4561.82	6669.90	52.70	36353.52
45	7.92	27.08	609300	150.56	15165.71	4430.92	6478.51	51.19	35310.37
46	4.88	30.12	677700	167.46	16868.21	4928.34	7205.79	56.94	39274.32
47	19.04	15.96	359100	88.73	8938.14	2611.43	3818.21	30.17	20810.69
48	16.72	18.28	411300	101.63	10237.41	2991.04	4373.24	34.55	23835.81
49	10.64	24.36	548100	135.44	13642.42	3985.87	5827.79	46.05	31763.69
50	9.64	25.36	570600	141.00	14202.45	4149.49	6067.03	47.94	33067.62
51	14.52	20.48	460800	113.86	11469.49	3351.01	4899.55	38.71	26704.45
52	11.52	23.48	528300	130.54	13149.59	3841.88	5617.26	44.38	30616.23
53	15.72	19.28	433800	107.19	10797.45	3154.66	4612.47	36.45	25139.73
54	13.28	21.72	488700	120.76	12163.93	3553.90	5196.21	41.06	28321.32
55	4.60	30.40	684000	169.02	17025.02	4974.15	7272.78	57.47	39639.42
56	10.00	25.00	562500	138.99	14000.84	4090.59	5980.90	47.26	32598.20
57	5.52	29.48	663300	163.90	16509.79	4823.62	7052.68	55.73	38439.80
58	2.24	32.76	737100	182.14	18346.70	5360.30	7837.37	61.93	42716.69
59	9.40	25.60	576000	142.33	14336.86	4188.76	6124.44	48.39	33380.56
60	7.16	27.84	626400	154.78	15591.34	4555.28	6660.33	52.63	36301.36
61	5.84	29.16	656100	162.12	16330.58	4771.26	6976.12	55.12	38022.55
62	8.24	26.76	602100	148.78	14986.50	4378.56	6401.96	50.58	34893.12
63	6.04	28.96	651600	161.01	16218.57	4738.53	6928.28	54.74	37761.76
64	1.80	33.20	747000	184.58	18593.12	5432.30	7942.64	62.76	43290.42
65	4.12	30.88	694800	171.69	17293.84	5052.69	7387.61	58.37	40265.30
66	2.64	32.36	728100	179.91	18122.69	5294.85	7741.68	61.17	42195.12
67	6.28	28.72	646200	159.68	16084.17	4699.27	6870.86	54.29	37448.82
68	1.04	33.96	764100	188.81	19018.74	5556.65	8124.46	64.20	44281.40
69	4.76	30.24	680400	168.13	16935.42	4947.97	7234.50	57.16	39430.79
70	5.32	29.68	667800	165.01	16621.80	4856.34	7100.53	56.10	38700.59
71	5.32	29.68	667800	165.01	16621.80	4856.34	7100.53	56.10	38700.59

72	6.24	28.76	647100	159.90	16106.57	4705.81	6880.43	54.37	37500.97
73	7.36	27.64	621900	153.67	15479.33	4522.55	6612.48	52.25	36040.57
74	8.40	26.60	598500	147.89	14896.89	4352.38	6363.68	50.28	34684.49
75	2.08	32.92	740700	183.03	18436.31	5386.48	7875.65	62.23	42925.32
76	2.60	32.40	729000	180.14	18145.09	5301.40	7751.25	61.25	42247.27
77	3.32	31.68	712800	176.13	17741.87	5183.59	7579.00	59.89	41308.44
78	12.20	22.80	513000	126.76	12768.77	3730.61	5454.58	43.10	29729.56
79	17.32	17.68	397800	98.30	9901.39	2892.86	4229.69	33.42	23053.45
80	14.00	21.00	472500	116.75	11760.71	3436.09	5023.96	39.70	27382.49
81	3.56	31.44	707400	174.80	17607.46	5144.32	7521.58	59.43	40995.50
82	8.12	26.88	604800	149.45	15053.70	4398.20	6430.66	50.81	35049.59
83	0.96	34.04	765900	189.25	19063.54	5569.74	8143.59	64.35	44385.71
Total	813.76	2091.24	47052900	11626.77	1171164.70	342175.89	500299.98	3953.10	2726826.74

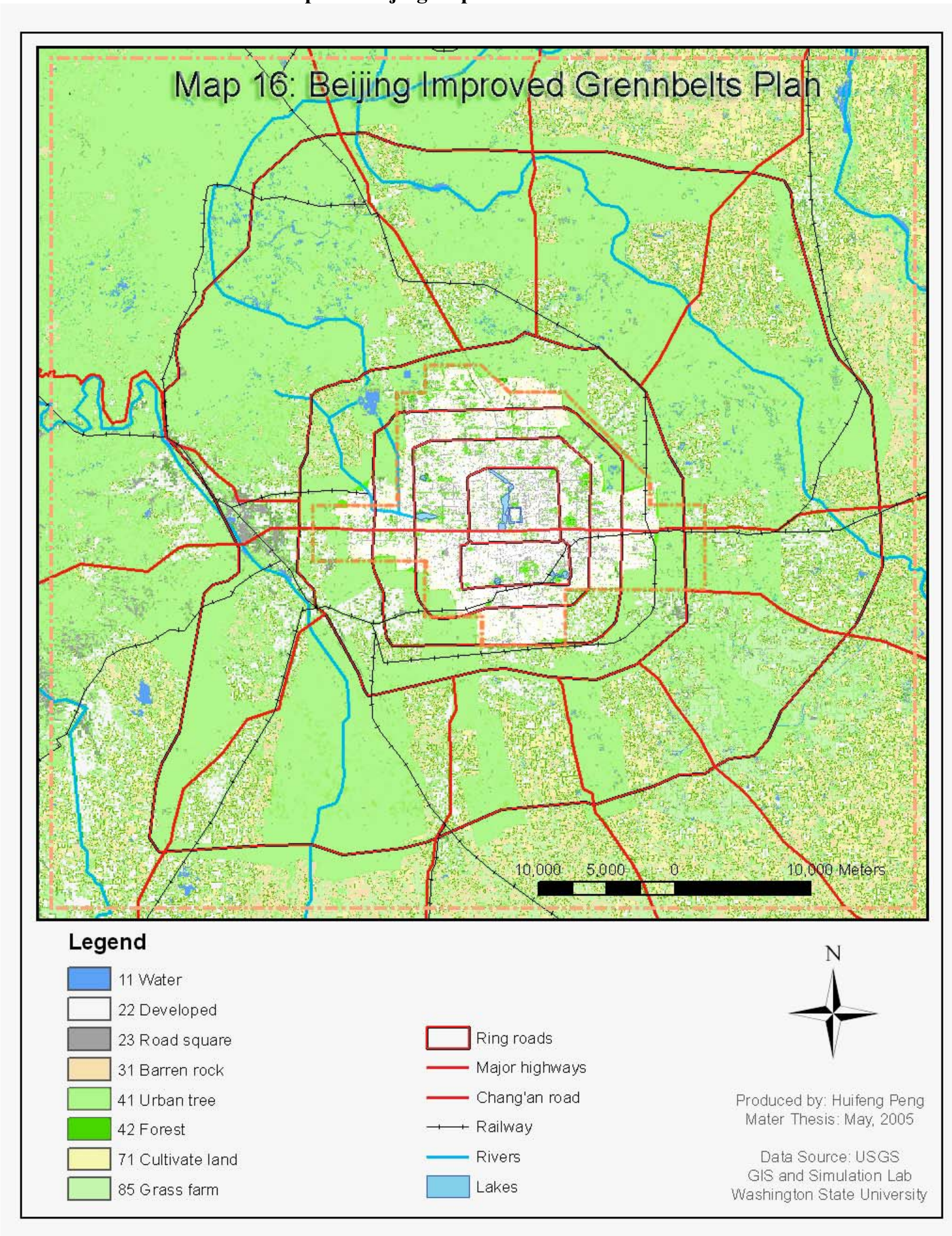
Source: Author, 2005

Table 7 indicates that insufficient green space in the urban area of Beijing and more green space should be developed. Due to a large population in urban core of Beijing, it is difficult to build up large area parks. In this case, community parks could be a feasible choice. According to the finding from the case study of New York City, community parks can not only improve the tree canopy in compacted urban areas but also provide spaces for recreation and maintenance of physical health. Therefore, it is suggested to create more community parks and improve surrounding ecology by planting trees, shrubs, and herbs in the parks. Community parks can be incorporated with athletic recreation facilities to provide people more opportunities to participate outdoor activity and enrichment.

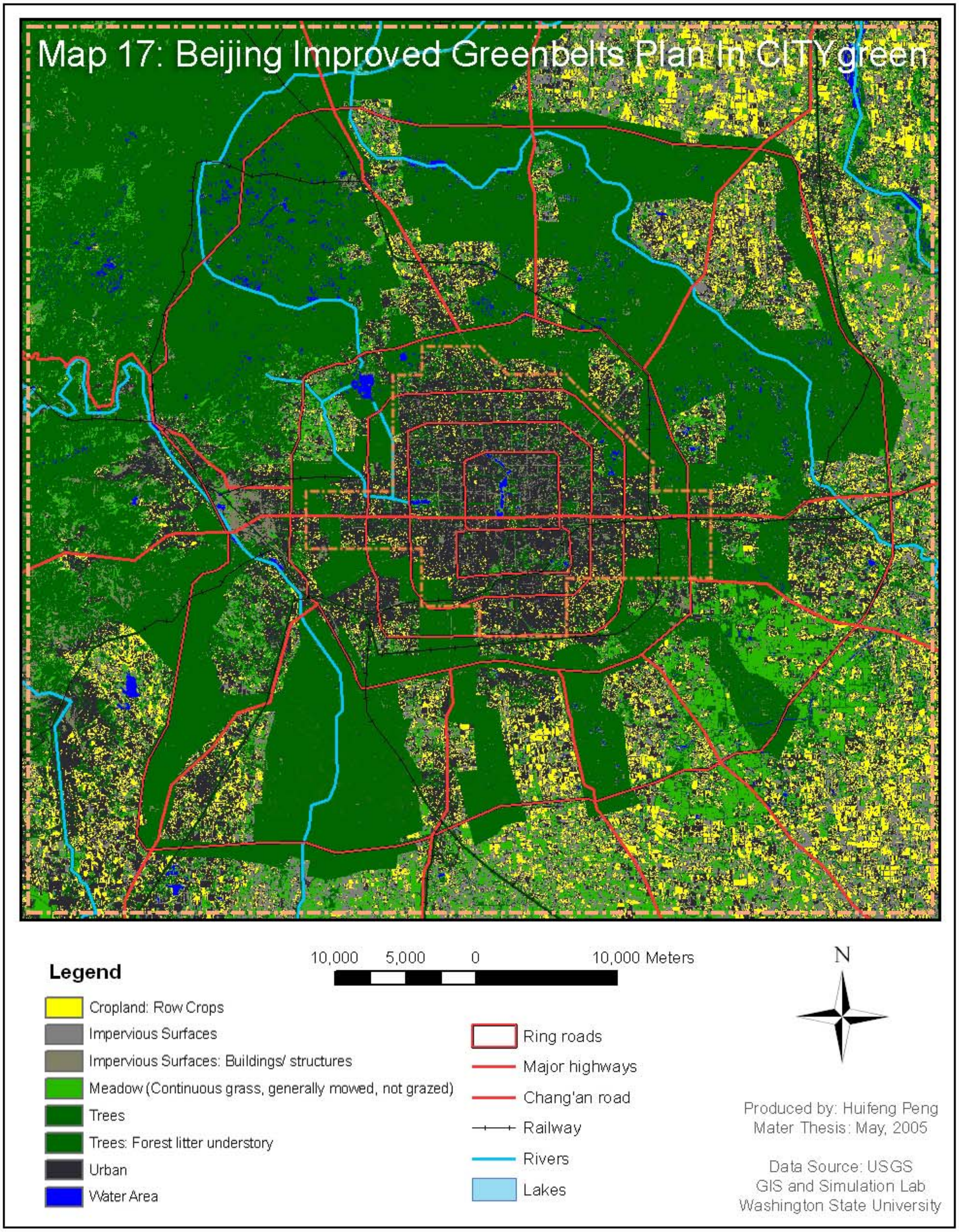
Performing Analysis and Creating the CITYgreen Report

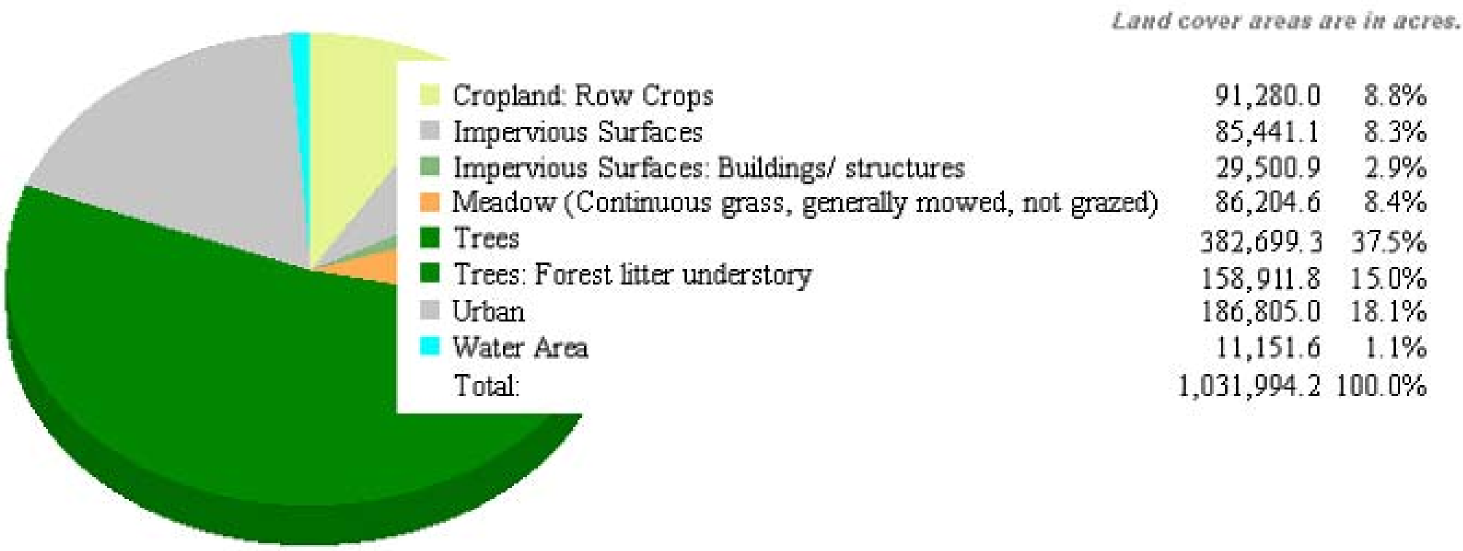
To create the CITYgreen report, the same steps as the second scenario are performed. First, the improved greenbelts proposed at region and city level are combined, and the attributes table is edited (Map 16). Then the city and greenbelts layers are joined, and the attributes of combined layer are edited. After converting the polygon of combined layer to raster (Map 17). The statistics report is produced with CITYgreen (Figure 26).

Map 16: Beijing Improved Greenbelts Plan



Map 17: Beijing Improved Greenbelts Plan In CITYgreen





Total Tree Canopy: 541,611.1 acres (52.5%)

Air Pollution Removal

By absorbing and filtering out nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), carbon monoxide (CO), and particulate matter less than 10 microns (PM10) in their leaves, urban trees perform a vital air cleaning service that directly affects the well-being of urban dwellers. CITYgreen estimates the annual air pollution removal rate of trees within a defined study area for the pollutants listed below. To calculate the dollar value of these pollutants, economists use "externality" costs, or indirect costs borne by society such as rising health care expenditures and reduced tourism revenue. The actual externality costs used in CITYgreen of each air pollutant is set by the each state, Public Services Commission.

Nearest Air Quality Reference City: **Washington DC**

	Lbs. Removed/yr	Dollar Value
Carbon Monoxide:	2,413,987	$1,030,193
Ozone:	18,829,097	$57,847,090
Nitrogen Dioxide:	9,655,947	$29,665,175
Particulate Matter:	15,932,313	$32,679,914
Sulfur Dioxide:	7,724,758	$5,797,137
Totals:	**54,556,101**	**$127,019,509**

Carbon Storage and Sequestration

Trees remove carbon dioxide from the air through their leaves and store carbon in their biomass. Approximately half of a tree's dry weight, in fact, is carbon. For this reason, large-scale tree planting projects are recognized as a legitimate tool in many national carbon-reduction programs. CITYgreen estimates the carbon storage capacity and carbon sequestration rates of trees within a defined study area.

Total Tons Stored: 23,306,327.15

Total Tons Sequestered (Annually): 181,445.96

Figure 26: Analysis Report For Improved Greenbelts Scenario

Result: The CITYgreen Report

After adding the environmental indicators at region, city and neighborhood level, a statistics table of The Improved Greenbelts Scenario is generated (Table 8). The table shows the total tree canopy is 557,762.55 acres equivalent to 54.0 % of green space coverage in Beijing. Air pollution removal is 56,183,036.56 lbs per year and the dollar value of saving expense is $130,807,508.60. The amount of particulate matter removal is 16,407,650.17 lbs. per year. The annual of carbon storage and sequestration are 24,001,324.04 tons and 186,937.45 tons.

Table 8: Table Of Environmental Indicators For The Improved Greenbelts Scenario

	Tree Canopy (acre)	Tree Percent	Air Pollution Removal(lbs/yr)	Particulate Matter(Lbs /yr)	Carbon Storage(ton)	Carbon Sequestered(ton)	Dollar Value
Region & City	541,611.10	52.50	54,556,101.00	15,932,313.00	23,306,327.15	181,445.96	127,019,509.00
Neighborhood	16,151.45	1.50	1,626,935.56	475,337.17	694,996.89	5,491.49	3,787,999.57
Total	557,762.55	54.00	56,183,036.56	16,407,650.17	24,001,324.04	186,937.45	130,807,508.60

Source: Author, 2005

Discussion

Scenarios Comparison

Table 9 compares the three scenarios on landcover and the environmental indicators. The landcover section lists the area and the percentage of eight landcover categories. The next two sections show the air pollution removal, carbon storage and sequestration. Figure 27-33 the changes of landcover area and environmental indicators, including total tree canopy (acre), tree canopy percentage (%), air pollution removal (lbs), air pollution removal ($), carbon storage (ton), and sequestration ($).

It can be seen in Figure 27 that the tree canopy increases from 228,609 acres in the first scenario to 557,763 acres in the third scenario, corresponding to a tree canopy percentage increasing from 22.20% to 54.0% (Figure 28). The increasing tree canopy leads to enhance the amounts of air pollution removal and carbon storage. The total air pollution removal increases from 23,027,608 lbs per year to 56,183,037 lbs, corresponding to a dollar value increasing from $53,613,718 for the first scenario to $130,807,509 for the third scenario (Figure 29-30). The particulate matter (PM) removal increases by approximately 10,000,000 lbs per year (from 6,724,877 lbs to 16,407,605 lbs per year) (Figure 31). Carbon storage increases from 9,837,378 tons to 24,001,324 tons, and the carbon sequestration from $76,587 to $186,938 (Figure 32-33).

Table 9: Comparisons Of Three Scenarios On Landcover And The Environmental Indicators

Section 1: Landcover Comparison

	1st Scenario	Existing 1999	2nd Scenario	Greenbelts Plan	3rd Scenario	Improved Greenbelts
Landcover categories	Area(Acres)	Percentage	Area(Acres)	Percentage	Area(Acres)	Percentage
Trees	79,636.80	7.70%	390,093.24	37.80%	398,850.75	39.00%
Trees: Forest litter understory	148,972.10	14.40%	105,263.25	10.20%	158,911.80	15.00%
Meadow (generally mowed, not grazed)	159,266.10	15.40%	91,633.30	8.90%	86,204.60	8.40%
Cropland: Row Crops	155,824.10	15.10%	100,412.70	9.70%	91,280.00	8.80%
Urban: Commercial/Business	291,919.90	28.30%	201,991.60	19.60%	186,85.0	18.10%
Impervious Surfaces	152,396.80	14.80%	99,898.70	9.70%	85,441.10	8.30%
Impervious Surfaces: Buildings/ structures	31,734.60	3.10%	30,667.20	3.00%	29,500.90	2.90%
Water Area	12,240.80	1.20%	11,787.60	1.10%	11,151.60	1.10%
Total Tree Canopy:	228,608.80	22.20%	495,601.70	48.00%	557,762.55	54.00%

Section 2: Air Pollution Removal Comparison

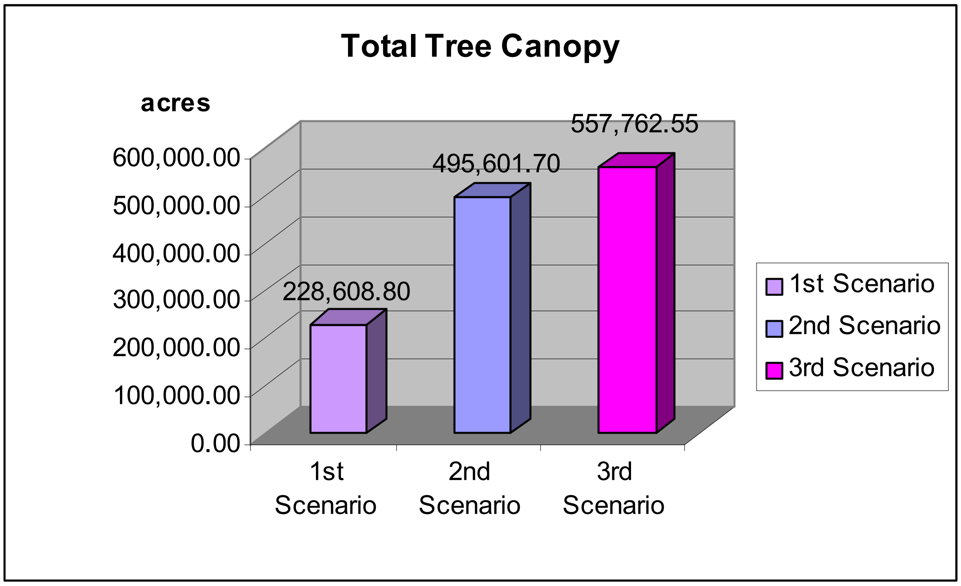
Air Pollution Removal	Lbs. Removed/yr	Dollar Value	Lbs. Removed/yr	Dollar Value	Lbs. Removed/yr	Dollar Value
Carbon Monoxide:	1,018,921	$434,835	2,208,921	$942,679	2,486,054	$1,060,781
Ozone:	7,947,581	$24,416,703	17,229,581	$52,933,030	19,390,574	$59,572,306
Nitrogen Dioxide:	4,075,683	$12,521,386	8,835,683	$27,145,144	9,943,985	$30,549,681
Particulate Matter:	6,724,877	$13,793,879	14,578,877	$29,903,784	16,407,650	$33,654,562
Sulfur Dioxide:	3,260,546	$2,446,916	7,068,546	$5,304,675	7,955,096	$5,970,006
Totals (air polution removal):	23,027,608	$53,613,718	49,921,608	$116,229,312	56,183,036.56	$130,807,508.6

Section 3: Carbon Storage and Sequestration Comparison

Carbon Storage: Tons	9,837,377.50		21,326,474.91		2,400,1324.04	
Carbon Sequestration:Tons	76,586.60		166,032.28		186,937.45	

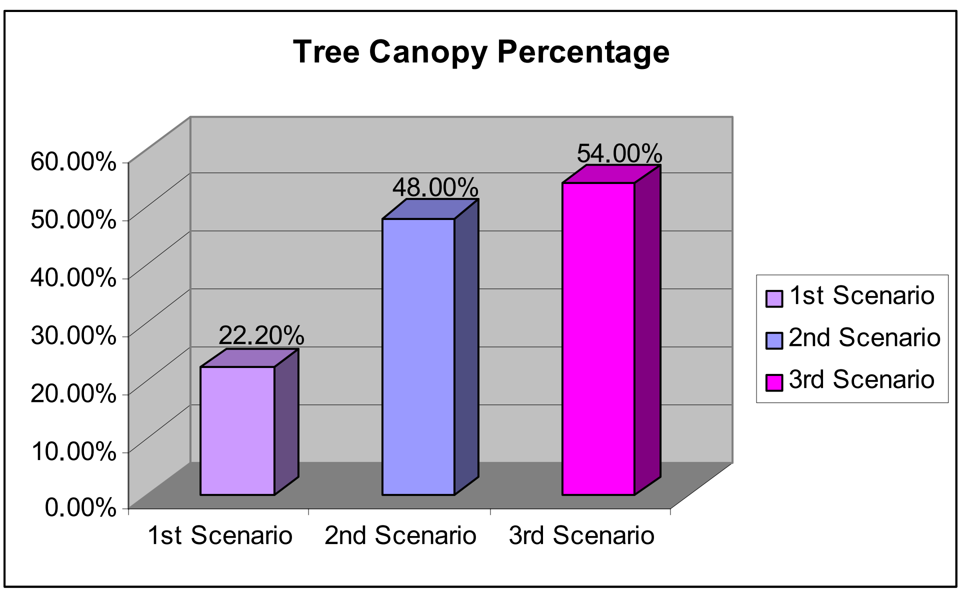
Source: Author, 2005

Figure 27: Comparison Of Total Tree Canopy



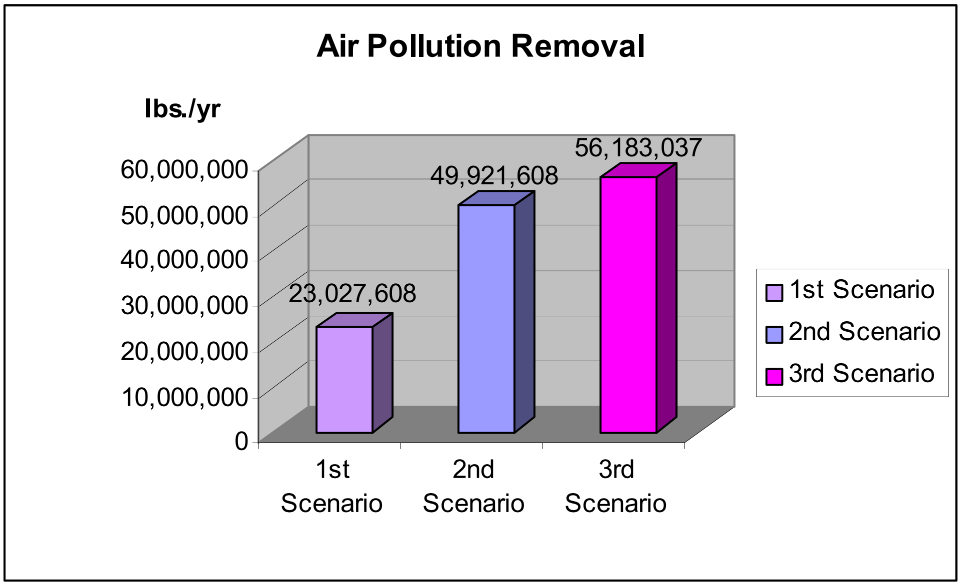
Source: Author, 2005

Figure 28: Comparison Of Total Tree Canopy Percentage



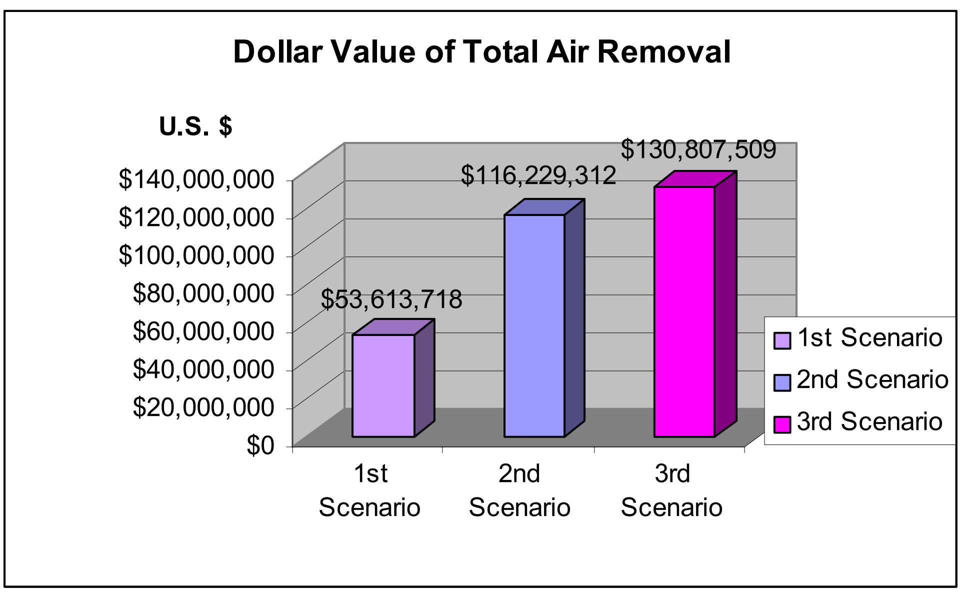
Source: Author, 2005

Figure 29: Comparison Of Total Air Pollution Removal



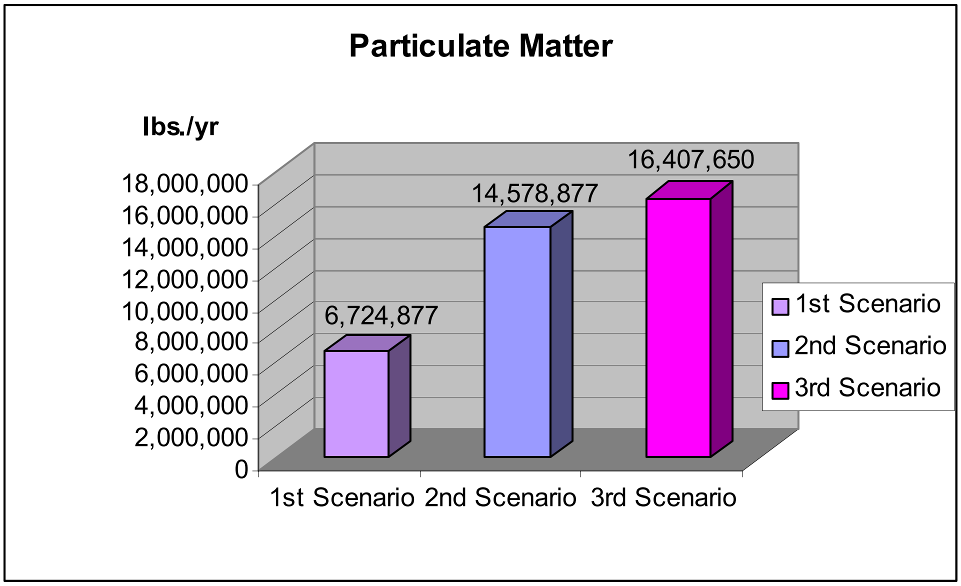
Source: Author, 2005

Figure 30: Comparison Of Total Dollar Value



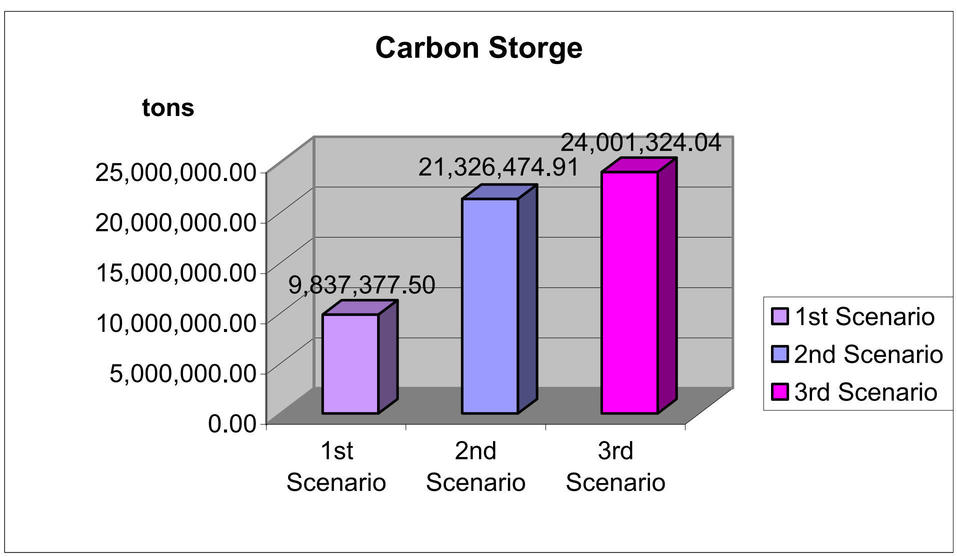
Source: Author, 2005

Figure 31: Comparison Of Total Particulate Matter



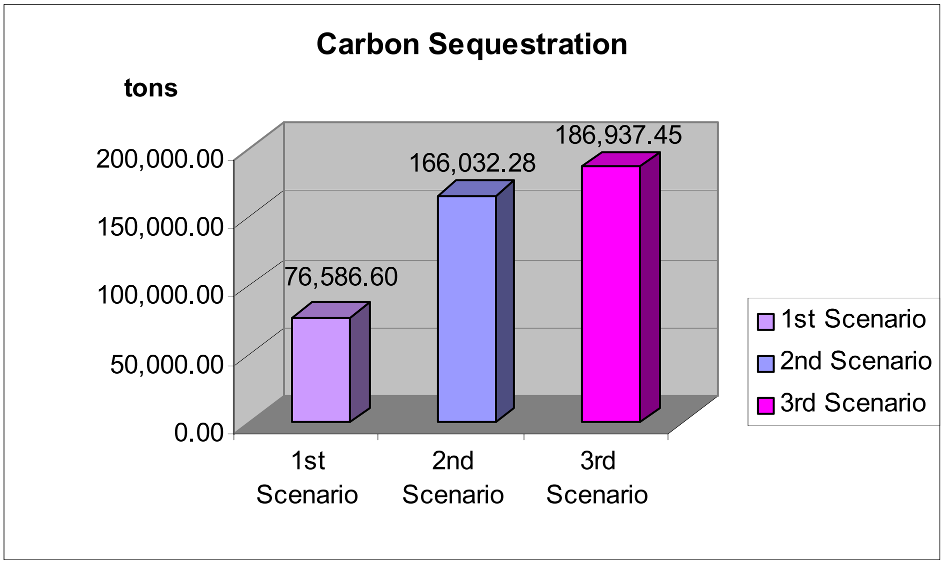
Source: Author, 2005

Figure 32: Comparison Of Total Carbon Storage



Source: Author, 2005

Figure 33: Comparison Of Total Carbon Sequestration



Source: Author, 2005

When comparing the first scenario with the second scenario, it can be seen the area of tree coverage increases 266,992.9 acres, and the percentage of canopy increases by 25.8%. The total air pollution removals increase 26,894,000 lbs. per year corresponding to $62,615,594 in dollar value. The total amount of particulate matter removal increases 13,906,000 lbs per year. Therefore, the Beijing Greenbelts Plan will effectively improve tree coverage and air quality in the city area, subsequently contribute to the fulfillment of a Green Olympic held in 2008.

Comparing the second scenario, the third scenario further improves upon landcover and environmental indicators. The area of tree coverage increases by 62,160.85acres (6.0 %). The total air-pollution removals increase 6,261,429 lbs. per year and the amount of particulate matter increases 1,828,773 lbs. per year, corresponding to the saving expense of $14,578,197. In other words, by increasing the tree canopy by 6.0% will remove 6,261,429 lbs. of air pollutants a year and save expenses of $14,578,197.

Compared to the large improvement brought about by conducting the second scenario, the change in environmental indicators caused by the third scenario seems not to be significant. However, rather than simply increasing tree coverage, the third scenario improves the distribution of Beijing's greenbelts by using different approaches at different levels. This is accomplished by enhancing the northwest of greenbelts to hamper sandstorms, reducing the southeastern greenbelts to increase moisture, creating connectivity between parks, and buffering along roads and rivers to make Beijing's green space as an organic, integrated and interconnected system.

Moreover, rather than only considering green area as a whole as did the second scenario, the third scenario makes an in depth analysis that calculated tree canopy for neighborhood-size areas and suggested concrete amounts of tree area needed for each cell to realize 35% tree canopy. Thus, the modifications in the third scenario could benefit Beijing's ecosystem from the regional level down to the neighborhood level. Its application is expected to achieve significant improvement for Beijing's environment system not only from macro perspective but also from micro perspective.

Other Considerations

As a historic city with high population density, Beijing's greenbelts construction experiences more difficulty than newly developed cities. It is necessary to comprehensively consider every aspect and take them into account. In this section, other considerations are discussed based on landscape ecology principles and case studies represented in Literature Review.

Multi-functions of Greenbelt

Greenbelts could be a pleasant space where the citizens can escape the tarmac and concrete world, and get in touch with nature, breathe fresh air, and smell the earth, trees and flowers. This function is extremely useful in Beijing's case because of the lack of public green space and physical exercise fields. According to the Beijing Greenbelts Plan, the second greenbelt will be built at the edge of the city. The greenbelt could be a transition between the concrete urban area and the natural forest for recreation. Yet, the plan does not fully consider the function. It is better to build up more free access to public parks and children's playgrounds. Furthermore, the greenbelt in the northwest of Beijing is adjacent to the mountain area. A part of the greenbelt could be an ecological park for public education. In this way, the greenbelt will contribute to the improvement for the life quality of Beijing residents.

Plants species selection and arrangement

According to the results from the case study of Canadian greenbelts, plant species selection and arrangement play an important role in terms of achieving the best ecological effect, such as hampering sandstorms. It is suggested that "a five-row conifers with an outside row of shrubs on two sides greenbelts, a double row of deciduous trees and a double inner row of conifers with staggered spaces is the ideal design for protection from both sandstorms and blowing snow" (Agriculture and Agri-Food Canada, 2003, np). This method is also suitable for Beijing which suffers strong sandstorms in spring and intensive snow in winter. Moreover, conifers are one of the popular tree species in Beijing. Therefore, Beijing could select specific conifers as a major species and develop properly arrangement for the greenbelt in the mountain area.

In addition, the greenbelt can produce large economic benefits if proper plant species are selected. This is particularly important because the local residents, many being peasants, will probably lose their income source when the farmland is changed to a forest planting area. Fruit trees, such as apple trees could planted as they can provide not only the ecological but economic benefits.

Vertical greening for high-density area

The compact urban core of Beijing features high-density settlement and crowded communities with inadequate green space, which make it difficult to implement green space plan. Turner proposed that vertical greening is an effective way to increase green space in highly developed areas. The approach is suitable for Beijing's current situation. Vertical greening can increase tree canopy and provide vertical richness. Beijing may reinforce vertical greening projects by developing roof gardens, wall greening, balcony greening, and windowsill greening.

Historic resource preservation

As a capital city with a long history, Beijing has a variety of historic and cultural resources, including historic districts, archaeological sites, and natural heritage areas, such as imperial parks and ancient temples. Visiting historic sites is an enjoyable recreational activity that provides people an opportunity to learn about the culture and history of an area. In fact, historic sites are the major pillars supporting Beijing's tourism and travel industry. Unfortunately, many historic sites and areas face demolition and deterioration during the urban development as well as in the course of green space construction. Therefore, the approach should enhance historic preservation during a process of developing greenbelts. Historic sites should be registered officially, and proper legislation should be established to protect historic properties and scenic views.

Policy and management

With the coming event of the 2008 Olympic Games, Beijing is facing a great opportunity as well as big challenge. The present study shows the Beijing Greenbelts Plan could almost reach its goal. However, doing this is much harder than planning. It will be a tough job to put this plan into implementation. During implementation of the greenbelts plan, special attentions should be paid to two questions. The first question is how to protect farmers' economic benefits when their farmlands are occupied for growing trees. As the Beijing greenbelts occupy a large amount of agricultural lands from which local farmers make their livings. The economic issue is always a key point in the process of implementing greenbelts plan, considering that China is still a developing country. To establish successful and sustainable greenbelts, it is worth doing in-depth research and in keeping a good balance between ecological and economic benefits.

The second question is about management. The previous greenbelts plans failed due to rapid real estate development. In order to guarantee the normal operation of the greenbelt project, it is necessary to adopt appropriate policies which provide restrictions to developers and protect greenbelts from tampering. Management is one of the important factors on green space in Beijing, which makes a difference in providing successful and sustainable outcomes. Studies should be carried out to explore effective management systems in order to provide a context for the restoration and conservation of greenbelts in urban areas. There is a lot of work to do to implement the greenbelts plan successfully and subsequently realize the proposed "Green Olympic" in 2008.

Summary

In this chapter, the analyses of the three scenarios were conducted and the results were discussed. The areas for different landcover categories and environmental indicators were calculated by CITYgreen software. The result shows the Beijing Greenbelts Plan will almost realize its goal of 50% tree canopy in the city area, if the greenbelts are developed successfully as the Beijing Greenbelts Plan proposed. The tree canopy will increase from 22.20% in 1999 to 54.0% in the Improved Greenbelts Scenario, corresponding to the total of air pollution removal increasing from 23,027,608 lbs. per year to 54,556,101 lbs. per year. The particulate matter (PM) removal will increase by approximately 10,000,000 lbs. per year.

The third scenario (Improved Greenbelts Scenario) was conducted to make improvement from the Beijing Greenbelts Plan. Aiming to make an integrated ecological network for urban sustainable development of Beijing, modifications were suggested based on landscape ecology principles combining Beijing's specific situation. The modifications were demonstrated at three different levels: the region, the city, and the neighborhood. The strategies used in the third scenario are to widen edges on the sides facing the predominant wind direction and open the south side of the greenbelts at region level, to enhance connectivity of green network and build up buffer zones along roads and rivers at city level, and to create community parks at neighbor level.

The analysis shows the implementation of the Greenbelts Plan may significantly inhibit the severity of sandstorms by reducing 10% wind speed subsequently decreasing sand volume transported into Beijing city. However, the construction of the studied greenbelts by themselves will not make Beijing air quality meet the National Grade II Standard. The third greenbelt as well as other measures will be needed to work together to realize the goal.

In addition, recreational and educational functions of the greenbelts are suggested to be strengthened; conifers and trees with economical values are recommended to be selected in Beijing; vertical greening could be considered as a good strategy which is particularly suitable for Beijing's high density urban area. It also suggests that measures should be taken to preserve historic resources during the construction of greenbelts.

Chapter Six: Conclusion and Recommendations

Conclusion

In this thesis, the Beijing Greenbelts Plan was described and examined from both ecological and scientific perspectives. Landscape ecological principles provide conceptual and qualitative explanations on examining Beijing greenbelts, while two software packages, ARCGIS and CITYgreen, offer quantitative evaluation on the greenbelts plan. Three scenarios correspond to existing green space in 1999, the Beijing Greenbelts Plan and the improved greenbelts plan were created, analyzed and compared.

The analysis for the first and second scenario indicates the Beijing Greenbelts Plan can almost realize its goal (50% tree canopy in city area). The tree canopy will increase from 22.20% in 1999 to 48.0%, corresponding to a total removal of air pollution increasing from 23,027,608 lbs. per year to 49,921,608 lbs. per year. The third scenario (Improved Greenbelts) can further increase tree canopy to 54.0%, corresponding to air pollution removal of 56,183,036.56 lbs. per year. The statistics report shows that the third scenario brings about 10,000,000 lbs. particulate matter (PM) than the first scenario.

The implementation of the Beijing Greenbelts Plan may decrease sand volume transported into the city by reducing wind speed. However, the construction of the studied greenbelts by themselves will not make Beijing air quality meet the National Grade II Standard. The third greenbelt as well as other measures will be needed to work together to realize the goal.

Recommendations

One of the major purposes for the study is to examine the Beijing Greenbelts Plan and suggest the improvements. Based on the analysis conducted and combined with Beijing's specific situation, recommendations are given below as an attempt to improve the Beijing Greenbelts Plan as well as green space construction:

1. At the region level, widen edges on the sides face the predominant wind direction and leave the south sides open to hamper sandstorm and receive more precipitation.

2. At the city level, create green network and build up buffer zone along roads and rivers to make Beijing green space an interconnected system and an organic whole.

3. At the neighborhood level, community parks could be a good way to increase green space and provide recreation sites for local residents.

4. Conifers could be selected as a major plant species for the greenbelts, and fruit trees might be planted to achieve economic benefits.

5. Vertical greening could be an efficient way to improve tree canopy in a high-density area.

6. More attention should be paid to make use of multi-functions of the greenbelts, such as recreational and educational functions.

7. Care should be taken to preserve historic resources during greenbelt construction.

8. Special attentions should be paid to policies and management to keep a good balance between ecological and economic benefits.

Beijing is facing big challenges like the transformation of industrial economy with a rapid growth of population; more practice and time are needed to implement the Beijing

Greenbelts Plan successfully. It is believed that Beijing will develop an integrated network of urban green space and have a better environment for “Green Olympic City 2008” after three greenbelts are accomplished.

Limitations and Future Research

The study analyzes the Beijing Greenbelts Plan based on landscape ecology principles and the application of CITYgreen from both qualitative and quantitative perspectives. However, there are still some limitations in the study.

In this study, ARCGIS and CITYgreen software were used to make quantitative evaluation and statistical assessment for the Beijing Greenbelts Plan. Approaches were proposed to improve the greenbelts plan based on landscape ecological principles as well as Beijing’s specific situation. Due to limitations in the study, there will be a lot of work to do in the future.

Limitation on Data Collection

This study was carried out in the USA. The information on Beijing greenbelts was mostly collected from open websites or provided by friends in China. Therefore, the information may be incomplete. Field study is needed in the future research to collect first-hand information, which will keep the study up-to-date and more accurate to reflect actual situation.

Influence of Periphery Region

This study investigated the greenbelts plan in a confined Beijing area. However, the ecosystem is an integrated organic system, with various elements interconnected and interacted. To make a more reasonable plan, the greenbelts plan should go beyond the city to take into account the regional environment. In the future study, it is necessary to consider the greenbelts plan in a larger ecosystem, including interactions between different ecological elements such as water, air, soil and connectivity with other areas around Beijing.

Limitations of CITYgreen Software

The calculation of dollar values used Washington, D.C. for reference. As the health care and medical systems are different from China and America, the dollar values may not be appropriate to reflect the situation in Beijing. It would be better if the software could develop dollar value modeling for different Chinese cities.

The indicator of air pollution removal on a site does not reflect varieties of types of green space. Nor does it represent the quality of green space. In other words, the indicator of air pollution removal per square meter of tree canopy is the same, regardless whether a site is well tree covered or poorly vegetated. An effective method to assess air pollution removal is needed.

It is well known that the size and age of trees make a significant difference in air pollution removal and carbon storage. However, the calculation of tree canopy in CITYgreen does not include the difference of the size of trees. In other words, the software does not change the indicator no matter whether the tree is big or small. To provide an accurate method to assess the quality of air and pollution removal, the ecological indicator of tree canopy needs to consider growing state of the trees to fulfill requirements of future research.

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