UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

USING INVEST TO EVALUATE THE PERFORMANCE OF URBAN GROWTH MANAGEMENT STRATEGIES IN CONSERVING ECOSYSTEM SERVICES IN THE CITY OF CORVALLIS, OREGON

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

Degree of

DOCTOR OF PHILOSOPHY

By

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Norman, Oklahoma
2016

USING INVEST TO EVALUATE THE PERFORMANCE OF URBAN GROWTH MANAGEMENT STRATEGIES IN CONSERVING ECOSYSTEM SERVICES IN THE CITY OF CORVALLIS, OREGON

A DISSERTATION APPROVED FOR THE COLLEGE OF ARCHITECTURE

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Acknowledgements

The author wishes to express hearty thanks to Dr. Tom Woodfin, Dr. Guoqiang Shen, Dr. Charles Warnken, Prof. Leehu Loon and Dr. Darren Purcell whose encouragement, guidance and support from the initial to the final level enabled me to develop this dissertation. The dissertation would never have been completed without the support of the College of Architecture, University of Oklahoma.

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Abstract

The world is undergoing a sustained wave of urbanization and through changing landuse and land cover, urbanization has been posing threats to "eco-environments" at various scales (Wang et al 2002). Urban growth management strategies including comprehensive plan with an urban growth boundary have been widely applied at both local and regional scales in the United States to control urban growth and conserve natural resources (Bengston et al 2003). Scholars have studied the performance of Urban Growth Management in environmental conservation, with the results varying due to different scales and research perspectives (Frenkel, 2004; Nelson 1992; Gordon, et al, 2009; Cathcart, et al 2006; Robinson, et al 2005; Kline and Alig, 1999). Through reviewing relevant literature, the author found that few studies explore this issue based on ecosystem service quantification, which could directly act as an indicator of the effectiveness of environmental conservation under different planning policies (Heldal and Baszka 2012).

The InVEST (Integrated Value of Ecosystem Services Tradeoffs) modeling program developed by the Natural Capital Project at Stanford University quantifies various ecosystem services under different planning scenarios. This research uses InVEST 3.2.0 on the parcel level to evaluate the City of Corvallis's current Comprehensive Plan in terms of alleviating future urbanization's impacts on environmental quality and conserving ecosystem services in purifying stormwater and storing carbon. Through spatial and temporal comparisons, the conclusion is made that the City's current Urban Growth Management conserves the land of high ecological value in carbon storage, but does not protect the land of high ecological value in stormwater purification. Using ecological unit monetary values from previous studies and the ecosystem service quantification results generated from InVEST, ecological values of each parcel are converted into a monetary value. Based on these monetized values, this research proposes a revised comprehensive plan for the City. The new plan directs future urbanization into the lands with least ecological values and conserves the lands with most ecological values while still matching the City’s estimated demand for developable land for different land uses.

Chapter 1

Introduction

1. Inextricable Urbanization Process and its Environmental Effects

Urbanization has been rapidly spreading in both developing and developed countries. Global urban population has risen rapidly since the 1950s from less than eight hundred million in 1950 to nearly four billion in 2014 (United Nations 2014). Due to the advantages in modernization, industrialization and the sociological process of rationalization during which traditional thinking ways were replaced by the analyses addressing social control, urbanization will be inextricable from development in the

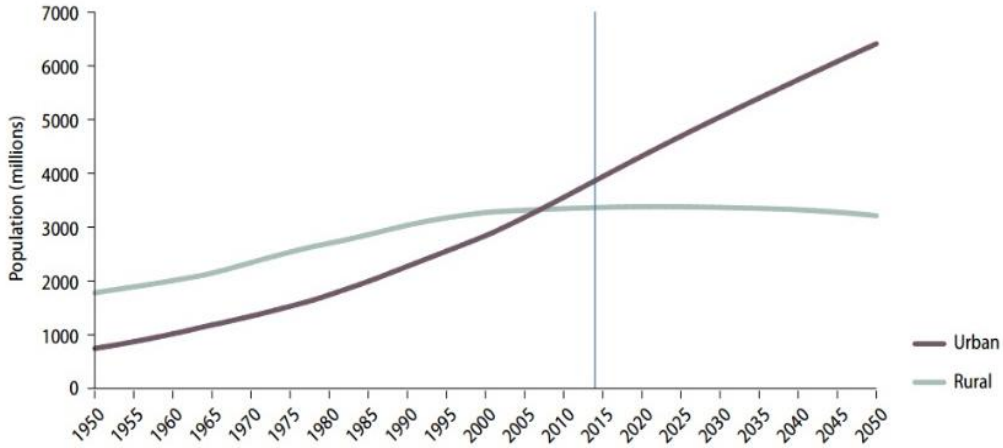


Figure 1. Urban and Rural Population of the World, 1950 – 2050. Source: United Nations, 2014. Department of Economic and Social Affairs, Population Division World Urbanization Prospects: The 2014 Revision, Highlights.

coming decades (Wang et al 2002). The 2014 World Urbanization Prospects predicts that the urban population could reach to 6.5 billion in 2050, accounting for sixty-six percent of the world's total population (United Nations 2014).

Urbanization has brought substantial social and economic development to our world resulting in more job opportunities and more efficient ways of using resources (United

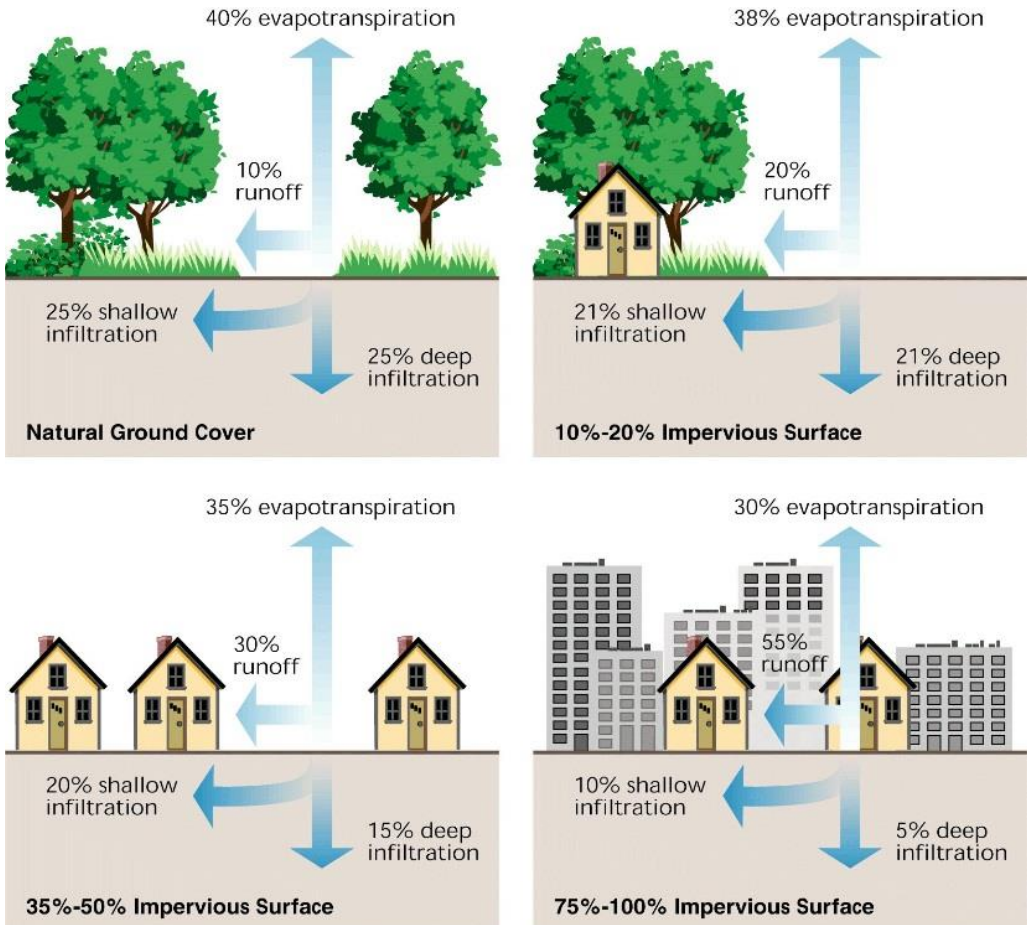


Figure 2. Degrees of Imperviousness and its Effects on Stormwater Runoff. By the Federal Interagency Stream Restoration Working Group (FISRWG).

Nations Population Fund 2015). However, through land use and land cover change, urbanization has been posing negative impacts on “eco-environments” at multiple scales (Wang et al 2002). For example, Faulkner (2004) found that urbanization in the southern United States has damaged forest and wetland ecosystems through fragmenting wildlife habitat, reducing biodiversity and disturbing biotic community functionality. Through collecting emission inventory data and building the population exposure spatial model in Chinese cities, Han, et al. (2004) found that rapid urbanization results in high concentrations of airborne fine particles which lead to the urban haze and does deadly damage to human respiratory system. As urbanization proceeds, a substantial amount of carbon stored in terrestrial natural ecosystems is released into the air (Conte et al 2011). For example, Gibbs et al (2007) found that more than two thirds of total carbon emissions come from deforestation because of urban sprawl in the Africa from 1990 to 2000.

Urbanization has been proven to impact the hydrological cycle. In urban areas, the natural pervious ground surface is replaced by impervious pavement. An increased percentage of impervious surface in urban watersheds results in less water evapotranspiration, less stormwater retention and more flash flooding during intensive precipitation events (Brilly et al 2006). For example, Rose and Peters (2001) documented stream flow in twenty-five streams in Georgia for forty years and their research showed that the peak flow in the urban area is 30% - 100% higher than in rural areas. Nirupama and Simonovic (2006) explored the correlation between the size of urban areas and flow discharges in the Thames River basin and drew the conclusion that because of the progressive upstream urbanization, the flooding risk has been significantly increased for the City of London, Ontario, Canada. Urbanization has also proven to be a factor affecting surface water quality and the levels of heavy metals, total phosphorous and total nitrogen in urban storm water are typically above standards (Bratieres et al 2007, Goonetilleke et al 2005). Through analyzing data from twelve stream sites located in a rural stream, a suburban stream and an urban stream, Mallin et al (2009) found that urban streams carry more phosphorus, biochemical oxygen demand (BOD), total suspended sediment (TSS) and surfactant concentrations than rural streams and suburban streams. While the environmental effects of urbanization have long been known, modern tools enable a better understanding of urbanization and its effects on ecological processes.

2. Urban Growth Management

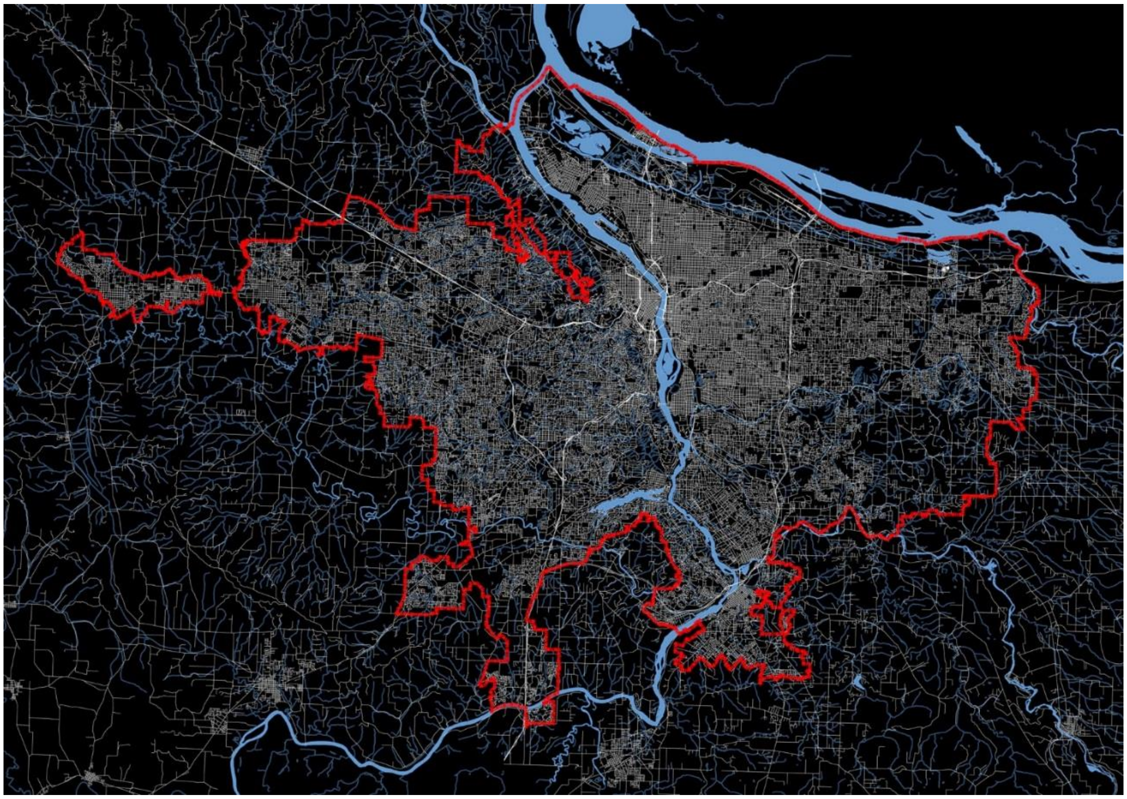


Figure 3. Portland's Current Urban Growth Boundary in 2009 (Source: Urban Grids, Free Association Design).

Urban growth management strategies refer to the planning tools and policies applied in managing where urbanization should occur, when urbanization happens, the appropriate percentage and its impacts (Pollock 2008). It includes but is not limited to:

(1) conservation easements (2) purchase of development rights (PDR) (3) transfer of development rights (TDR) (4) zoning ordinances, agricultural zoning districts (5) urban growth boundaries (UGB) (6) urban service boundaries (7) subdivision regulations (8) riparian buffers (9) comprehensive plans and phased growth regulations (Porter 1997).

Urban growth management strategies have been widely applied at both local and regional scales in the United States to control urban growth (Bengston et al 2003). A number of states have incorporated growth management strategies into their statewide planning programs. Oregon's planning system is considered to be the most successful one in the United States by planners and policy-makers in terms of directing urban growth into urban growth boundaries, making exurban development compatible with land conservation and restricting "resource lands to resource activities" (Nelson and Moore 1993, Knaap and Nelson 1992, Brody, 1991, Dempsey and Andrew 2013). The State of Oregon implements arguably the most restrictive set of urban growth regulations on urban sprawl in the United States. Population is inevitably growing in Oregon and the State's growth management program has been playing an important role in maintaining a balance between natural landscape preservation and urban development (Howe, 1991). In 1973, Oregon passed its statewide Land Conservation Act (LCA) to respond to the rapid urbanization. The Land Conservation Act set up nineteen planning goals to implement the state's land use policy. Those nineteen goals are summarized in Table 1.

As the main strategy to implement the urban growth management policy in Oregon, every city and county is required to create a comprehensive plan and update it every five years. The comprehensive plan must be reviewed and approved by the State Department of Land Conservation and Development Commission (LCDC). The local comprehensive plan should be consistent with the statewide goals and once acknowledged by LCDC, land zoning regulations and subdivision ordinances are adjusted and applied to put a community's comprehensive plan into practice (Oregon Department of Land Conservation and Development 2010). If a local city or county is not able to get its comprehensive plan approved by LCDC, the state may file sanctions to withhold its revenues and grants.

Goal 1	Develop a Citizen Involvement Program
Goal 2	Establish a Comprehensive Land Use Planning Process
Goal 3	Restrict Development on Agricultural Land
Goal 4	Preserve Forests and Maintain Forest Economy
Goal 5	Preserve Natural Resources
Goal 6	Control Water Pollution and Air Pollution
Goal 7	Reduce Society's Risk to Natural Disaster
Goal 8	Meet Citizens' Recreation Needs
Goal 9	Contribute to Healthy and Stable Economic Growth
Goal 10	Provide Variable Household to Citizens
Goal 11	Develop an Efficient and Organized Public Facility System
Goal 12	Develop a Convenient, Affordable and Safe Public Transportation System
Goal 13	Conserve Energy Capacity and Maximize Energy Efficiency
Goal 14	Accommodate Urban Development within the Urban Growth Boundary
Goal 15	Improve Greenway Quality along Willamette River
Goal 16	Protect and Maintain Estuary and Wetlands Values
Goal 17	Recognize and Preserve Coastal Shoreland's Value
Goal 18	Recognize and Preserve Coastal Beach's Value
Goal 19	Preserve Ocean's Resource to Provide Long Term Social, Economic and Ecological Values

Table 1. Goals of Land Use Policy Proposed by the Land Conservation Act (Oregon Department of Land Conservation and Development 2010)

Chapter 2

Literature Review

1. Urbanization and Impervious Surface Impacts on Environmental Quality

Through quantifying emergy, measurement of provisions of biosphere to urban systems and as an indicator of environmental quality and urbanization over time from 1990 to 2006, Mellino (2007) finds urban sprawl significantly decreases environmental quality in an inverse relationship. Previous studies have demonstrated the conversion of pervious surface to impervious surface from urbanization has been threatening environmental quality in multiple dimensions (Foley et al. 2005) such as urban hydrology (Sun and Lockaby 2012), water quality (Johnston 1991), wildlife habitat (Gardiner et al. 2013) and land surface temperature (Van et al. 2011). Hao et al (2015) investigated the change of stream flow and evapotranspiration because of urbanization in a southern China watershed. The results show that from 1986 to 2013 stream flow increased by 58% and land cover conversion to impervious surface contributed more than 80% of the stream flow increase. Lepeška (2016) demonstrates the crucial impacts of impervious surface on the City of Banská Bistrica’s downstream ecosystem. His research shows that urbanization dominated by impervious surface yields 64 times more runoff than the natural watershed dominated by undeveloped lands. Buildings, roads and parking lots contribute 40%, 31% and 25% to the total urban runoff respectively. Schneider et al (2012) uses the U.S. National Land Cover Database and models ecosystem services provision under three urbanized areas of different impervious surface percentage and turf grass percentage in the Agro-IBIS Ecosystem Model. The results show that urban sprawl decreases the city’s ability to regulate flooding and the residential area expansion results in 15-48% more urban runoff. Wu et al (2013) builds the Storm Water Management Model using stream flow monitoring data for five watersheds with different impervious surface percentages. Based on this model, three scenarios are designed to quantify the impacts of impervious surface and climate change on stream hydrology represented by peak discharge, flashiness (R−B Index; Richards–Baker Index), and runoff ratio. The results show that increased impervious surface percentages from 5.2% to 17.1% result in large increases for all these three indicators by 49.5%, 39.3% and 73.9% respectively.

Urbanization also degrades stormwater quality. Through applying a single-factor analysis of variance statistic model (ANOVA) to analyze impervious surface percentages and water samples collected in the city of Lubbock, TX., Heintzman et al (2015) concluded that impervious cover percentage is positively related with polycyclic aromatic hydrocarbons (PAHs - the toxic organic pollutants in stormwater) and suggests that in urban stormwater management, streams surrounded by more pervious buffers should have less PAH pollution. Applying the same methods and statistical model to a riparian wetland, Hogan and Walbridge (2007) found a significantly nonlinear correlation between phosphorus concentrations with impervious surface percentage and, as urbanization proceeds, a riparian wetland's ability to provide ecosystem services is negatively affected as nutrients are redirected from riparian wetlands to streams. Through the collection of empirical data, applying the Soil Conservation Service Curve and comparing dissolved silica export from two watersheds distinguished by impervious surface percentage, it is found that impervious surface limits short-term dissolved silica concentration in precipitation events and decreases long-term dissolved silica export into aquatic ecosystems (Loucaides et al 2007). With the ion concentration sample data and land cover data from different sources (e.g. Federal Census Bureau 2006 TIGER line files, the Puerto Rico Municipal Revenue Center and American Forests), Ramirez et al (2014) used stepwise multiple regressions to analyze how land cover variables are related with major ion concentrations in Puerto Rico. This research finds a strong linear regression among chemical concentration, impervious surface, building density, road density and drainage pipe density.

Land cover conversion into impervious surface results in carbon storage loss. Yan et al (2016) employs Landsat TM images to analyze land cover change and quantifies carbon storage with data from field survey and literature reviews in the period of 1990 to 2010 in the largest dryland city in Urumqi, China. The results show that cropland and desert conversion into impervious surface results in ecosystem carbon loss up to 82%. Until now in the urban area, carbon storage in the soil under capped surfaces has not been characterized clearly and assessment of impervious surface sprawl impacts on soil carbon storage varies (Wei et al 2014a). For example, Raciti et al (2012) suggest that the soil organic carbon storage under capped surfaces is apparently lower than in the open soil. But Edmondson et al (2012) explores the carbon storage in the urban environment in a mid-sized British city and assesses the carbon storage under impacts of different impervious types including roads, pavements, footpaths and patios. Contrasting with general understanding that urbanization is degrading ecosystem services, this research reports that urban soil stores more carbon than rural soil with same soil depth and there is no significant change between the soil under impervious surface and the soil under unsealed surface.

2. Urban Growth Management's Efforts in Environmental Conservation

One of the original goals of the Urban Growth Management policy is to restrain urban sprawl and preserve natural resources. Scholars have studied the performance of urban growth management in environment conservation. Frenkel (2004a) researched the role of growth management policies in concentrating urban development and environmental conservation at the national level in Israel. Through running the Land-Consumption model (Frenkel 2004b) and a comparison of different planning scenarios, Frenkel predicted that the urban growth management policy taking place from 1995 to 2020 reduced unprotected open space loss from 8.2% to 6.5% and dropped farmland loss from 11.1% to 8.7%. Similarly, Nelson (1992) demonstrated that Oregon's planning policies including urban growth management, urban growth boundaries, and exurban development separation play an important role in conserving productive farmland and forest. Gordon et al (2009) indicated that the urban growth management in the City of Melbourne, Australia could be an effective planning tool in protecting threatened species habitat. Cathcart et al (2006) drew the conclusion that through directing urban development into the urban growth boundary, the natural resources preserved by Oregon's planning program could potentially capture substantial carbon dioxide up to 15 million tons in the future ten years. However the adverse effects of urban growth management policy are also pointed out by some scholars. Robinson et al (2005) argued that under the urban growth management, urban density within the urban growth boundary did increase in the past 25 years in the Seattle region. However low-density development has been increasingly sprawling in natural areas outside the boundary. Based on the database and plant community inventory collected by United States

Department of Agriculture, Kline and Alig (1999) drew the similar conclusion that in Oregon, development under the urban growth management is tending to be more intensive within the urban growth boundary but it is not clear that the tendency of development within forest and farmland is decreased outside of the boundary.

3. Urban Growth Management's Impacts on Property Values

Many scholars have studied the relationship between urban growth management and land prices. Lillydahl (1987) notes that the urban growth management policy has the potential to dampen development by increasing land and housing prices. Knapp and Nelson (1988) argue that the urban growth management policy can increase property prices because it restrains the supply of developable urban land. In addition, the urban growth management enhances the environmental quality of land parcels that are inside but close to the urban growth boundary. These parcels might enjoy the open space and the expansive views provided by the low-density development outside the boundary. Some research has demonstrated that the property price rises because of environmental amenities improvement (Cho et al., 2008; Seo and von Rabenau, 2011).

However, Dawkins (2002) argues that, similar with other commercial goods, whether or not the urban growth management policy is impacting property values ultimately depends on the relationship of demand and supply elasticity. Urban growth management policy may not increase the house prices if the flexible land supply can mitigate the inflationary pressure on land prices by bringing in new supply. This might explain Mathur's (2013) finding that the property values around the urban growth boundary is slightly decreasing in King County, Washington.

4. The Framework of Ecosystem Services in Urban Planning

Ecosystem services refer to the benefits provided by ecosystems for humans and are categorized into provisioning services, regulating services, supporting services and cultural services (Millennium Ecosystem Assessment 2005). Provisioning ecosystem services are the material or energy generated from the ecosystems, including food, raw materials, water and medical materials. Regulating services indicate the benefits provided by ecosystems in the way of regulating ecological processes, for example regulating qualities of water, air and soil. Supporting services are the necessary conditions created by the ecosystem to provide other services, for example, soil formation and nutrient recycling. Cultural services denote the nonmaterial benefits humans gain from ecosystems through experiences, such as cultural heritage, landscape aesthetics and outdoor recreation (The Economics of Ecosystems and Biodiversity 2008). Ecosystem services are vital for humans and provide invaluable and innumerable benefits. Without ecosystem services, humans do not have food, living conditions or wilderness to enjoy. For example, the global population is projected to be more than 9 billion by the middle of 21th century. Since humans depend on agricultural products for food, our ecosystems will need to supply and regulate 10^9 hectares more agricultural land for food production (Goldman 2010).

Urbanization has brought substantial social and economic development to our world, and it has been widely recognized that through land use and land cover change, urbanization has inevitably impacted the environmental quality at multiple scales. The ecological-social ecosystem service trade-offs as a framework is a powerful approach to analyze and pursue the three pillars of sustainability (ecological sustainability, economic sustainability and social sustainability) (Cavender-Bares et al 2015). The public welfare depends significantly on the "quality, quantity and diversity" of the ecosystem services and urban planners play a significant role in organizing cities' process and enhancing the public welfare (McPhearson et al 2014 and Hansen et al., 2015). However there is little research on how the urban planning process or research relates to and addresses different aspects of ecosystem services (Erixon et al., 2014). This dissertation reviewed the framework of ecosystem services in urban planning by asking the question: "how is the ecosystem services framework applied by urban planners and designers in making spatial interventions?"

Niemela et al (2010) reviewed the application of the ecosystem service approach in land-use planning at the regional scale. He identifies the three main services provided by the urban ecosystem as provisioning services, regulating services and cultural services. Through interviewing of planners, Niemela summarizes the advantage and disadvantages of the concept of ecosystem service and concludes with the challenge of its application in spatial planning. Similarly through reviewing previous studies in Europe and United States, Gómez-Baggethun and Barton (2013) describe and categorize most provisioning ecosystem services and regulating services, and summarize the methods to convert the biophysical ecological value to economic value. Gómez-Baggethun and Barton propose four methods to evaluate the cultural values of ecosystem services (hedonic pricing, travel cost, avoided cost and stated preference methods) and indicate that compared with the ecological values, the knowledge for how to quantify cultural ecosystem services is limited. Gaston et al (2013) reviews the relevant studies in the United Kingdom and addresses the challenges for urban planners in managing urban ecosystem services. Gaston suggests that high resolution data from remote sensing technology, applied ecology principles and systematic planning processes could assist planners in conserving ecosystem services from urbanization. Kabisch (2014) examines to what extent the framework of ecosystem services is utilized in spatial planning by reviewing Berlin's planning context and interviewing local land owners. This review draws the conclusion that some types of ecosystem services are addressed in most of Berlin's planning documents, but the comprehensive framework of the ecosystem services, especially the tradeoffs among ecosystem services, is barely considered. Kabisch concluded that financial constraints, lack of professional expertise and less awareness of ecological benefits are the main challenges in comprehensively applying the framework of ecosystem service. Geneletti and Zardo (2016) addressed the importance of the framework of Ecosystem-based Adaptation (EbA), a measurement of ecosystem service, including EbA classification and the scoring system, and reviewed how this framework is applied in three European cities' climate adaptation plans. Cavan et al (2014) classified the land cover of two African cities into 35 and 43 Urban Morphology Types (UMTs) respectively, and demonstrated that UMTs could be applied in assessing ecosystem services in regulating land surface temperature.

Grêt-Regamey (2013) ranks three vegetation composition styles' efficiency in cooling temperature and providing habitat using indicators of shadow area and suitable area. Furthermore, Grêt-Regamey embeds this analysis process into three-dimensional GIS-based modeling, and through this model, decision-makers could deal with the tradeoffs among the ecosystem services' biophysical, economic and esthetic values. Lakes and Kim (2012) analyze the advantages and disadvantages of using biotype area ratio as indicators to assess regulating ecosystem services in Seoul and Berlin at a city scale. The results indicate that with the assistance of high-resolution remote sensing data, biotype area ratio is a successful indicator and could be applied by planners to assess urban regulating ecosystem services. Lee et al (2015) analyzed the ecosystem services changing trend from 1970 to 2006 in Taiwan by quantifying paddy rice field coverage percentage as an indicator for provisioning services, percentage of pervious surface as an indicator for regulating services and the rice field patches as an indicator for cultural services. This study shows an example that landscape metric and configuration analysis could inform planners in prioritizing agricultural fields for conservation. Huang et al (2011) quantified the ecological energetic difference for each land use and land cover, though this provisioning ecosystem service and regulating ecosystem service changes were evaluated from 1971 to 2006 in Taiwan. Martinico et al (2014) assessed the urban ecosystem service under the City of Catania in Italy through using the amount of new urban farmlands as the indicator for provisioning ecosystem services, the amount of new greenspace in resource zones as the indicator for regulating ecosystem services and greenspace connectivity as the indicator for cultural ecosystem services (recreational services).

Three methods frequently used to qualitatively analyze urban ecosystem services could be summarized as through (1) the green infrastructure or pervious surface percentage, (2) the landscape metrics quantification, i.e. green patch size and connectivity, and (3) ecological energetic analysis.

Some studies have quantified ecosystem services. Dupras et al (2015) pointed out that due to the lack understanding of natural capital and ecosystem services, planning policy may have unknowingly been contributing to the degradation of the environment. Dupras maps the total non-market values of biodiversity in the Greater Montreal area in Canada and through mapping the distributions of the values of ecosystem services, decision-makers are able to make more effective land planning policies. In Dupras' study, the methodology to quantify the ecological values provided by forests, woodlands and urban wetlands is by calculating the areal amount of those three land covers in ArcGIS and using the secondary data regarding the economic values of the ecosystem services provided by the Environmental Valuation Reference Inventory database (Dupras et al 2015). Larondelle et al (2014) quantifies and maps ecosystem services in regulating urban temperature and storing carbon for 300 European cities using the land use high-resolution data from Urban Atlas Dataset combined with the f-evapotranspiration and carbon storage values for each land use type from previous research. Derkzen et al (2015) quantified five regulating ecosystem services (air purification, stormwater retention, surface temperature regulation, noise reduction and carbon storage) and the ecosystem service for recreation in Rotterdam, Netherlands through using high-resolution urban land use and land cover data with eight categories and unit values of each category in providing ecosystem service retrieved from previous studies. All this research indicates that planners could and should pay more attention to the urban planning culture that is crucial for conserving urban regulating ecosystem services. A similar method was used by Zhou et al (2014) in quantifying the relationship between the ongoing processes of urbanization and the corresponding loss of ecological values in the City of Wuhan, China. Zhou explores the influences of three developing urban patterns on the ecological values by quantifying the urbanization patterns, determining the changes in ecosystem services and attempting to build the Pearson Correlation between those two factors. The method to quantify the ecosystem services changes in this case was to quantify the landscape patterns in the process of urbanization and use the secondary data provided by the Ecosystem Service Valuation Coefficients for China, as developed by Xie et al. (2003). The weakness of this method is that it assumes the same land use land cover type provides the exactly same ecological values regardless of the different locations, various climate and biophysical situations (for example, the different soil conditions), and different structural components (for example, the different plant components of urban forests and urban wetlands).

Liu and Li (2012) quantify the carbon sequestration and storage by the urban forest in the City of Shenyang, China. The improvement in their method is that rather than using the same general ecosystem services valuation index for all types of urban forests, Liu and Li used the satellite images and the field survey to document the plant species in the urban forests. Then the Biomass Equation was applied to quantify the carbon storage of each type of species. This study also demonstrates that the ability to store carbon varies among different urban forest types with different "species composition and age structure" (Liu and Li 2012). However this study still does not take into consideration various biophysical conditions.

Jansson and Colding (2007) used the Transport, Retention, Kallfordelling (TRK) model (a hydrological model) to quantify the nitrogen loading to the Baltic Sea from Stockholm County both under the present scenario and two alternative future development scenarios predicted by the county's planning department. Schaffler and

Swilling (2012) used the same method to calculate the size of the vegetation components and quantified the ecosystem services provided by the urban green infrastructure in Johannesburg, South Africa. Compared to the methodologies mentioned earlier, these methods are more accurate by using the local data instead of the ecosystem services quantification reference index. But this method requires extensive field surveys to create accurate localized standard values.

InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) was developed by the Natural Capital Project at Stanford University to quantify the ecosystem services under different planning scenarios and assess how the ability to provide ecosystem services could be affected by alternative plans (Mckenzie, et al 2011). With the assistance of InVEST, Tao et al (2015) quantify a Chinese City's ability to provide ecosystem service in storing carbon from 1986 to 2011, and find the carbon storage decreasing from the urban edge to the urban core. Bai et al (2012) applies InVEST to quantify an urban watershed's ability to provide ecosystem services in producing agriculture, generating hydropower and improving water quality, and analyzes the tradeoffs among them under five alternative urban planning scenarios in the City of Baiyangdian, China. Based on the ecosystem services qualification results, the author argues that areas with high ecological values could be located for conservation in further study (Bai et al. 2012). This has been demonstrated by Liu et al (2013) who used InVEST to identify the areas with high ecological values in storing carbon, producing timber, generating hydropower, improving water quality and retaining sediment in Fuzhou, China. After generating the ecosystem services quantification results, this paper applied the "ordered weighted averaging (OWA)" methodology to create the conservation planning scenarios that address the tradeoffs of the ecosystem services (Liu et al. 2013). Converting the ecological values into economic values is another way to balance ecosystem services tradeoffs. For example, Lee et al (2014) applied the Least-Cost Path Methods to delineate the landscape corridors based on estimation of the monetary value of ecosystem services provided by different land use typologies.

Ecosystem service quantification in the human built environment is crucial for further alleviating urbanization's negative influence on natural resources (Jansson and Colding 2007). But through the literature review, few studies were found to incorporate ecosystem service quantification into environmental conservation and land use decision-making. Through reviewing the application of ecosystem services modeling in urban planning, three methods and their limitations are summarized to quantify the ecological values as follows:

- Simple Biomass Equation: Area Size times General Ecosystem Service Index.

This method has advantages in estimating ecosystem services ranges in the condition that available local datasets were limited. The weakness of this method is that it assumes the same land use land cover type provides the exactly same ecological values regardless of the different locations, various climate and biophysical situations (for example, the different soil conditions), and different structural components (for example, the different plant components of urban forests and urban wetlands).

- Advanced Biomass Equation: Area times Local Ecosystem Service Index (More land cover pattern, local data and field survey).

Compared to the above one, this method is more accurate by using the local data instead of the ecosystem services quantification reference index. But this method requires extensive field surveys to create accurate localized standard values.

•Biophysical Models: Advanced Biomass Equation in Various Biophysical Conditions.

This method is more accurate than the previous two, but the weakness of this one is that it is a complex process to adjust the data and it requires planners to have a science background (for example, hydrology) and understand the model principles in building the model. These studies barely attract the policy maker's attention because they cannot transfer the ecological values into the economic values at a local community or neighborhood scale. People would appreciate the environment benefits more if they have an understanding of what an important role their community or neighborhood is playing in providing ecosystem services. Therefore it is strongly recommended that new methodologies and models that can address both the local lands' ecological values and economic values are developed to assist in exploring the effects of the land use policy, for example, on the urban growth management.

5. Limitations to Previous Studies

Through the literature review, it was noted that although there are some studies evaluating the performance of urban growth management in environmental conservation, the results vary due to different scales and research perspectives. Few studies explore this question based on ecosystem service quantification, as a comprehensive framework exploring the relationship between nature and society by the extent of environmental conservation under different planning scenarios (Heldak and Raszka 2012). Most of these studies exploring urbanization's impacts on environmental quality are completed utilizing a single environmental quality indicator data from field sample surveys and impervious surface percentage data from remote sensing data (e.g. National Land Cover Database) with limited urban land use categories on the regional watershed scale. However urbanization and impervious surface environmental impacts at a local land use scale generates more information for urban planners. Land owners may not regulate environment change drivers on the regional scale but they are able to alleviate urbanization's impact on environmental quality through controlling local impervious coverage (Nelson et al 2009).

The following key points found in the literature review are summarized as follows:

- While the environmental effects of urbanization have long been known, modern tools applicable to local scales that enable a better understanding of urbanization and its effects on ecological processes are needed.
- Ecosystem service quantification in the human built environment is crucial for further alleviating urbanization's negative influence on natural resources (Jansson and Colding 2007).

- Limited studies were found to incorporate ecosystem service quantification into environmental conservation and land use decision-making.
- Few studies used the ecological models to quantify the ecosystem services provided either by the rural landscape or urban landscape. These studies rarely attract the policy maker’s attention because they cannot transfer the ecological values into the economic values at a local community or neighborhood scale.

Chapter 3

The City of Corvallis, Oregon and Research Objectives

1. The City of Corvallis, Oregon.

The City of Corvallis is in Benton County, Oregon. It is located near the middle of the Willamette Valley (City of Corvallis 2002). The City is within 90 minutes' drive of the Portland Metropolitan area. The City's population grew from 44,816 in 1990 to 54,953 in 2013. The City has a total area of 14.40 square miles, of which 0.17 square miles is water and 14.23 square miles is land (U.S. Census Bureau 2011). According to the National Land Cover database from the Pacific Northwest Ecosystem Research Consortium, the city had 54 land use and land cover categories in 2000 (see Table 2)

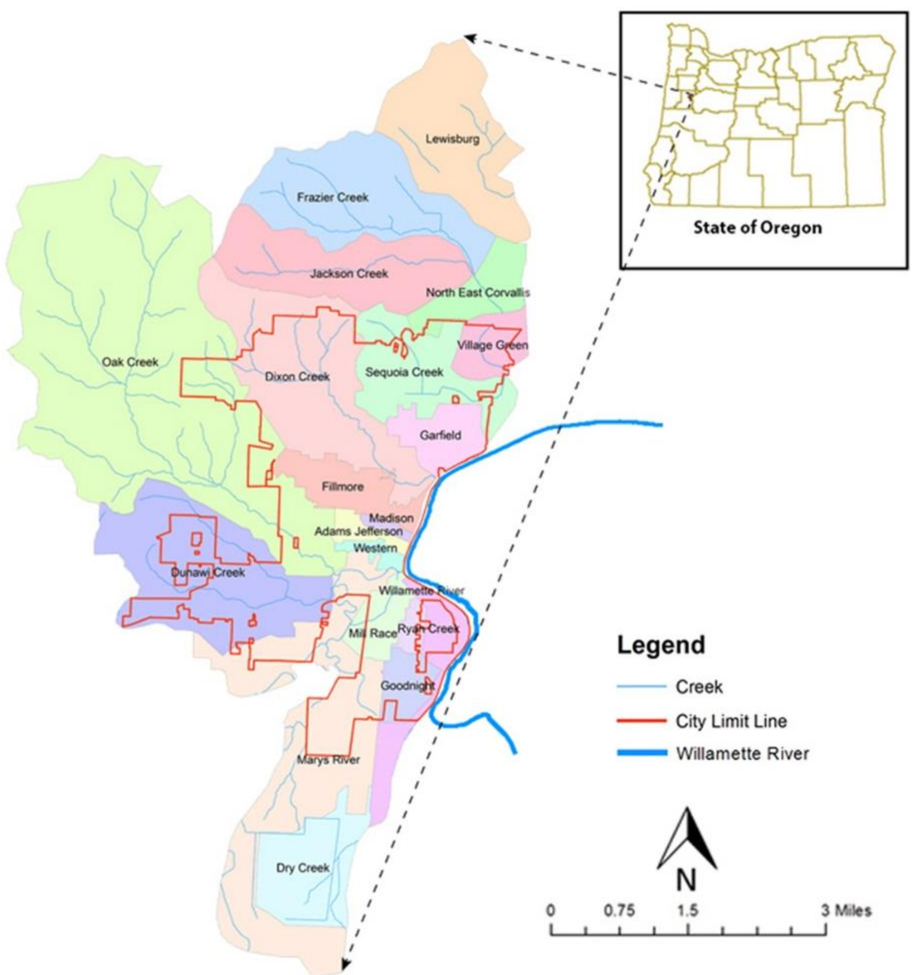


Figure 4. City of Corvallis, Oregon and Subwatersheds

The City is located in a drainage basin that intersects with the Willamette River Watershed (HUC 1709000306) and Marys River Watershed (HUC 1709000302) in central western Oregon, and encompasses twenty subwatersheds (see Figure. 4). Table 2 shows the land use and land cover in this stormwater basin. The Willamette River does not meet the water quality standard established by EPA's Clean Water Act and the City developed the Total Maximum Daily Loads (TMDL) model for the Willamette Basin in 2006. According to the Willamette Basin TMDL model, it requires at least 20 years and $100 million to meet the water quality standard. The City's waste water treatment plant discharges into the Willamette River and urban stormwater has negatively impacted the water quality in urban streams and the Willamette River (City of Corvallis 2007).

Land Use and Land Cover	Area (m^2)	Percentage	Land Use and Land Cover	Area (m^2)	Percentage
Residential Area (0-4 DU/ac)	17,156,700	14.38%	Forest closed conifer older than 200 yrs	513,900	0.43%
Residential Area (4-9 DU/ac)	1,794,600	1.50%	Upland Forest Semi-closed hardwood	238,500	0.20%
Residential Area (9-16 DU/ac)	792,000	0.66%	Hybrid poplar	32,400	0.03%
Residential Area (16 DU/ac)	138,600	0.12%	Grass seed rotation	3,087,000	2.59%
Commercial	2,358,000	1.98%	Irrigated annual rotation	54,000	0.05%
Commercial and Industrial Area	321,300	0.27%	Grains	657,900	0.55%
Industrial Area	1,392,300	1.17%	Berries & Vineyards	292,500	0.25%
Urban non-vegetated unknown	7,012,800	5.88%	Double cropping	177,300	0.15%
Rural structures	702,900	0.59%	Hops	900	0.00%
Railroad	864,000	0.72%	Mint	15,300	0.01%
Secondary roads	972,000	0.81%	Sugar beet seed	900	0.00%
Light duty roads	6,559,200	5.50%	Row crop	1,246,500	1.04%
Rural non-vegetated unknown	459,000	0.38%	Grass	3,894,300	3.26%
Main channel non-vegetated	54,900	0.05%	Burned grass	37,800	0.03%
Stream	317,700	0.27%	Field crop	5,090,400	4.27%
Permanent lentic water	156,600	0.13%	Hayfield	2,744,100	2.30%
Urban tree overstory	2,095,200	1.76%	Late field crop	306,000	0.26%
Upland Forest open	24,300	0.02%	Pasture	5,639,400	4.73%
Upland Forest Semi-closed mixed	111,600	0.09%	Natural grassland	1,962,900	1.64%
Forest Closed hardwood	10,387,800	8.70%	Natural shrub	8,140,500	6.82%
Forest Closed mixed	11,803,500	9.89%	Bare/fallow	1,820,700	1.53%
Upland Forest Semi-closed conifer	22,500	0.02%	Flooded/marsh	229,500	0.19%
Conifers 0-20 yrs	1,522,800	1.28%	Irrigated perennial	918,000	0.77%
Forest closed conifer 21-40 yrs	1,453,500	1.22%	Turfgrass	1,411,200	1.18%
Forest closed conifer 41-60 yrs.	2,401,200	2.01%	Orchard	314,100	0.26%
Forest closed conifer 61-80 yrs	3,313,800	2.78%	Christmas trees	917,100	0.77%
Forest closed conifer 81-200 yrs	5,357,700	4.49%	Conifer Woodlot	46,800	0.04%
			ToTal	**119,336,400**	**100.00%**

Table 2. Land Use and Land Cover within the Watershed of Corvallis in 2000

2. Corvallis' Urban Growth Management

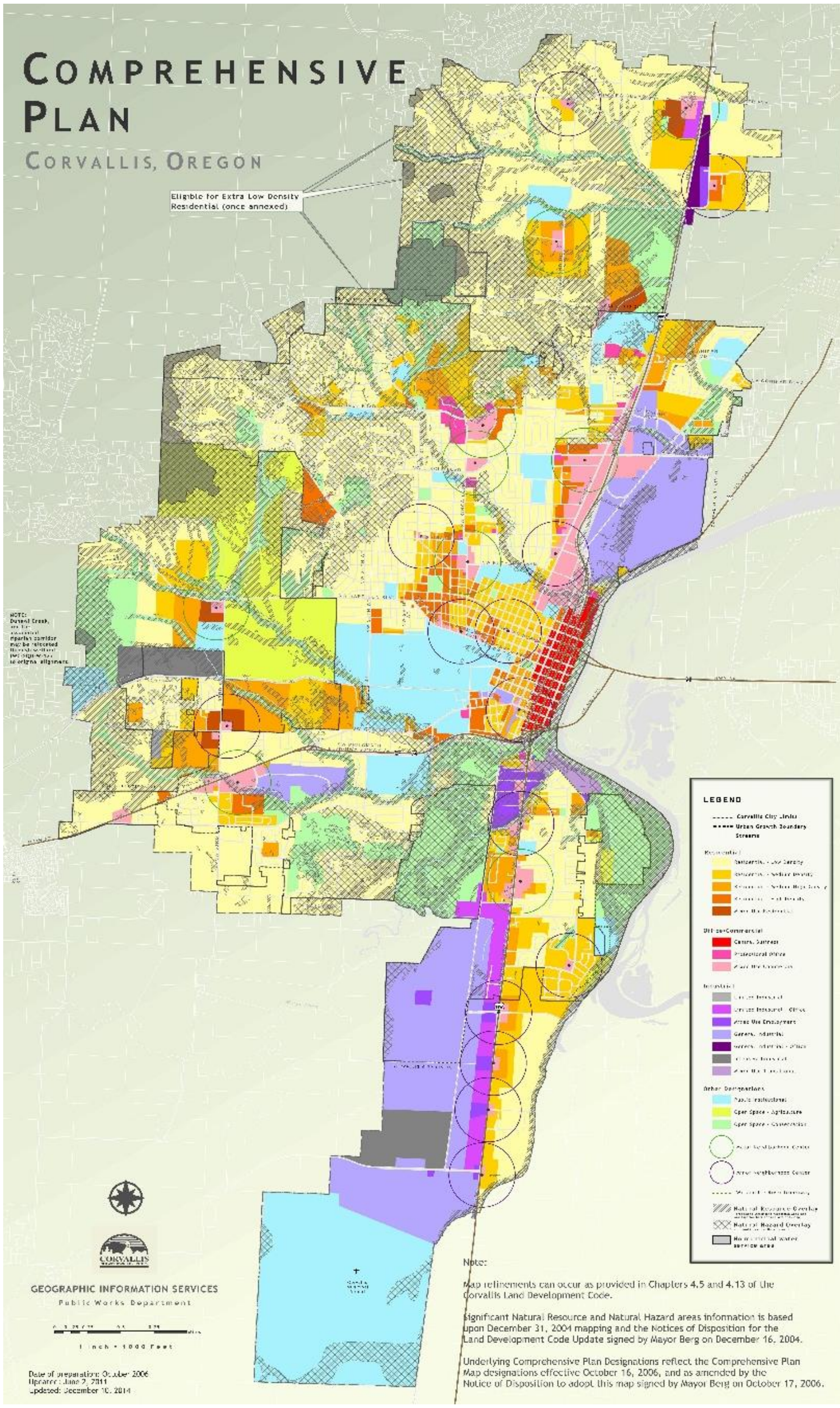


Figure 5. Comprehensive Plan, Corvallis Oregon Source (City of Corvallis, updated December 2014)

The City implemented its first comprehensive plan in 1980. It was updated in 1990 and 1998 in the periodic reviews (City of Corvallis, 2006). The comprehensive plan currently used by the city was developed by the city's planning division in 1998 and was acknowledged by Oregon Land Conservation and Development Commission on June 26, 2000. On December 31, 2006 it was officially approved and implemented by the City Council. The most recent update was in 2014 (see Figure 5).

The current Comprehensive Plan Statement is in conformance with Oregon Statewide Goals and Envisions in 2020, the city is going to be:

· A Compact City with Population Ranging from 57,500 to 63,500;
· The Economic, Cultural and Political Center of Benton County;
· An Environmental-friendly Community with Beautiful and Functional Natural Landscape;
· An Integrated City with Stable and Clean Economy;
· A Community Filled with Arts and Recreation;
· A Community in Support for its Kids and Families;
· A City Applying Local Standards to Assess its Development Progress in Area such as Life Quality, Housing Vitality and Environment Quality;
· A Community in Support of High Education Quality;
· A City Providing Comprehensive Services for Elderly People and Disabled People;
· A Regional Transportation Center Connecting Benton County, Linn County and Rail System;
· A City Involving its Citizens in Policy and Decision Making;
· Various Communities without prejudice and Discrimination (City of Corvallis 1998).

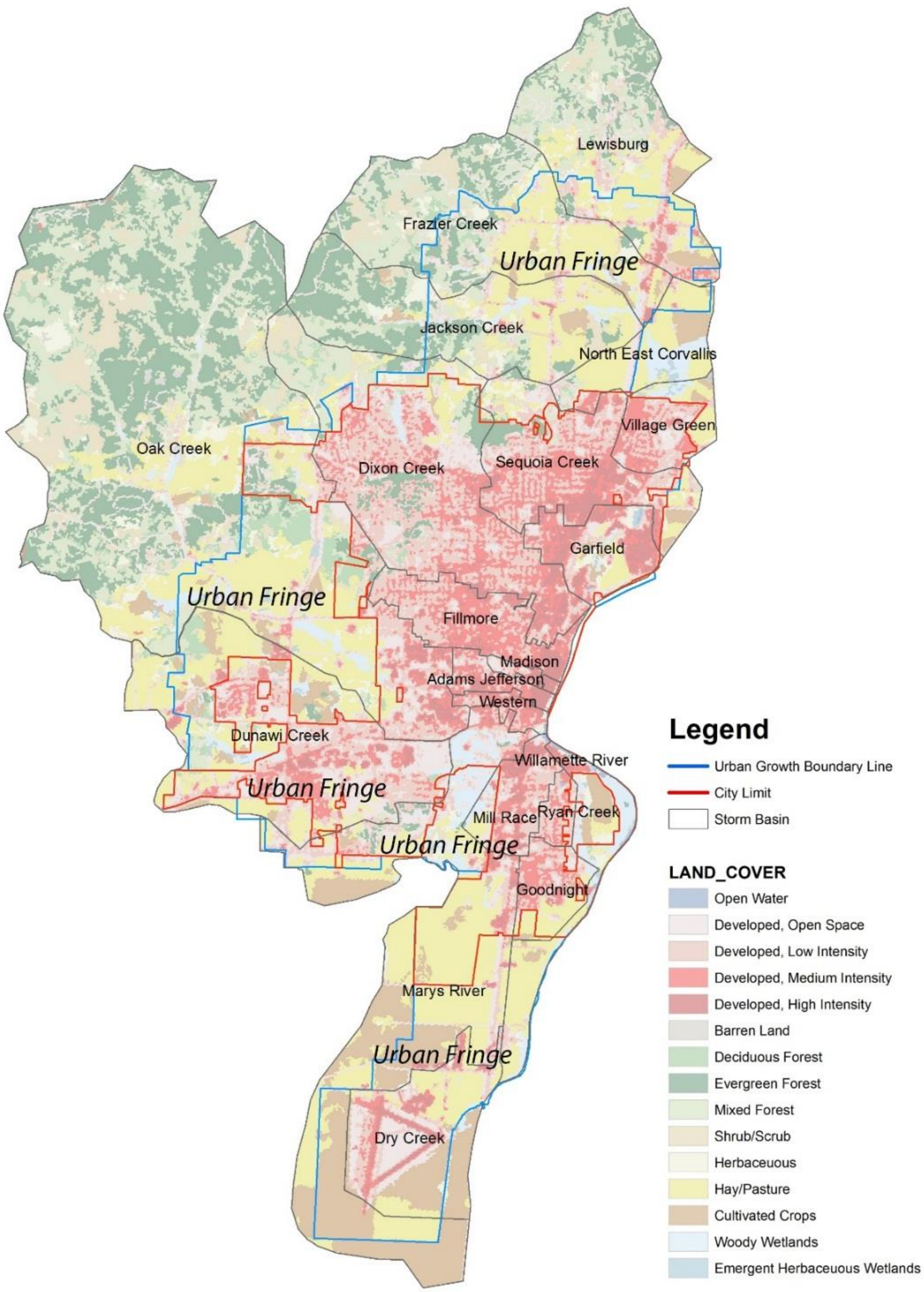


Figure 6. The City's Urban Growth Boundary, City Limit, Watershed and Land Cover in 2000.

According to the City's 2014 updated Comprehensive Plan, the current Corvallis city limit encompasses 14.4 square miles and the area circumscribed by the Urban Growth Boundary (UGB) is 28.1 square miles (see Figure 6). Therefore the area within the Urban Growth Boundary but outside the city limit, which is referred to as Urban Fringe, is nearly 14 square miles. In 2000, these areas were mainly covered with forest and pasture. According to the City of Corvallis's Land Development Code, this Urban Fringe zone is going to be filled mostly with general industry, residential neighborhoods, public institutes and open space.

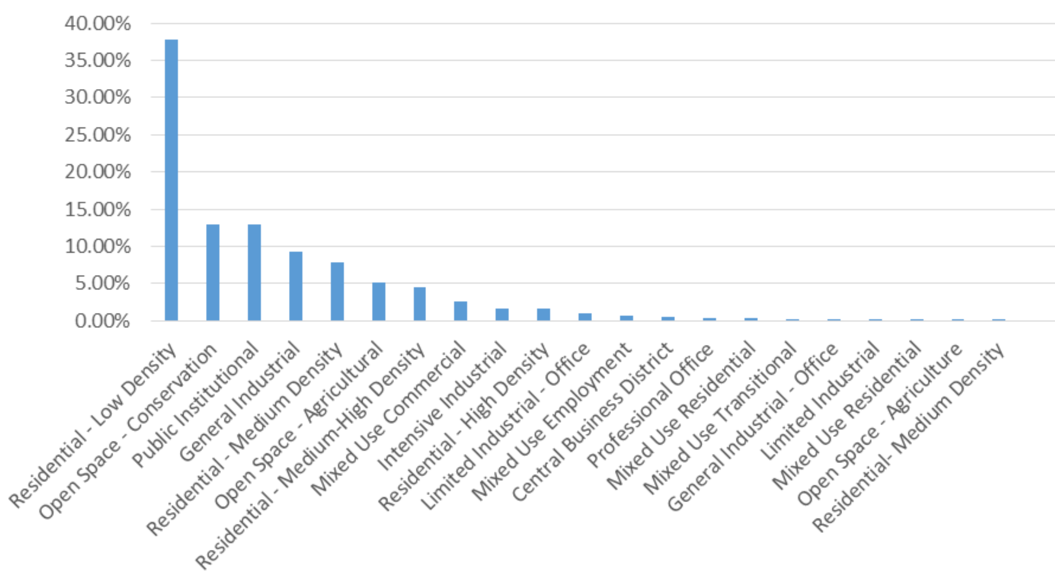


Figure 7. Proposed Land Use Percentage in Urban Fringe in 2020.

Figure 7 describes the proposed land use coverage percentage in 2020 within the Urban Growth Boundary based on the current comprehensive plan. More details of the land use changes from 2000 to 2020 are described in Chapter 5.

3. Research Objectives

One of the original goals of urban growth management is to restrain urban sprawl and thereby preserve natural resources. Scholars have studied the performance of urban growth management in environment conservation (Frenkel, 2004; Nelson 1993; Gordon, et al, 2009; Cathcart, et al 2007; Robinson, et al 2005; Kline and Alig, 1999). Through the literature review, the author found that there is not yet anyone exploring this issue based on ecosystem service quantification, which could directly act as an indicator of the extent of environmental conservation under different planning scenarios (Heldak and Raszka 2012). Enacting a locally-appropriate urban growth management program requires a full understanding of different variables affecting urban growth and spatial distribution. The Comprehensive Plan and Urban Growth Boundary are commonly used to apply the urban growth management policy. However, in practice, planners used to make the comprehensive plan and delineate urban growth boundaries based on their hypothesis with scant supporting data and evidence. This lack of baseline data affects whether the Urban Growth Management program's performance in restricting urbanization and conserving natural landscape can be quantified (Anderson 1999).

This research uses InVEST (Integrated Value of Ecosystem Service Tradeoffs) to quantify the ecosystem services under the City of Corvallis's current comprehensive plan, and analyzes the results to show how the city's planning policy performs in environmental conservation, especially in the Urban Fringe zone. The value of providing ecosystem services is not comprehensively captured by current commercial markets for land valuation (Costanza et al 1997). Some studies have found that neighborhoods surrounding the urban growth boundary are spreading partly due to the undervalued land market price. This research also puts forward a new land property value system for the City of Corvallis that combines its market prices and the anticipated monetary value in providing ecosystem services. The result could be used by the city to adjust the development fees for the urban fringe areas. The methodology used in this study could be utilized by Oregon Land Conservation and Development Commission (OLDC) to evaluate the performance of each cities' Urban Growth Management strategies in environmental conservation.

3.1 Objective 1: Environmental Quality Quantification through Time and Space

The current Corvallis city limit encompasses 14.4 square miles and the area circumscribed by the urban growth boundary is 28.1 square miles (City of Corvallis, 2006). Therefore the area within the urban growth boundary (UGB) but outside the city limit, which is referred to as Urban Fringe, is nearly 14 square miles. According to the City of Corvallis's Land Development Code, this Urban Fringe zone is going to be filled mostly with general industry, residential neighborhoods, public institutes and open space (see Figure 5). There are five Urban Fringe zones in the comprehensive plan: one on the north of the City, two on the west of the City and two on the south of the City (see Figure 5). During the process of urbanization, the ecosystem services provided by the Urban Fringe are likely to be compromised and possibly depleted in the coming decades. The first objective of this research is to model future urbanization's impacts on ecological quality using indicators of nitrogen export, phosphorus export and carbon storage from the current situation and to the projected future. This research also quantifies the ecosystem service provision by the urbanization area (the area within the City Limit and the Urban Fringe Area) and the conservation area (the area outside the Urban Growth Boundary) based on the Comprehensive Plan. Comparisons of the ecological quality through time and the ecosystem services through space create the analytic metric by which to evaluate the performance of the City's Urban Growth Management program in conserving natural resources.

3.2 Objective 2: Ecological Monetary Value Conversion and Its Relationship with Impervious Surface

According to the Corvallis 2000 Land Development Code, almost half of the Urban Fringe is planned as residential neighborhood (see Figure 7). The citizens' preference of residential development land in the urban fringe area is partly due to the fact that the land price does not capture its value in providing ecosystem services and makes residences more affordable in the urban edge area rather than around the city's center. The second objective of this study is to calculate the ecological monetary value based on the ecosystem service quantification results for each parcel modelled in InVEST and to analyze the relationship between impervious surfaces with the ecological monetary values at the subwatershed level.

3.3 Revised Comprehensive Plan Proposed for Future Urbanization and Conservation

As approaches for growth management, comprehensive plans and urban growth boundaries have been widely used in United States. The delineation of an appropriate urban growth boundary requires full understanding of different variables affecting urban growth and spatial distribution. However, in practice, planners typically draw the UGB limits based on their unsupported hypotheses with few supporting scientific data and evidence. Urban growth management's performance in restricting urbanization and conserving natural landscape is thereby difficult to quantify (Anderson 1999). Too few models developed for comprehensive plan and urban growth boundary fully consider ecological factors. The third objective of this study is to explore how to develop a comprehensive plan in ArcGIS that accommodates the city's development and theoretically preserves most ecological values in storm water purification and carbon sequestration for the city of Corvallis.

Land Use	Area Size (m^2)	Coverage Percentage	Land Use	Area Size (m^2)	Coverage Percentage
Central Business District	2522486	3.87%	Open Space - Conservation	8475049	13.00%
General Industrial	6216210	9.54%	Professional Office	274048	0.42%
Intensive Industrial	1110276	1.70%	Public Institutional	8388296	12.87%
Limited Industrial	45593	0.07%	Residential - Low Density	24577315	37.70%
Limited Industrial - Office	669361	1.03%	Residential - Medium Density	5115586	7.85%
Mixed Use Residential	305167	0.47%	Residential - Medium-High Density	2928253	4.49%
Mixed Use Transitional	170185	0.26%	Residential - High Density	1044234	1.60%
Open Space - Agricultural	3349517	5.14%	Total	65191576	100.00%

Table 3. Projected Land Use in 2020

According to the current Comprehensive Plan, the City needs 15 land use categories, and the urban growth boundary encompasses 25.17 square miles lands for urban development with the remainder of the land for conservation (see Table 3 - Open Space - Conservation). This research quantifies the ecological value for each one of the City's parcels and proposes a revised comprehensive plan that conserves the most ecological value while still meeting the City's land demands for urbanization.

Chapter 4

Research Methodology

The research methodology in this study could be briefly described as generating planning scenarios based on research objectives in ArcGIS 10.2.2, collecting secondary data and running InVEST 3.0 biophysical models with the land use and land cover data. Based on the ecosystem service quantification results generated from InVEST, the ecological monetary value could be estimated by the unit value in providing ecosystem service and the number of units.

$$EcoSystem\_Service\_Value = Unit\_Value \times Units$$ (Costanza et al 1997)

More specifically, conceivable costs for stormwater purification and carbon storage are considered using data from relevant case studies in the literature, including direct costs and avoidance costs (Gómez-Baggethun and Barton 2013).

1. Biophysical Models and Ecological-Economic Conversion Models

Ecosystems provide a flow of services that are significant to humans including the production of goods (e.g., food), life-support processes (e.g., water purification), and life-fulfilling conditions (e.g., beauty, recreation opportunities), and the conservation of options (e.g., genetic diversity for future use) (The Economics of Ecosystems and Biodiversity 2008). InVEST and ARIES are the most commonly used modeling tools in ecosystem services quantification. InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) consists of a set of models dependent on ArcGIS to quantify the ecosystem services under different planning scenarios (Mckenzie et al 2011). ARIES (Artificial Intelligence for Ecosystem Services), developed by the University of Vermont, quantifies ecosystem services in a way that “acknowledges dynamic complexity and its consequences” while keeping the model simple enough to be tractable (Villa et al 2014). InVEST is more suitable in a situation in which the undergoing ecological processes are well understood; and ARIES is more suitable in a situation of data inaccessibility (Vigerstol and Aukema, 2011). In this study, InVEST is applied to quantify ecosystem services of stormwater purification and carbon storage for the following two reasons. First, the required data to run InVEST for the City of Corvallis, Oregon are accessible through different sources (see Table 4). Second, InVEST was developed and calibrated by Stanford University using data collected from the Willamette Valley Watershed, within which Corvallis is located.

The specific models used in this study are the InVEST stormwater yield model, the InVEST purification model and the InVEST carbon storage model.

1.1 InVEST Water Yield Model

The InVEST water yield model calculates the amount of storm water yield contributed by various landscape surfaces. The storm water referred to in InVEST is the water generated on the ground during precipitation events that is neither evaporating nor transpiring including storm water flowing both on and under the surface (see Figure 8). The model runs on raster GIS and the grid size depends on the available data's resolution. The first step in running the model is to distinguish the grid that actually generates runoff and the grid on which potential evapotranspiration is more than actual precipitation. Then the model determines the amount of storm water produced by each one of the grids that actually yields storm water. The last step is to accumulate the water

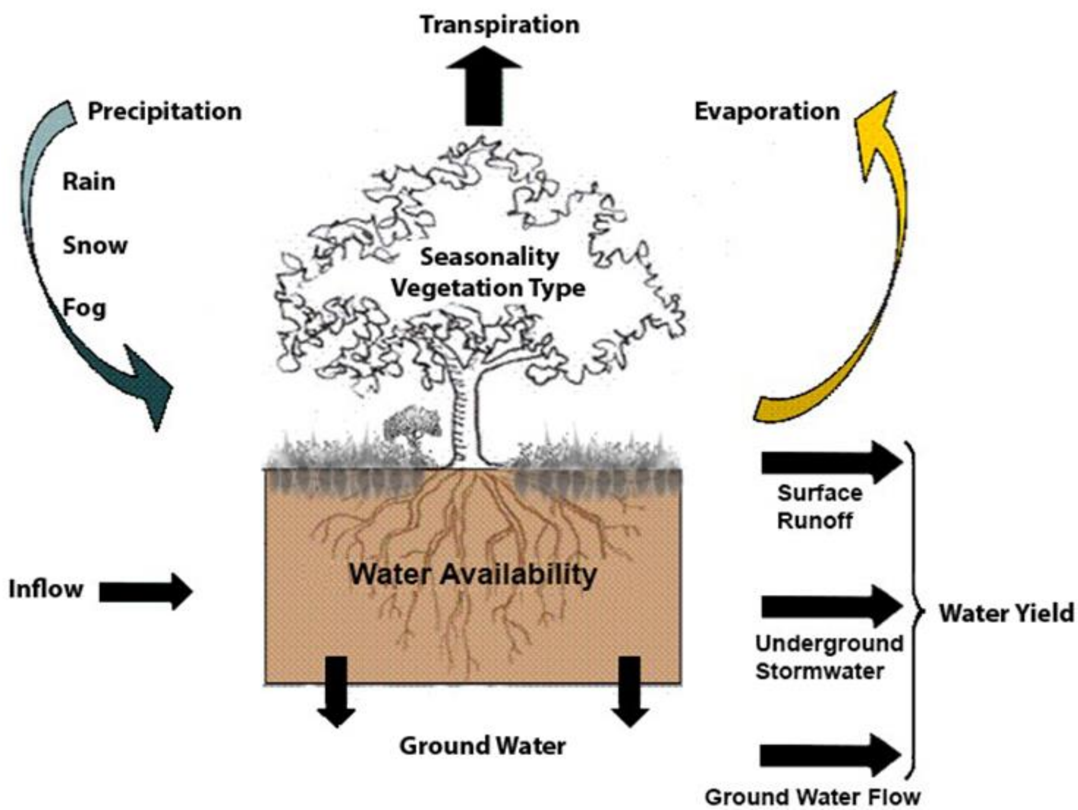


Figure 8. Water Yield in InVEST

yield result of each pixel into sub watershed levels and watershed levels (Mendoza et al 2011).

The water yield model is based on Budyko Curve and the annual average precipitation, which is described as the following equation:

$$Y(x) = [1 - AET(x)/P(x)] \times P(x) \text{ (Budyko Curve)}$$

In the Budyko Curve, *AET (x)* is the annual actual evapotranspiration for grid cell x and *P (x)* is the annual precipitation on grid cell x. For the urban impervious surface, annual *AET (x)* is the same with evaporation and for the area covered by vegetation, actual evapotranspiration could be determined by a model put forward by Zhang in 2004:

$$AET(x)/P(x) = 1 + PET(x)/P(x) - \{1 + [PET(x)/P(x)]^{\omega}\}^{1/\omega}$$

PET (x) is the potential evapotranspiration which equals reference evapotranspiration of each grid cell ($ET_0(x)$) times a plant evapotranspiration factor ($K_c(l_x)$). $ET_0(x)$ is determined by site climatic conditions based on the hypothesis that the field is fully covered by vegetation and there is enough available water in the soil. The equation is described as follows:

$$PET(x) = K_c(l_x) \times ET_0(x)$$

In the urban area, $K_c(l_x)$ could be simply calculated according to a model proposed by Allen (Allen et al 1998):

$$K_c(l_x) = f \times 0.1 + (1 - f) \times 0.6$$

where *f* is the percentage of impervious cover in the built environments. The natural soil properties are characterized by ω and calculated in the following way:

$$\omega(x) = Z \times AWC(x)/P(x) + 1.25 \text{ (Donohue et al 2012)}$$

AWC (x) represents the amount of water in the soil that could be used by vegetation. Z is the empirical factor that reflects the local precipitation characteristics (Sharp et al 2014).

1.2 InVEST Nutrient Retention Model

The InVEST nutrient retention model also runs on raster GIS. It calculates the amount of nutrients trapped by the ground surface. The first step is to estimate average water yield produced by each pixel, which is the same process of running the InVEST water yield model. This process is automatically operated as the first step of InVEST nutrients retention model. The second step is to calculate the amount of nutrients that could be captured by each pixel and the amount of nutrients that are transported out of each pixel based on the concept of export factor proposed by Reckhow (1980). Export factor refers to nutrient flux developed from different ground surfaces. Because this factor is an average flux, the InVEST model applies a hydrology-sensitive coefficient number that takes into consideration the variance between the situation of the measured site and the situation on which the model is applied. The equation is described as following:

$$ALV_x = HSS_x \times pol_x$$

In this equation, ALV_x is the calibrated loading value on grid cell *x*. HSS_x is the hydrologic sensitivity score at grid cell x. pol_x is the pollutant loading coefficient based on land use and land cover at grid cell x. HSS_x could be estimated by the flowing equation:

$$HSS_X = Rx / Ave(Rw)$$

In this equation, *Ave (Rw)* means the average of storm water flow coefficient of the watershed. R_x is the storm water flow coefficient on grid cell *x*, which could be estimated as:

$$R_x = log\ (SUM\ (Yu))$$

In this equation, *SUM (Yu)* is the accumulation of storm water of grids along the flowing route over grid cell *x*.

With the results of ALV_X, the amount of nutrients retained by grid cell *x* is calculated by:

$$\mathrm{Re}t_x = ALV_x \times E$$

In this equation, Ret_x is the amount of nutrients retained by grid cell *x*. E is the vegetation nutrients filtering value (removal efficient) of the pixel based on its land use and land cover type.

Based on results of nutrient retention at each grid, the amount of nutrition retained and exported by all grids along the route could be estimated since storm water eventually transports the nutrients to the stream. The model then calculates the cumulative loading contributed by each grid cell up to sub-watershed level.

1.3 InVEST Carbon Storage Model

The InVEST Carbon Storage and Sequestration model quantifies the carbon storage in each category of landuse and land cover by aggregating the amount carbon captured in four carbon pools: above surface vegetation components, soil, under surface biomass and dead organic matter. The model is operating on raster GIS too, in which each pixel is representing a landuse unit in urban areas or a land cover unit in rural areas. The

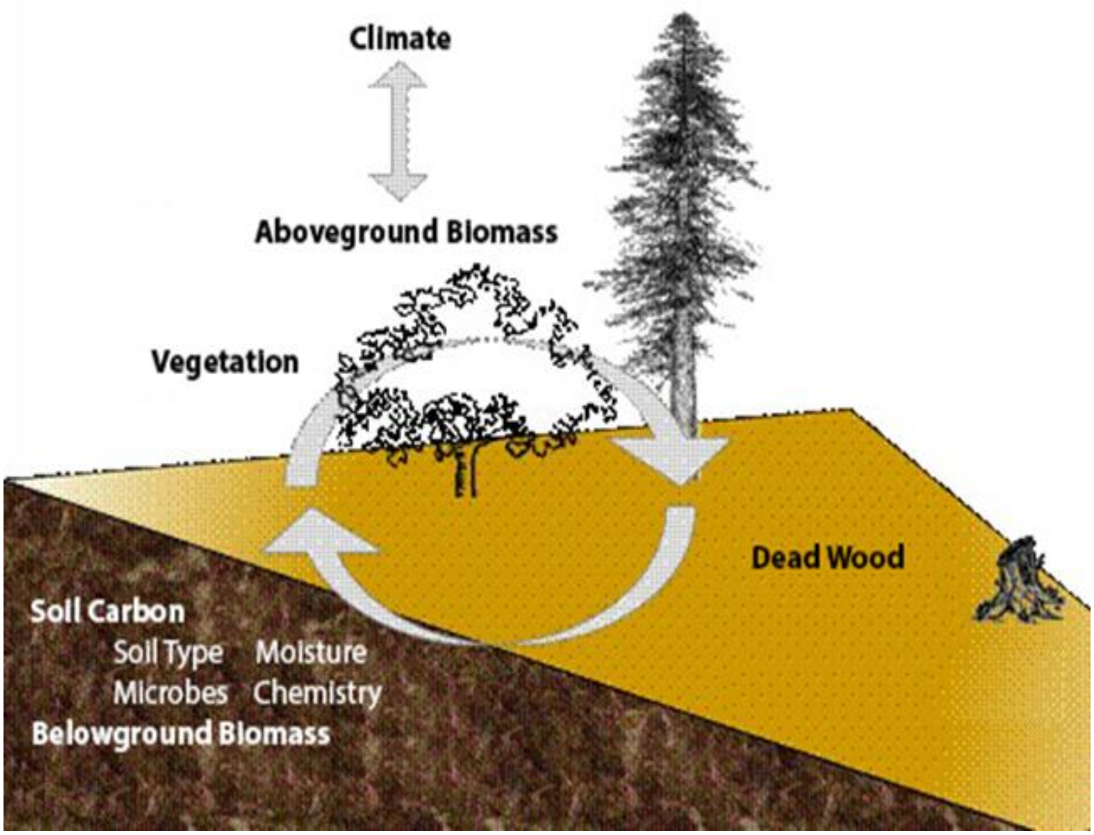


Figure 9. Carbon Cycle in InVEST

information of the amount of carbon stored by four carbon pools for each landuse and land cover category in Oregon can be found in the biophysical table attached with the model. Then the model quantifies the amount of carbon stored in different landscape categories such as wetlands, forests, and neighborhoods by accumulating the results for each pixel.

1.4 Monetization Model

Any discussion of sustainability barely attracts land owners' awareness without converting the ecological values into economic values. In general, the value of ecosystem service could be estimated by the unit value in providing ecosystem service and the number of units:

$$EcoSystem\_Service\_Value = Unit\_Value \times Units \; (Costanza\ et\ al\ 1997)$$

In this research, the amount of ecosystem services in stormwater purification and carbon storage are modeled in InVEST biophysical models. The conceivable monetary value of ecosystem services in purifying stormwater and storing carbon are estimated by the following equations:

$$wp\_value_x = \cos t(p) \times retained_x$$

$$cs\_value_x = price(c) \times carbon\_storage_x$$

wp_value_x is the value of watershed x in providing ecosystem services of water purification. *cost (p)* is the amount of money in need to treat one kilogram of pollutant. $retained_x$ is the amount of nutrition retained by watershed x. cs_value_x is the value of watershed x in providing ecosystem services of carbon storage. *price (c)* is the price of carbon per ton in carbon exchanged market. $carbon\_storage_x$ is the amount of carbon stored by watershed x. Previous studies reported that the average cost for the municipal stormwater treatment to remove one pound nitrogen and phosphorous are \$8.255 and \$55.225 respectively in 2007 (EPA 2007). The nitrogen and phosphorous retained by the ecosystem saves the City's stormwater treatment operation cost in purifying urban runoff. The monetary value of a ton of carbon storage equals the social damage avoided by not releasing the carbon into the air (Stern 2007). Computation of the carbon's social cost are controversial and complicated (Weitzman 2007 and Nordhaus 2007b). But Nordhaus (2007a) and Stern (2007) estimate the average value of carbon storage is \$345 per ton.

2. Data Collection

According to the modelling requirements of the InVEST water yield model, nutrition retention model and carbon storage and sequestration model, four categories of data are required to be collected and adjusted before running the model: climate data, geographic data, planning data and the biophysical attributes (see Table 4).

Climate data includes the city's annual precipitation and annual reference evapotranspiration from NOAA Climate Prediction Center. Geographic data includes the area of the stormwater basin, the digital elevation model (DEM) from USGS National Elevation Dataset, and the original land cover data. Planning data from the City of Corvallis Planning Department includes the raster data of land use and land cover in 2000, the predicted land use and land cover in 2020, the data showing the location of impervious surface (building footprint, road & driveway, sidewalk & path and parking lot) and parcel data. Biophysical data from InVEST Basic Data Package includes the evapotranspiration coefficient, nitrogen and phosphorus loading coefficient, nitrogen and phosphorus filtering coefficient, the amount of carbon stored in aboveground biomass, the amount of carbon stored in belowground biomass, the amount of carbon stored in soil and the amount of carbon stored in the dead organic body for each land use and land cover category. The land use and land cover data for the condition in 2000 is generated by overlaying the year 2000 zoning data from the City's planning department on the top of the 1990 land cover data provided by Pacific Northwest Ecosystem Research Consortium. The land use and land cover for the future condition is generated by overlaying the Comprehensive Plan with the 1990 original land cover data.

	Data Need	Source	Location	Format	Units
Climate Data	Preicipitation	NOAA- Climate Prediction Center	InVEST 3.2.0 Freshwater Input Data Package	GIS Raster --- GRID	Millimeter
	Reference Evapotranspiration	USGS-National Elevation Dataset	InVEST 3.2.0 Freshwater Input Data Package	GIS Raster --- GRID	Millimeter
Geographic Data	Stormwater Basin	City of Corvallis, OR	City of Corvallis --- GIS Data Download	GIS Vector --- Polygon	None
	Subwatershed	City of Corvallis, OR	City of Corvallis --- GIS Data Download	GIS Vector--- Polygon	None
	DEM (Digital Elevation Model 2013)	National Elevation Datebase	ned.usgs.gov/downloads.asp	GIS Raster --- GRID	Meter
	Plant Available Water Content	InVEST Basic Data	InVEST 3.2.0 Freshwater Input Data Package	GIS Raster --- GRID	None
	Root Restricting Layer Depth	InVEST Basic Data	InVEST 3.2.0 Freshwater Input Data Package	GIS Raster --- GRID	Millimeter
	Land Cover Data (1990)	Pacific Northwest Ecosystem Resea	InVEST 3.2.0 Freshwater Input Data Package	GIS Raster --- GRID	None
Planning Data	Land Use and Land Cover (LULC_Future)	City of Corvallis, OR	City of Corvallis --- Comprehensive Plan	GIS Vector --- Polygon	None
	Zoning Data	City of Corvallis, OR	City of Corvalllis --- Department of Planning	GIS Vector --- Polygon	None
	Impervious Surface	City of Corvallis, OR	City of Corvalllis --- Department of Planning	GIS Vector --- Polygon	None
	Parcel	Benton County, OR	Benton County, Oregon GIS Date Assessment	GIS Vector --- Polygon	None
Biophysical Data	Kc (Plant Evapotranspiration Coefficient	InVEST Basic Biophysical Table	InVEST 3.2.0 Freshwater Input Data Package	None	None
	Load_N and Load_P (Nutrient Loading for LULC)	InVEST Basic Biophysical Table	InVEST 3.2.0 Freshwater Input Data Package	None	Kg/Ha.Yr
	Efficiency_N and Efficiency_P (Vegetation Filtering for LULC)	InVEST Basic Biophysical Table	InVEST 3.2.0 Freshwater Input Data Package	None	Kg/Ha.Yr
	C_above (Amount of Carbon Stored in Aboveground Biomass)	InVEST Carbon Pools Table	InVEST 3.2.0 Carbon Input Data Package	None	Mg/Ha
	C_below (Amount of Carbon Stored in Belowground Biomass)	InVEST Carbon Pools Table	InVEST 3.2.0 Carbon Input Data Package	None	Mg/Ha
	C_soil (Amount of Carbon Stored in Soil)	InVEST Carbon Pools Table	InVEST 3.2.0 Carbon Input Data Package	None	Mg/Ha
	C_Dead (Amount of Carbon Stored in Dead Body)	InVEST Carbon Pools Table	InVEST 3.2.0 Carbon Input Data Package	None	Mg/Ha

Table 4. Data Collection, Formatting and Manipulation

3. Scenarios Design

Based on the City's Comprehensive Plan, the entire stormwater basin is divided into three zones: the area within the City Limit; the area between the City Limit and the Urban Growth Boundary (Urban Fringe); and the area outside the Urban Growth Boundary (see Figure 4). This research quantifies these three zones' ability to provide ecosystem services in stormwater purification and carbon storage in both the years of 2000 and 2020 under the City's current planning policy. There are six results generated from the model showing how many nutrients in stormwater are retained and how much carbon is stored in these three areas in 2000 and 2020. The scenario of the year of 2000 is based on the land use and land cover data as the baseline. The scenario of the year of 2020 is projected results from the InVEST model based on the proposed future land use and land cover in the Comprehensive Plan.

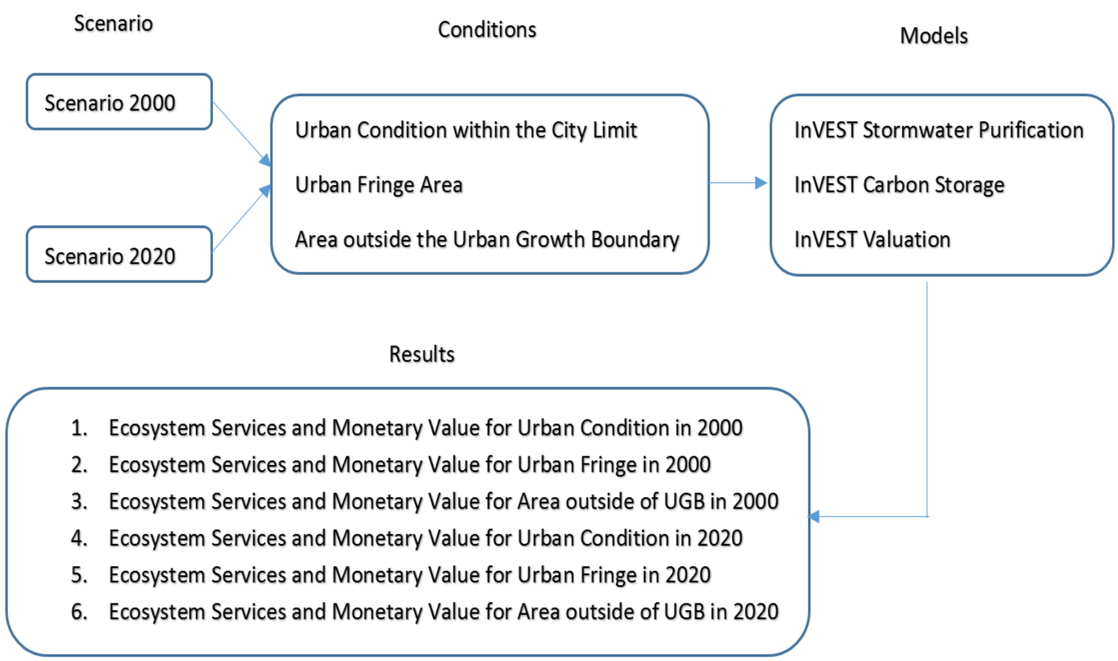


Figure 10. Research Flow Chart

Figure 10 shows the research processes. Result 1 and Result 4 are used to compare the city's overall ability to provide urban ecosystem services respectively in 2000 and 2020. If Result 4 is bigger than Result 1, it indicates that Corvallis's development under the urban growth management plan from 2000 to 2020 enables the city to provide more urban ecosystem services in stormwater purification and carbon storage in 2020. Otherwise, the current urban growth management policy needs to be revised and more urban green space is necessary in terms of providing more ecosystem services to the city. Besides, with the assistance of the city's impervious surface data, Result 1 is used to explore the correlations between the ecological monetary value and the size of different impervious surfaces. Result 2 and Result 5 are used to calculate the ecosystem services of stormwater purification and carbon storage provided by the urban fringe area in 2000 and 2020. The results show how much ecosystem services would be depleted from 2000 to 2020 because of the city's sprawl. Comparison of the ecosystem service depletion from 2000 to 2020 with the city's historical periods indicate whether or not the current planning policy slows the ecosystem service loss trend. Result 3 and Result 6 quantify the ecosystem services provided by the area outside urban growth boundary but within the stormwater basin. An effective urban growth boundary conserves the land of high ecological values and directs urbanization into the land of low ecological value. Comparing Result 2 with Result 3, if the ecosystem service per unit (ESPU) of urban fringe area under the Comprehensive Plan is higher than the ESPU of the area outside urban growth boundary but within the stormwater basin, it indicates that the urban growth boundary encompasses the land that has high ecological values into the area to be developed in future. Therefore the urban growth boundary is not performing well in environmental conservation and a new one needs to be delineated.

Chapter 5

Results and Discussion

1. Urbanization Impacts on Environment.

1.1 Land use and Land Cover Changes

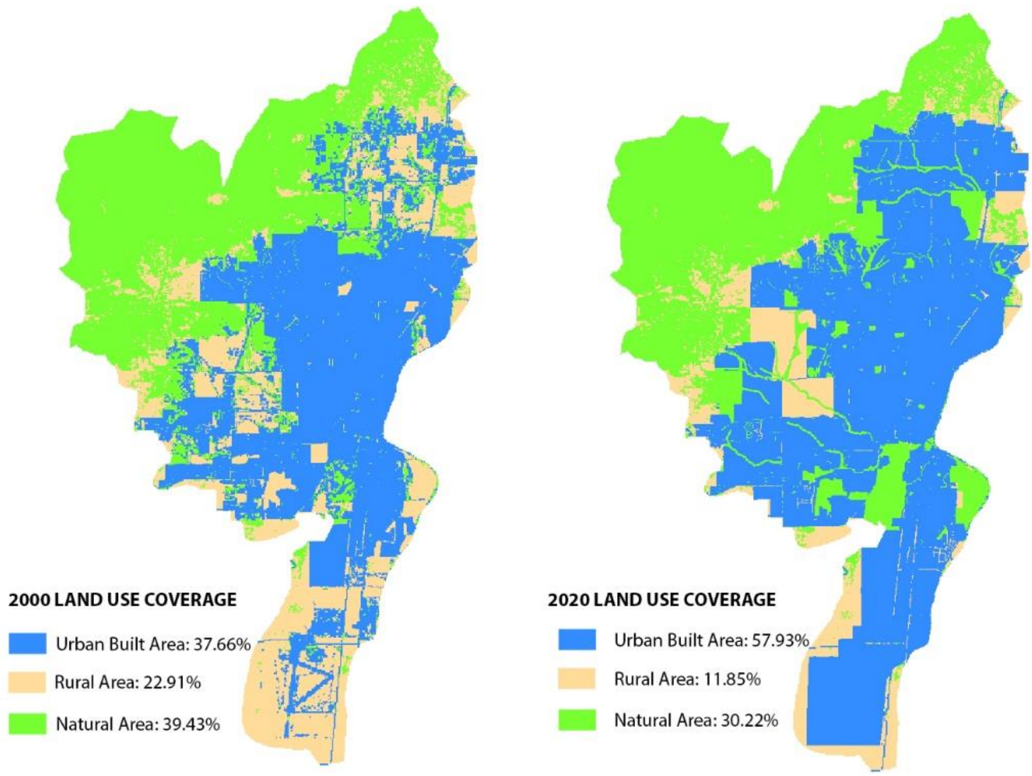


Figure 11. Projected Land Use Changes

Figure 11 shows the land use coverage changes from 2000 to 2020. All the land use and land cover are reorganized and summarized into the categories of the urban built area, the rural area and the natural area. Based on the current Comprehensive Plan, the total built area coverage increases from 37.66% to 57.93%. The rural area drops from 22.91% to 11.85% and the natural area drops from 39.43% to 30.22%. The rural land is urbanized faster than the natural land due to its proximity to the city limit and compactness in the urban fringe areas.

Table 5 shows the land use and land cover change from 2000 to 2020 in detail. The total built area increases by nearly 60%, while the rural area and the natural area drop by 45% and 24% respectively in the period of 2000 to 2020. In the urban built area, the mix-used of residential and commercial area increases by nearly 300% followed by the high density residential area (Residential area > 16DU/AC) increasing by more than 200%. In the rural area the double cropping area and the bare/fallow decrease most over 90%. In the natural area, turfgrass and marsh decrease most by 73.73% and 58.37% respectively.

From the above analysis, it is apparent that during the urbanization process, rural area and natural area are converted into urban built area. Most of the urbanization from 2000 to 2020 are planned in the Urban Fringe. Table 6 shows the land use and land cover changes in Urban Fringe. In 2000, the urbanization's coverage in Urban Fringe is 36.04%, which is lower than the average urbanization in the entire watershed. However, the urbanization in 2020 is predicted to be more than 76.88%, which is much higher than the predicted urbanization percentage across the entire watershed. Correspondingly, in 2020 the rural area's coverage decreases from 38.64% to 12.11% and the natural area's coverage decreases from 25.32% to 11.01%. In the new urban built area, the residential area accounts for 68.40%; the commercial area accounts for 23.81%; and the industrial area accounts for 18.75%.

Land Use and Land Cover	2000 Area Size (m^2)	2020 Area Size (m^2)	Difference (m^2)	Difference (%)	Land Use and Land Cover	2000 Area Size (m^2)	2020 Area Size (m^2)	Difference (m^2)	Difference (%)
Residential Area 0-4 DU/ac	18,217,920	27,214,986	8,997,066	49.39%	Late field crop	257,605	83,885	-173,720	-67.44%
Residential Area 4-9 DU/ac	7,240,564	12,980,102	5,739,538	79.27%	Pasture	5,485,684	6,221,708	736,024	13.42%
Residential Area 9-16 DU/ac	1,789,908	5,272,835	3,482,927	194.59%	Irrigated perennial	848,828	228,561	-620,267	-73.07%
Residential Area >16 DU/ac	1,255,077	3,998,298	2,743,221	218.57%	Bare/fallow	1,850,692	99,064	-1,751,628	-94.65%
Commercial	3,259,964	9,416,538	6,156,574	188.85%	**Rural Area**	**26,001,813**	**13,985,588**	**-12,016,225**	**-46.21%**
Industrial Area	5,252,088	8,398,251	3,146,163	59.90%	Upland Forest open	33,300	33,300	0	0.00%
Residential and Commercial	77,403	305,235	227,832	294.35%	Upland Forest Semi-closed mixed	127,800	127,800	0	0.00%
Urban non-vegetated unknown	4,226,625	587,750	-3,638,875	-86.09%	Forest Closed hardwood	9,662,640	6,709,262	-2,953,378	-30.56%
Urban tree overstory	1,418,452	175,987	-1,242,465	-87.59%	Forest Closed mixed	12,376,406	11,035,070	-1,341,336	-10.84%
Urban Built Area	**42,738,001**	**68,349,982**	**25,611,981**	**59.93%**	Upland Forest Semi-closed conifer	30,600	30,600	0	0.00%
Hybrid poplar	29,700	10,669	-19,031	-64.08%	Conifers 0-20 yrs	554,400	554,400	0	0.00%
Grass seed rotation	4,954,779	4,129,224	-825,555	-16.66%	Forest closed conifer 21-40 yrs	644,649	621,450	-23,199	-3.60%
Grains	735,298	622,594	-112,704	-15.33%	Forest closed conifer 41-60 yrs.	3,803,986	3,662,195	-141,791	-3.73%
Berries & Vineyards	244,592	93,523	-151,069	-61.76%	Forest closed conifer 61-80 yrs	2,792,671	2,631,807	-160,864	-5.76%
Double cropping	102,820	5,156	-97,664	-94.99%	Forest closed conifer 81-200 yrs	3,655,619	3,341,729	-313,890	-8.59%
Hops	900	900	0	0.00%	Forest closed conifer older than 200 yrs	315,900	289,572	-26,328	-8.33%
Mint	15,358	3,136	-12,222	-79.58%	Upland Forest Semi-closed hardwood	242,100	242,100	0	0.00%
Row crop	939,661	196,585	-743,076	-79.08%	Natural grassland	1,454,188	606,359	-847,829	-58.30%
Grass	3,764,915	497,106	-3,267,809	-86.80%	Natural shrub	7,043,152	4,472,414	-2,570,738	-36.50%
Burned grass	34,920	4,050	-30,870	-88.40%	Flooded/marsh	181,481	75,550	-105,931	-58.37%
Field crop	4,234,242	767,409	-3,466,833	-81.88%	Turfgrass	691,337	185,741	-505,596	-73.13%
Hayfield	2,501,819	1,022,018	-1,479,801	-59.15%	Orchard	312,622	297,573	-15,049	-4.81%
Late field crop	257,605	83,885	-173,720	-67.44%	Christmas trees	770,026	691,543	-78,483	-10.19%
Pasture	5,485,684	6,221,708	736,024	13.42%	Conifer Woodlot	46,800	43,588	-3,212	-6.86%
Irrigated perennial	848,828	228,561	-620,267	-73.07%	**Natural Area**	**44,739,677**	**35,652,053**	**-9,087,624**	**-20.31%**
Bare/fallow	1,850,692	99,064	-1,751,628	-94.65%					

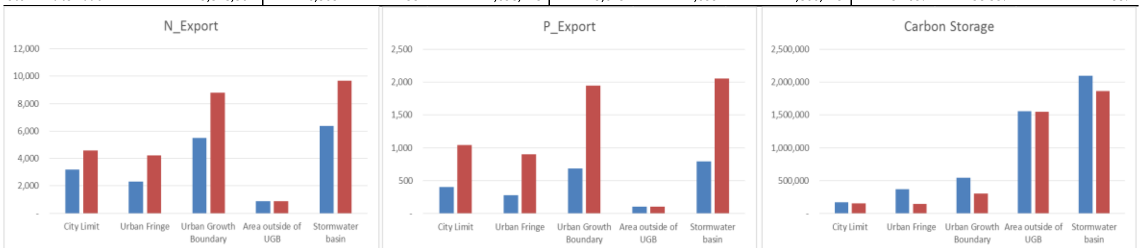
Table 5. Projected Land Use and Land Cover Change

Land Use and Land Cover	2000 Area Size (m^2)	2020 Area Size (m^2)	Difference (m^2)	Difference (%)	Land Use and Land Cover	2000 Area Size (m^2)	2020 Area Size (m^2)	Difference (m^2)	Difference (%)
Residential Area (0-4 DU/ac)	5,070,960	14969270	9,898,310	195.20%	Field crop	3,528,333	115771	-3,412,562	-96.72%
Residential Area (4-9 DU/ac)	3,727	714654	710,927	19075.05%	Hayfield	1,488,139	51859	-1,436,280	-96.52%
Residential Area (9-16 DU/ac)	13,502	1971664	1,958,162	14502.76%	Late field crop	79,269	759	-78,510	-99.04%
Residential Area (16 DU/ac)	10,367	1412815	1,402,448	13528.00%	Pasture	1,033,838	717452	-316,386	-30.60%
Commercial	174,693	4539409	4,364,716	2498.51%	Irrigated perennial	608,726	23164	-585,562	-96.19%
Commercial and Industrial Area	223,439	450279	226,840	101.52%	Bare/fallow	1,759,734	4616	-1,755,118	-99.74%
Industrial Area	150,001	3574845	3,424,844	2283.21%	**Rural Area**	**13,518,902**	**4,296,790**	**-9,222,112**	**-68.22%**
Urban non-vegetated unknown	3,660,352	117027	-3,543,325	-96.80%	Forest Closed hardwood	2,941,657	89631	-2,852,026	-96.95%
Light duty roads	1,103,757	93291	-1,010,466	-91.55%	Forest Closed mixed	1,351,314	38854	-1,312,460	-97.12%
Urban tree overstory	1,097,988	33306	-1,064,682	-96.97%	Forest closed conifer 21-40 yrs	24,491	1415	-23,076	-94.22%
Urban Built Area	**11,508,786**	**27876559.61**	**16,367,774**	**142.22%**	Forest closed conifer 41-60 yrs.	133,918	2523	-131,395	-98.12%
Rural structures	15,822	586	-15,236	-96.30%	Forest closed conifer 61-80 yrs	164,978	5020	-159,958	-96.96%
Rural non-vegetated unknown	58,868	3523	-55,345	-94.02%	Forest closed conifer 81-200 yrs	314,876	4033	-310,843	-98.72%
Hybrid poplar	19,122	46	-19,076	-99.76%	Forest closed conifer older than 200 yrs	27,014	642	-26,372	-97.62%
Grass seed rotation	842,711	20143	-822,568	-97.61%	Natural grassland	777,333	32604	-744,729	-95.81%
Grains	112,953	96	-112,857	-99.92%	Natural shrub	2,452,179	94711	-2,357,468	-96.14%
Berries & Vineyards	139,928	5177	-134,751	-96.30%	Flooded/marsh	100,407	6095	-94,312	-93.93%
Double cropping	94,530	1111	-93,419	-98.82%	Turfgrass	470,548	13050	-457,498	-97.23%
Mint	4,500	0	-4,500	-100.00%	Orchard	14,616	266	-14,350	-98.18%
Burned grass	30,858	0	-30,858	-100.00%	Christmas trees	81,850	4622	-77,228	-94.35%
Row crop	389,775	7986	-381,789	-97.95%	Conifer Woodlot	3,210	0	-3,210	-100.00%
Agriculture	0	3283969.211	3283969.211	None	Conservation Area	8,547,022	10957721	2,410,699	28.21%
Grass	3,311,796	60532	-3,251,264	-98.17%	**Natural Area**	**17,405,413**	**11251187**	**-6,154,226**	**-35.36%**

Table 6. Projected Land Use Change in Urban Fringe

1.2 Environmental Impacts

		2000			2020			Difference		
Area	Size (m^2)	N_Export (kg)	P_Export (kg)	Carbon Storage(Mg)	N_Export (kg)	P_Export (kg)	Carbon Storage (Mg)	N_Export (kg)	P_Export (kg)	Carbon Storage(Mg)
City Limit	41,246,847	3,195	405	172,445	4,585	1,039	157,234	43.54%	156.53%	-8.82%
Urban Fringe	33,164,041	2,297	282	372,010	4,210	906	150,270	83.28%	221.36%	-59.61%
Urban Growth Boundary	74,410,888	5,491	687	544,455	8,795	1,946	307,504	60.16%	183.13%	-43.52%
Area outside of UGB	44,937,479	872	107	1,553,993	880	109	1,553,225	0.95%	1.28%	-0.05%
Stormwater basin	119,348,367	6,363	795	2,098,448	9,675	2,055	1,860,729	52.05%	158.55%	-11.33%



Note: N_Export: Nitrogen Export; P_Export: Phosphorus Export
City Limit Results are from Model Result 1 and 4; Urban Growth Boundary Results are from Model Result 2 and 5; Area Outside of UGB results are from Model Result 3 and 6.

Table 7. Urbanization's Impacts on Environment in 2000 and 2020

Table 7 shows the urbanization's environmental impacts in the InVEST model. From 2000 to 2020, the City exports 52.05% more nitrogen and 158.55% phosphorous in stormwater, and stores 11.33% less carbon. The area within the City Limits exports 43.54% more nitrogen, 156.53% more phosphorous and 8.82% less carbon. All of these indicators are less than the average difference across the entire stormwater basin, which implies that urbanization process within the city limit tends to be slower from 2000 to 2020. However, in the Urban Fringe, 83.23% more nitrogen and 221.36% more phosphorous are exported into stormwater, and 59.61% less carbon are stored in this area. All of these three indicators are much higher than the average difference across the entire watershed and implies that the urbanization in Urban Fringe has more impacts on the environmental quality from 2000 to 2020.

According to the current Comprehensive Plan, 8,768 acres land are under urbanization, due to which, the entire storm basin is projected to export 3,312kg more nitrogen and 1,260kg more phosphorous, and store 237,719Mg less carbon. On average, one acre more urbanization results in 0.38kg more nitrogen, 0.14kg more phosphorous in the urban runoff, and 27.11Mg less carbon stored in the watershed. In order to render those numbers more meaningful, this research models the City's historical urbanization process and the corresponding environmental impacts (see Figure 12). The first parcel was built in 1853, and until 1998, there had been 14,885 parcels with the total area size of 9,229 acres. The map series divide the City's growth history into 10 periods of 16 years each and quantifies the City's impacts on stormwater quality and carbon storage from 1853 to 1988. Table 8 and Figure 13 describe urbanization's impact on stormwater quality and carbon storage in each period.

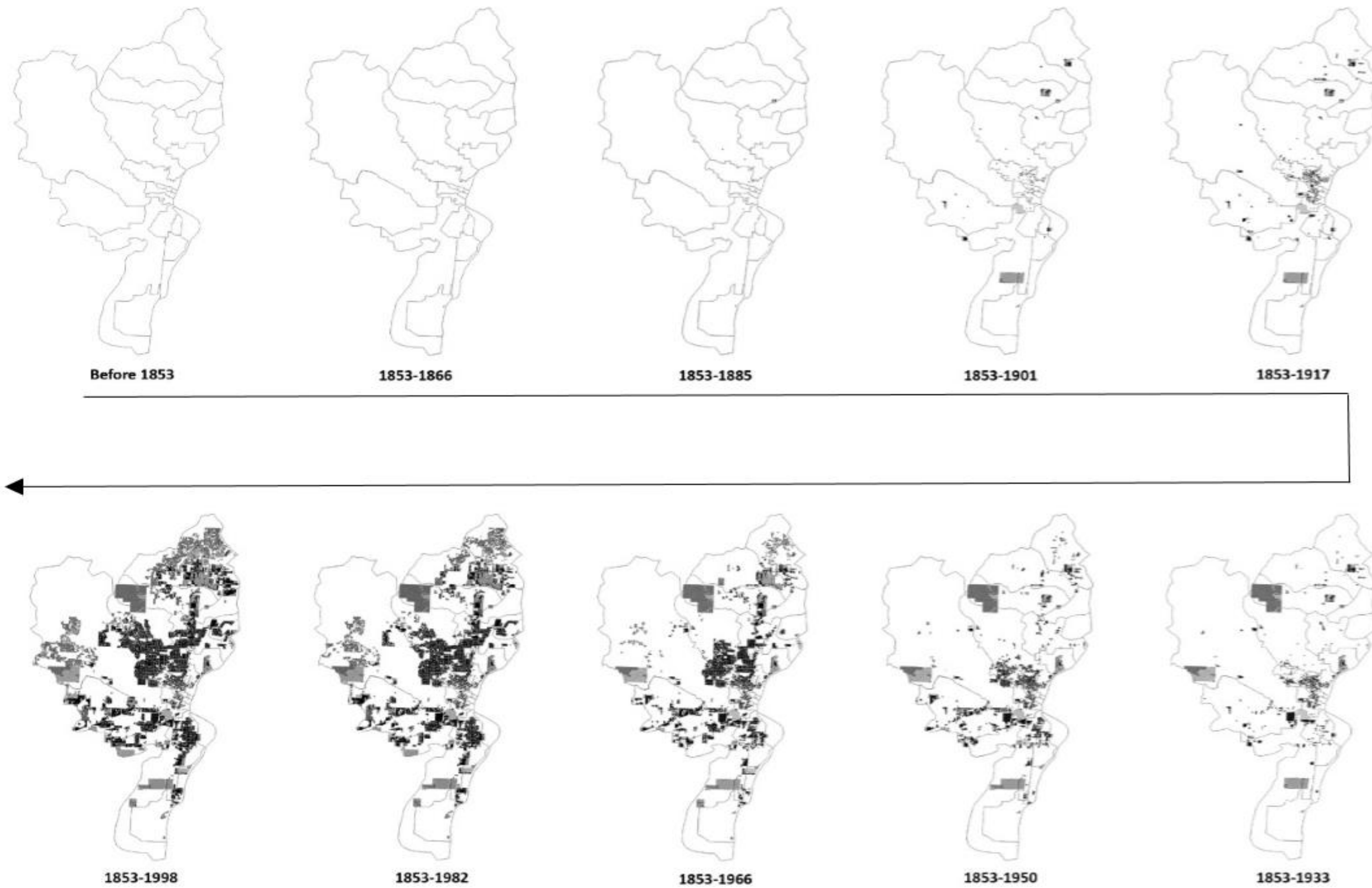


Figure 12. The City's Urbanization History from 1853 to 1998

Period	Time	Total Parcel Size (Acre)	Urbanization Size (Acre)	N_Export_Differnece (Kg)	P_Export_Difference (Kg)	Carbon_Storage_Difference (Mg)	Carbon Lost (Mg/Acre)	P_Export (Kg/Acre)	N_Export (Kg/Acre)
1	Before 1853	0	0	None	None	None	None	None	None
2	1853-1869	3.37	3.37	0.29	0.05	-226.35	-67.17	0.01	0.09
3	1869-1885	15.21	11.84	1.60	0.34	-1057.98	-89.36	0.03	0.14
4	1885-1901	450.79	435.58	109.46	15.73	-46378.11	-106.47	0.04	0.25
5	1901-1917	619.04	168.25	66.56	13.60	-19566.19	-116.29	0.08	0.40
6	1917-1933	1963.53	1344.49	145.75	23.40	-16978.27	-12.63	0.02	0.11
7	1933-1950	2743.49	779.96	289.16	29.54	-83384.29	-106.91	0.04	0.37
8	1950-1966	4351.76	1608.27	560.81	47.43	-154578.15	-96.11	0.03	0.35
9	1966-1982	6441.71	2089.95	612.75	41.75	-142850.44	-68.35	0.02	0.29
10	1982-1998	8021.99	1580.28	358.10	29.20	-100747.00	-63.75	0.02	0.23

Note: N_Export_Difference: Nitrogen Export Difference with the Previous Period; P_Export_Difference: Phosphorus Export Difference with the Previous Period; N_Export: Nitrogen Export; P_Export: Phosphorus Export.

Table 8. Urbanization's Impacts on Environment in the Historical Periods

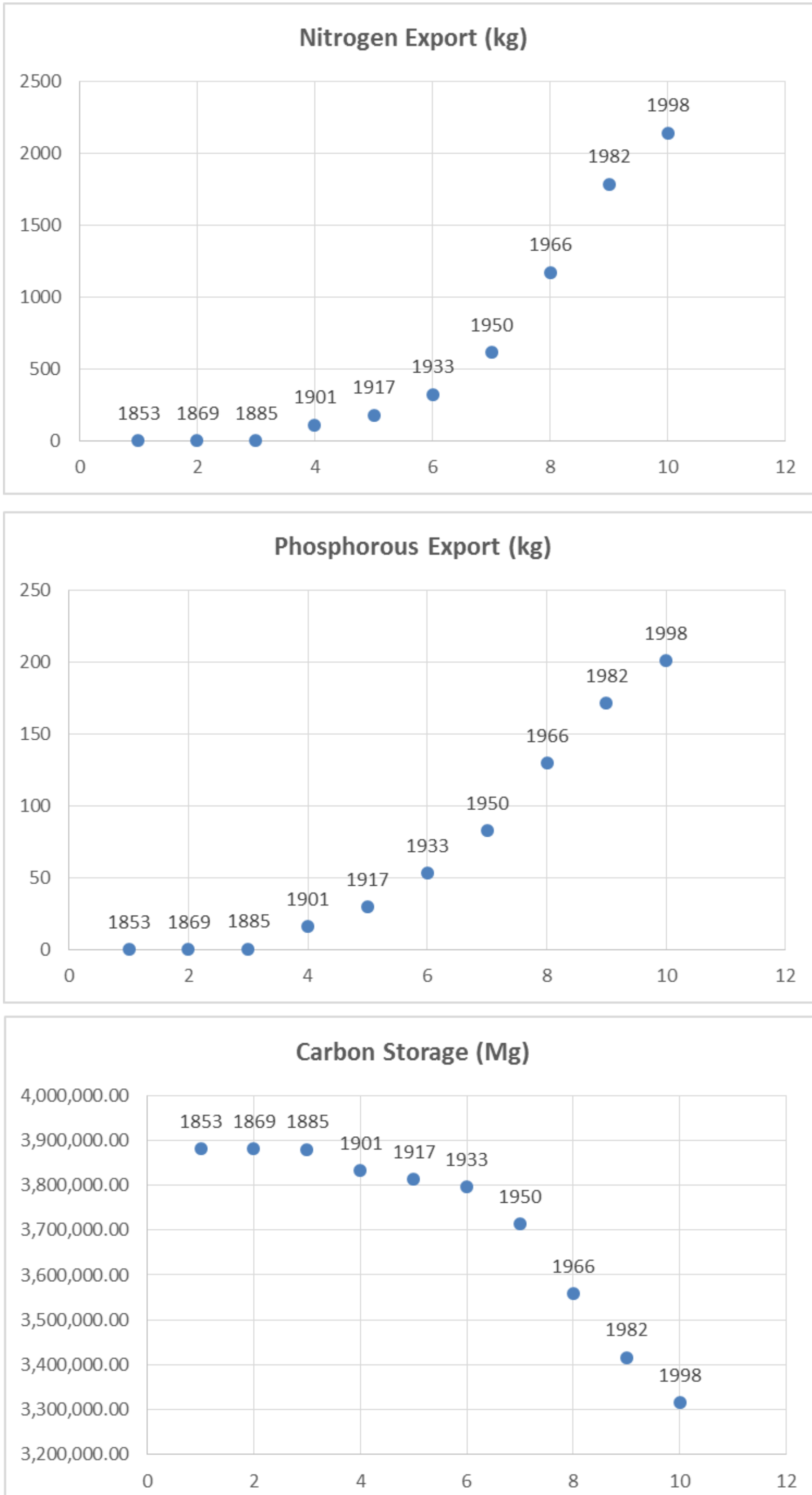
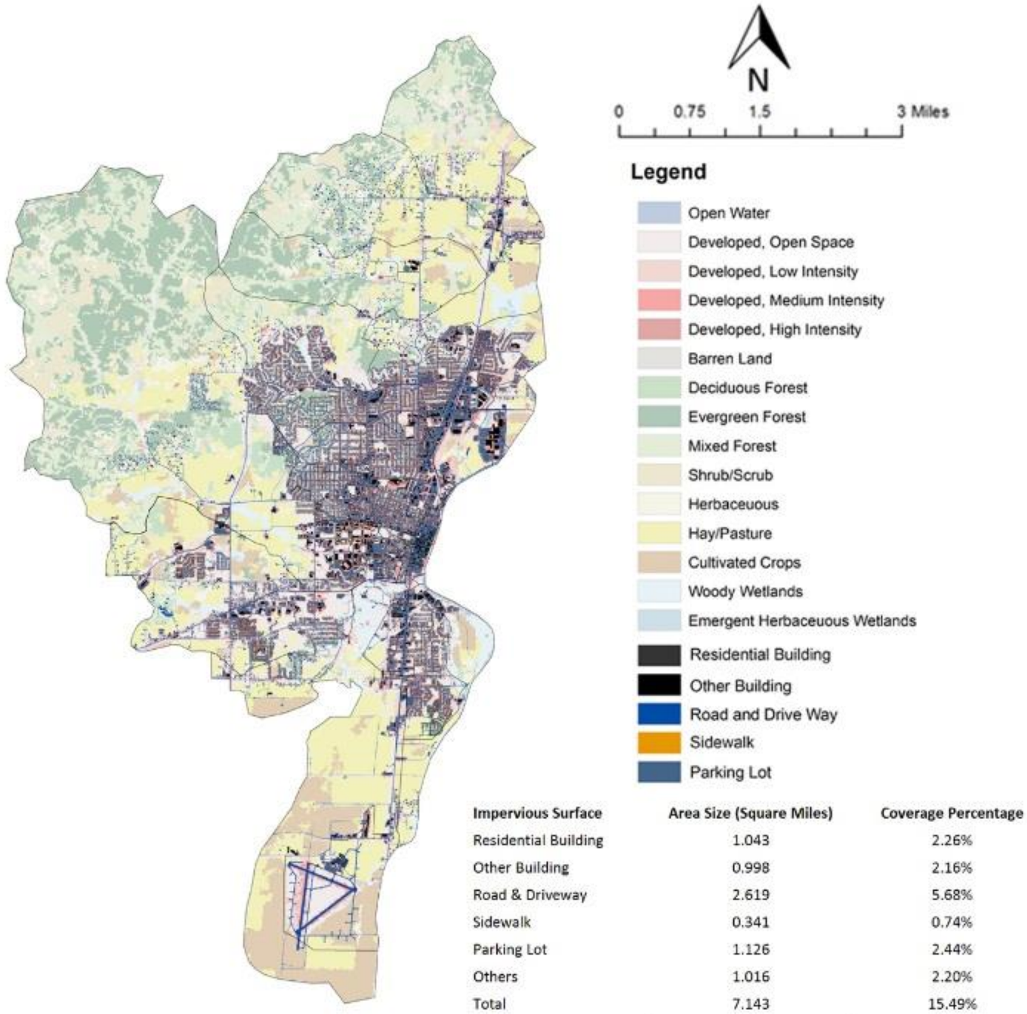


Figure 13. Urbanization Impacts Change through History



Impervious Surface	Area Size (Square Miles)	Coverage Percentage
Residential Building	1.043	2.26%
Other Building	0.998	2.16%
Road & Driveway	2.619	5.68%
Sidewalk	0.341	0.74%
Parking Lot	1.126	2.44%
Others	1.016	2.20%
Total	7.143	15.49%

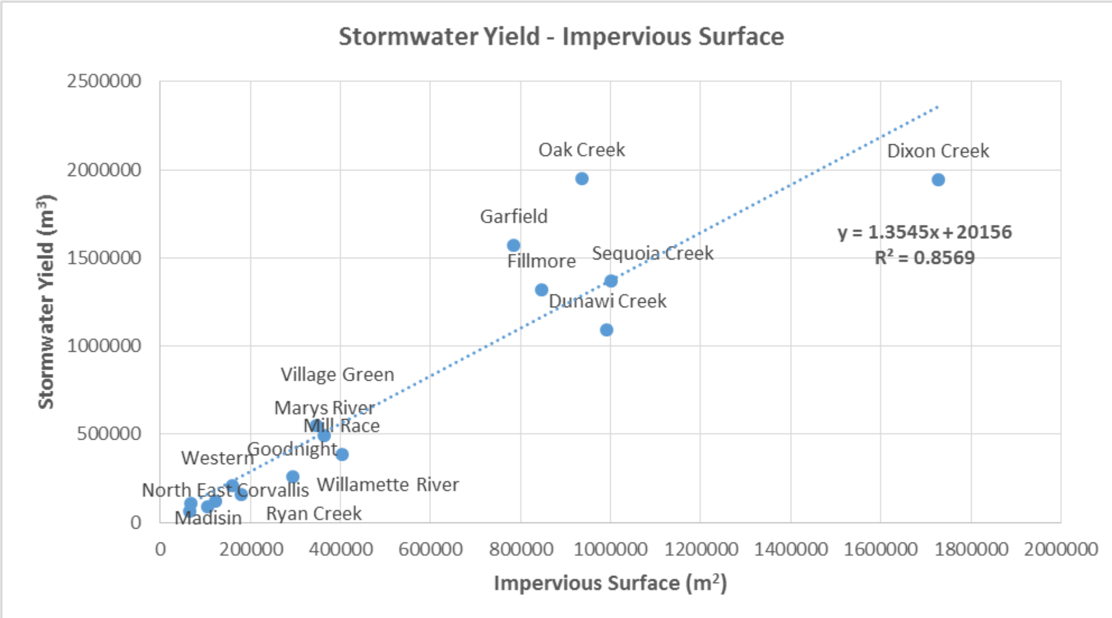
Figure 14. Land Use and Impervious Surface in 2013

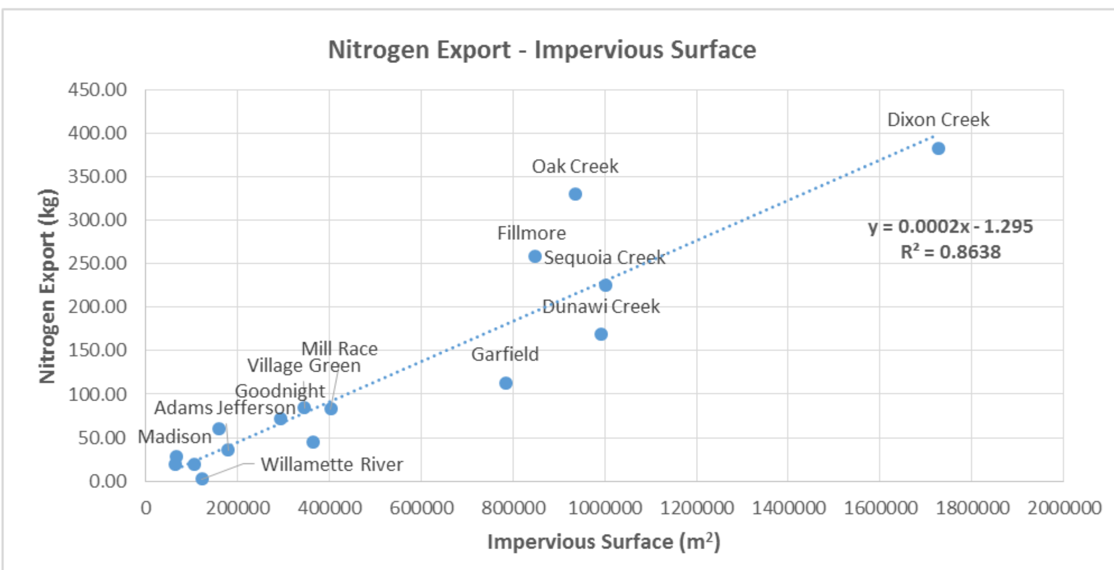
Comparing the results of the 2000-2020 period and the historical periods, it is apparent that the urbanization speed from 2000 to 2020 is faster than any previous historical period. Under the current urban growth management strategies, the carbon storage loss is 1.36 Mg/acre per year, which is lower than the historical mean and median. However, the nitrogen export and the phosphorous export rates are 0.019 kg/acre per year and 0.012kg/acre per year respectively, both of which are higher than the historical mean and median. Based on this point, it is indicated that the current urban growth management strategies are effective in conserving the watershed's capacity in storing carbon, but it does not restrain the City's trend in exporting more nitrogen and phosphorus through stormwater.

By 2013, the impervious surface had covered 15% of the total watershed (see Figure 14). Table 9 quantifies the urbanization in each of the urban subwatersheds and the impacts on stormwater quality and carbon storage.

Subwatershed	Size (m^2)	Impervious Surface (m^2)	Water Yield (m^3)	N_Export (Kg)	P_Export (Kg)	Carbon Storage (Kg/m^2)
Madison	122,256	64,900	64,646	19.02	4.79	0.79
North East Corvallis	198,944	66,963	107,830	28.66	0.13	7.97
Ryan Creek	433,500	105,218	91,958	19.00	1.54	1.53
Willamette River	1,484,024	122,755	119,998	2.34	5.94	0.29
Western	322,656	159,313	206,306	60.46	17.15	0.18
Adams Jefferson	311,284	180,209	161,962	35.63	8.63	0.37
Goodnight	1,046,235	295,140	260,044	71.39	13.15	0.37
Village Green	1,380,910	346,265	547,453	84.52	6.97	3.58
Marys River	4,382,426	365,331	492,204	44.96	14.78	0.70
Mill Race	1,035,187	402,905	388,128	82.88	27.59	0.35
Garfield	2,667,933	785,724	1,574,385	113.22	127.78	0.35
Fillmore	1,860,058	847,150	1,322,679	258.20	50.04	1.28
Oak Creek	4,626,694	936,829	1,952,547	329.90	96.87	0.51
Dunawi Creek	6,608,441	992,107	1,093,824	168.82	34.57	1.30
Sequoia Creek	3,082,048	1,001,361	1,369,330	224.89	52.18	2.74
Dixon Creek	7,337,605	1,726,488	1,945,099	382.99	45.09	1.99

Table 9. Urbanization's Impacts on Environment for Subwatersheds in 2013





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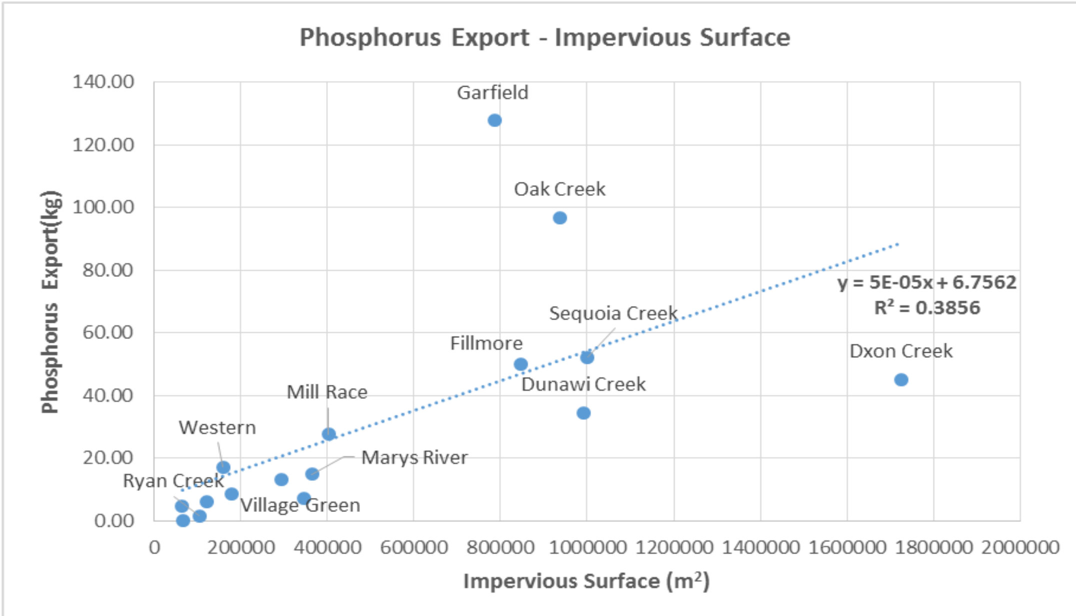


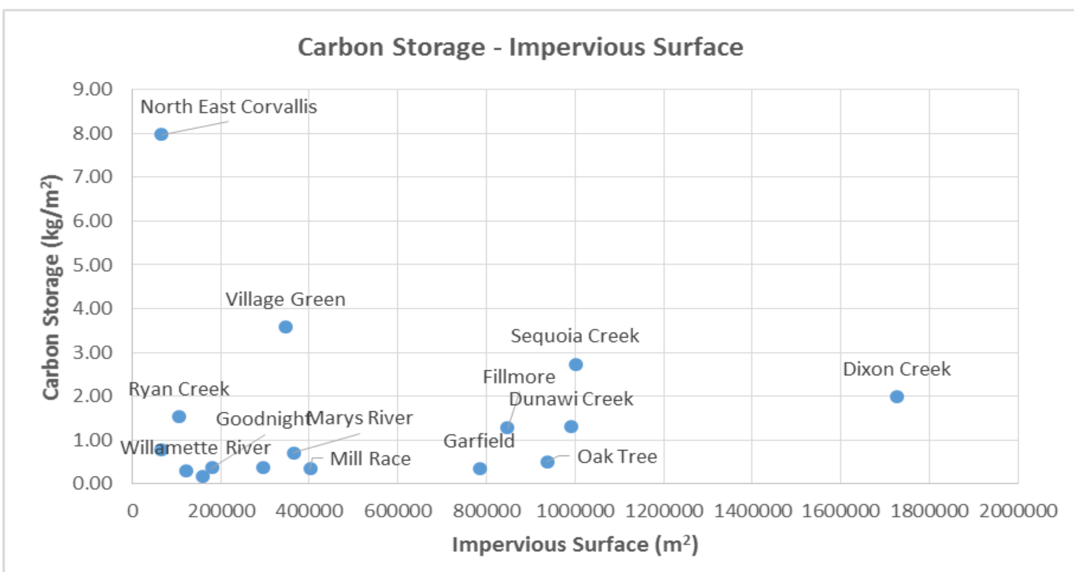


Figure 15. Relationship between Impervious Surface and Urbanization Impacts on Environment in 2013

Through statistical analysis, it is found that urban water yield and nitrogen export are strongly related to the extent of impervious surface. The phosphorus export is also related to impervious extent, but it is not as strong as urban water yield and nitrogen. There is no evident relationship existing between carbon storage and impervious surface (see Figure 15).

2. Ecosystem Service Conservation and Values

2.1 Ecosystem Service Conservation

The ecosystem services provided by the different zones in the entire stormwater basin in purifying stormwater and storing carbon in 2000 are given in Table 10. According to the Land Conservation Act (LCA), a sustainable urban growth plan should conserve the land providing high ecosystem services and direct urban development onto the land that provides less ecosystem services. Therefore an efficient urban growth management strategy for environmental conservation should conserve the land providing high ecosystem services outside an urban growth boundary and delineate the land providing least ecosystem services within the urban fringe area for future urban development (ODLCD 2010).

Zone	Size (m^2)	N_Retention (Kg)	P_Retention (Kg)	Carbon Storage(Mg)	N_R_Rate (g/m^2)	P_R_Rate (g/m^2)	C_R_Rate (kg/m^2)
Urban Area	41,246,847	15,978	2,931	172,445	0.3874	0.0710	4.1808
Urban Fringe	33,164,041	16,507	2,327	372,010	0.4977	0.0702	11.2173
Urban Growth Boundary	74,410,888	32,485	5,258	544,455	0.4366	0.0707	7.3169
Area outside of UGB	41,838,404	15,073	1,255	1,553,993	0.3354	0.0279	34.5812
Stormwater basin	116,249,292	47,558	6,513	2,098,448	0.3985	0.0546	17.5825

Note: N_Retention (Kg): Nitrogen Retention (Kg); P_Retention (Kg): Phosphorus Retention (Kg); N_R_Rate (g/m^2): Nitrogen Retention Rate (g/m^2); P_R_Rate (g/m^2): Phosphorus Retention Rate (g/m^2); C_R_Rate (kg/m^2): Carbon Storage Rate (kg/m^2).

Table 10. Ecosystem Service Provided by Different Zones in 2000

The City's current urban growth management divides into the zone within the City Limit, the Urban Fringe area between the City Limit and the UGB, and the zone outside of the UGB. The zone within the City Limit is where urbanization had been happening since 2000. The Urban Fringe is the zone projected to receive most of the urbanization from 2000 to 2020. The zone outside the UGB is where the current urban growth management policy attempts to conserve ecosystem services. After quantifying the ecosystem services provided by those three different zones, it is found that the zone outside the UGB has a greater efficacy in storing carbon than the Urban Fringe. However the Urban Fringe zone has a higher ecological value in purifying stormwater than the zone outside the UGB (see Table 10 and Figure 16 to 18). Based on this analysis, a conclusion is drawn that the current urban growth management strategy conserves the land of high ecological value in carbon storage, but does not protect the land of high ecological value for stormwater purification.

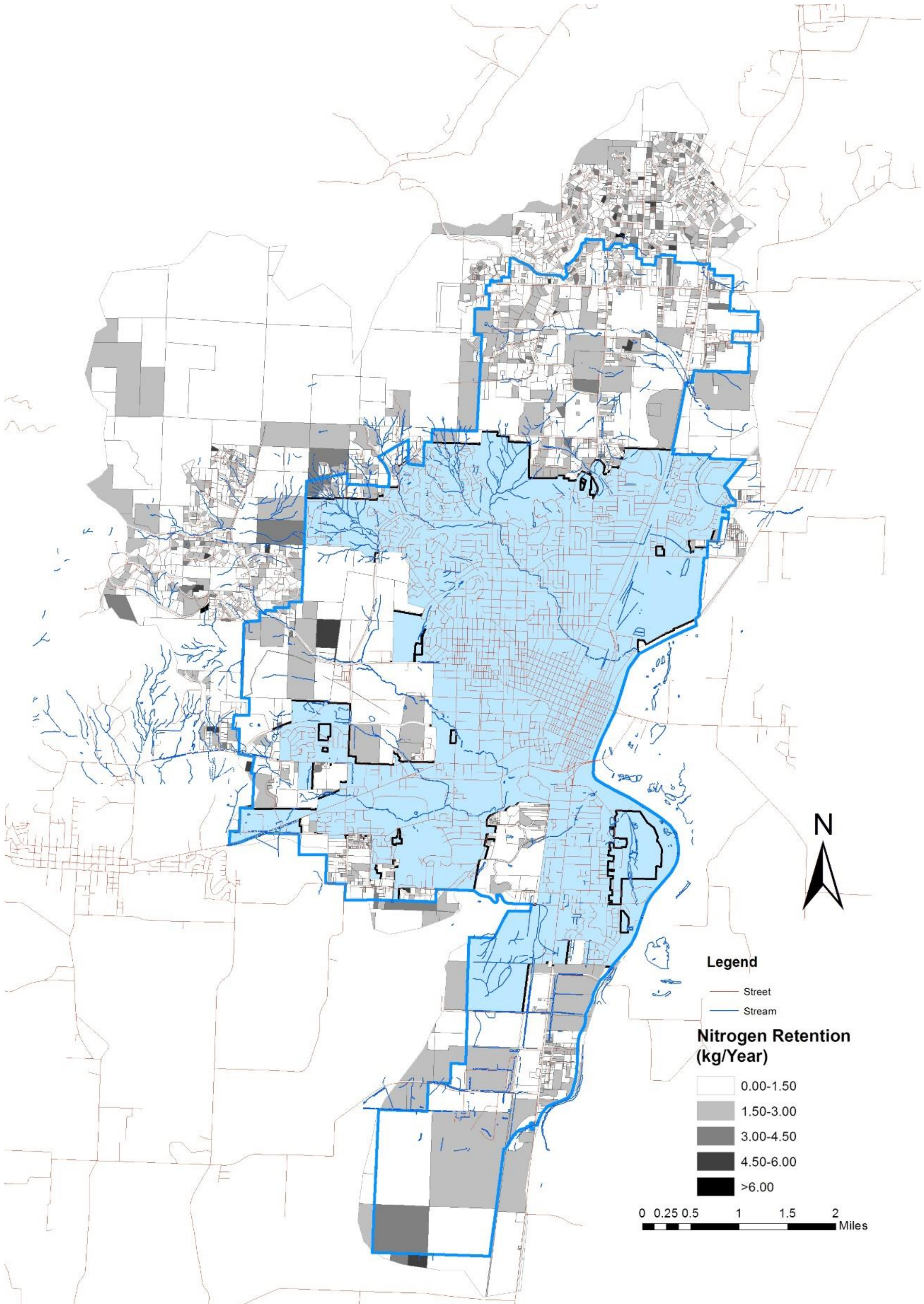


Figure 16. Nitrogen Retention on the Parcel Level

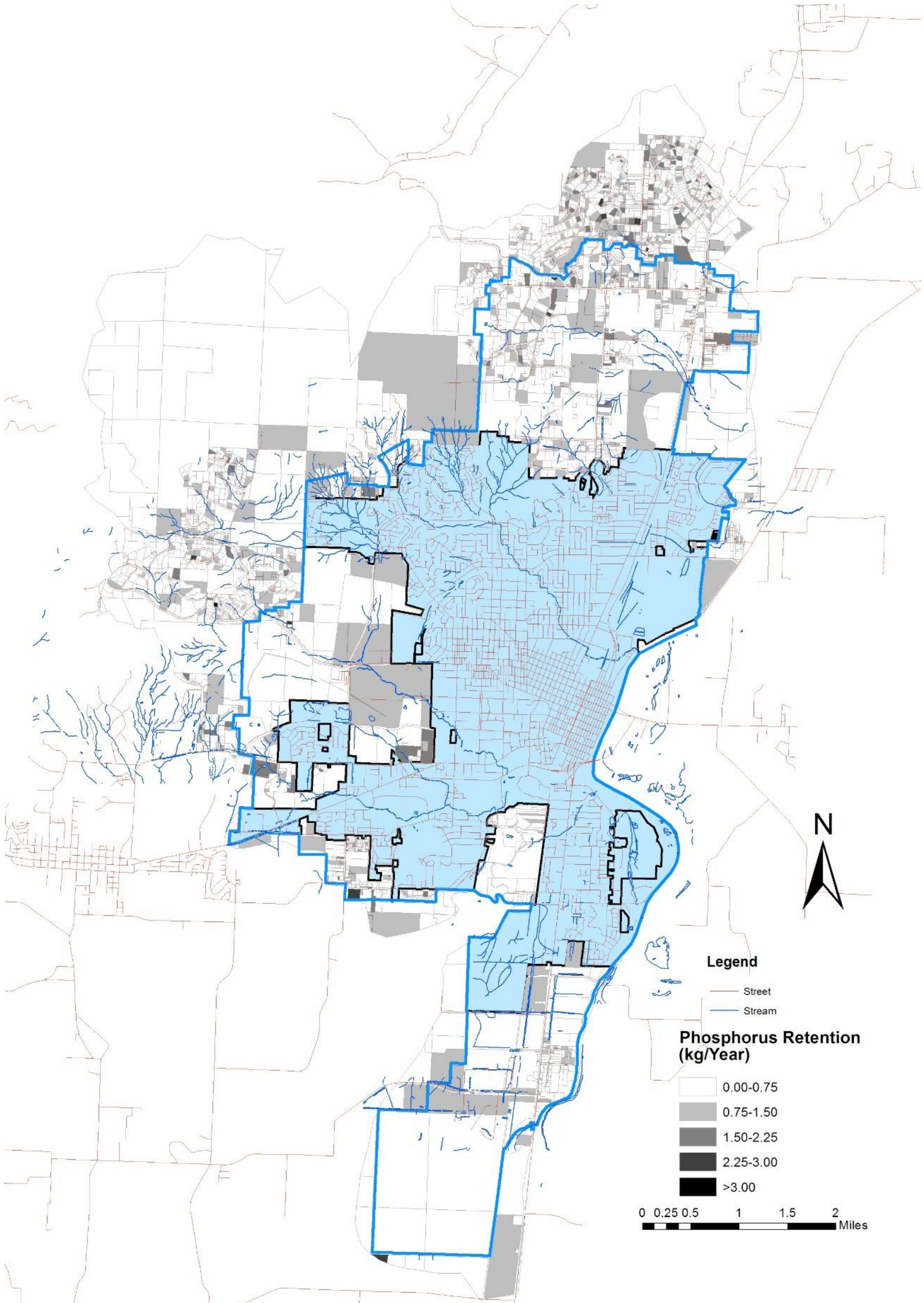


Figure 17. Phosphorus Retention on the Parcel Level

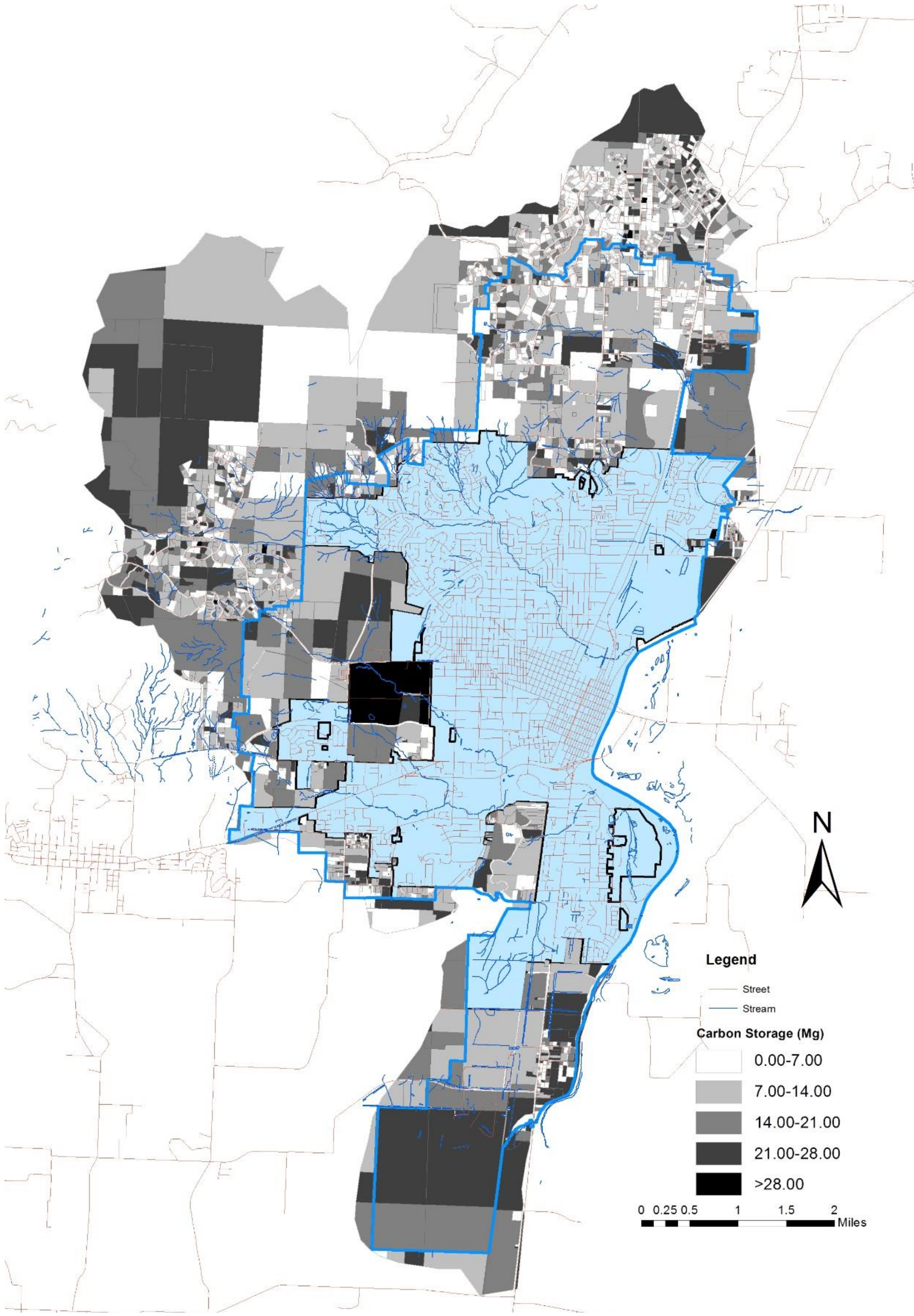


Figure 18. Carbon Storage on the Parcel Level

Zoning	Area Size	C_Storage (Mg)	N_Retention (kg)	P_Retention (kg)	C_S_R (kg/m²)	N_R_R (g/m2)	P_R_R (g/m²)
RS-3.5 (Low Density)	9171767	78792.47	3936.81	17.28	8.5908	0.4292	0.0019
RS-5 (Low Density)	2662023	9960.59	1251.29	154.27	3.7417	0.4701	0.0580
RS-6 (Low Density)	1749044	8602.32	779.98	105.69	4.9183	0.4459	0.0604
RS-9 (Medium Density)	3093442	8576.61	1400.94	211.69	2.7725	0.4529	0.0684
RS-12 (Medium-high Density)	1433476	1401.78	706.23	114.33	0.9779	0.4927	0.0798
RS-20 (High Density)	1037959	26.95	527.27	89.05	0.0260	0.5080	0.0858
MUR (Mixed Use)	36885	29.51	17.77	2.81	0.8001	0.4817	0.0761
Residential Area	**19184596**	**107390.22**	**8620.29**	**695.11**	**5.5977**	**0.4493**	**0.0362**
P-AO (Office Zone)	290761	3.70	246.75	52.34	0.0127	0.8486	0.1800
NC (Neighborhood Center)	464832	978.78	155.36	36.93	2.1057	0.3342	0.0795
RF (Riverfront)	35460	0.33	23.23	5.03	0.0093	0.6551	0.1419
CB (Central Business)	405934	4.27	300.23	64.81	0.0105	0.7396	0.1597
MUCS (Community Shopping)	754483	630.73	143.45	146.01	0.8360	0.1901	0.1935
MUGC (General Commercial)	182538	123.53	28.65	32.71	0.6767	0.1570	0.1792
Commercial and Office Area	**2134008**	**1741**	**898**	**338**	**0.8160**	**0.4207**	**0.1583**
MUT (Transitional Zone)	169889	0.78	29.24	32.55	0.0046	0.1721	0.1916
LI-O (Industrial - Office)	241895	0.36	15.92	54.76	0.0015	0.0658	0.2264
LI (Limited Industrial)	45535	0.09	3.91	10.08	0.0019	0.0858	0.2214
GI (General Industrial)	3206262	62.10	249.94	717.22	0.0194	0.0780	0.2237
II (Intensive Industrial)	319973	1.02	17.28	64.36	0.0032	0.0540	0.2011
RTC (Research Technology)	383820	58.45	176.92	69.42	0.1523	0.4609	0.1809
MUE (Employment Zone)	283247	53.90	45.10	57.22	0.1903	0.1592	0.2020
Industrial Area	**4650621**	**176.69**	**538.31**	**1005.61**	**0.0380**	**0.1157**	**0.2162**
OSU (Oregon State University)	2145201	746.88	1752.34	368.86	0.3482	0.8169	0.1719
AG-OS (Agriculture - Open Space)	2475966	14246.00	881.47	53.16	5.7537	0.3560	0.0215
Others	**4621167**	**14992.88**	**2633.81**	**422.03**	**3.2444**	**0.5699**	**0.0913**

Note: C_Storage (Mg): Carbon Storage (Mg); N_Retention (kg): Nitrogen Retention (kg);); P_Retention (kg): Phosphorus Retention (kg); C_S_R (kg/m²): Carbon Storage Rate (kg/m²); N_R_R (g/m²): Nitrogen Retention Rate (g/m²); N_R_R (g/m²): Nitrogen Retention Rate (g/m²); P_R_R (g/m²): Phosphorus Retention Rate (g/m²).

Table 11. Ecosystem Service in Municipal Zoning Categories in 2000

Table 11 shows the ecosystem services and efficiency provided by different zoning and land use in 2000. The Residential Area stores the most carbon and retains most nitrogen, and the Industrial Area retains the most phosphorous. The Agriculture-Open Area and the Residential Area have the most efficiency in storing carbon per unit. The Oregon State University campus and the Agriculture-Open Space are most efficient in retaining nitrogen. The Industrial Area is most efficient in filtering out phosphorous in stormwater.

	2000				2020			
Area	Size (m^2)	N_Filtration	P_Filtration	Carbon_S_R (Kg/m^2)	Size (m^2)	N_Filtration	P_Filtration	Carbon_S_R (Kg/m^2)
Urban Area	41,246,847	83.39%	84.06%	4.18	74,410,888	78.09%	73.79%	8.06
Other Area	78,101,520	91.31%	90.58%	24.66	44,937,479	94.50%	92.08%	19.89
Stormwater basin	119,348,367	88.58%	88.10%	18.05	119,348,367	82.77%	76.65%	16.01

Note: N_Filtration: Nitrogen Filtration; P_Filtration: Phosphorus Filtration; Carbon_S_R (Kg/m^2): Carbon Storage Rate (Kg/m^2).

Table 12. Ecosystem Service Provided by Different Areas in 2000 and 2020

The urban area sprawls from less than 40 million square meters to more than 70 million square meters. Table 12 describes the ecosystem services provided by different subwatersheds in stormwater purification (nitrogen filtration and phosphorous filtration) and storing carbon. Apparently the urban area may have more ability to store carbon in 2020. However, the urban ecosystem service in filtering nitrogen and phosphorous in 2020 is less than it in 2000, which indicates that stormwater quality is still an issue in 2020 under this comprehensive plan and more green infrastructure is needed in 2020 to purify urban stormwater.

2.2 Ecosystem Service Valuation

The most recent available parcel data is from the 2014 Tax Lot Dataset (City of Corvallis 2014). This research quantifies the ecosystem service for each parcel on the entire stormwater basin in 2014 and converts the ecological values in retaining nitrogen and phosphorous, and storing carbon into monetary value. Previous studies reported the average costs for the municipal stormwater treatment to remove one pound nitrogen and phosphorous at $8.255 and $55.225 respectively in 2007 (EPA 2007). Therefore, if the ecosystem retains one more pound of nitrogen and phosphorus, it creates $8.255 and $55.225 values respectively for the City. Although computing carbon storage monetary value is controversial and complex (Nordhaus 2007b), the range from $9.55 to $84.55 per metric ton of CO_2 has been suggested by Nordhaus (2007a) and Stern (2007). Based on these data, all the City's ecological values are converted to the monetary values in 2014 with a 3% annual discount rate.

Subwatershed	Size (m^2)	Impervious Surface (m^2)	Imperious Percentage	Carbon Value ($\$/m^2$)	S_P_Value ($)	S_P_Value ($\$/m^2$)	E_Value ($)	E_V ($\$/m^2$)
Jackson Creek	7,252,646	252,935	3.49%	13.86	84,901	0.0117	100,616,412	13.87
Oak Creek	33,565,869	1,622,962	4.84%	13.40	334,421	0.0100	450,272,116	13.41
Lewisburg	7,549,264	395,846	5.24%	10.47	96,326	0.0128	79,119,257	10.48
North East Corvallis	2,468,807	133,956	5.43%	3.56	66,360	0.0269	8,854,665	3.59
Frazier Creek	8,287,789	469,234	5.66%	12.17	97,709	0.0118	100,952,122	12.18
Marys River	14,165,147	956,163	6.75%	1.31	393,231	0.0278	18,977,870	1.34
Willamette River	2,592,320	183,319	7.07%	2.26	74,775	0.0288	5,921,004	2.28
Dry Creek	4,591,240	631,354	13.75%	0.79	154,820	0.0337	3,772,860	0.82
Dunawi Creek	10,722,055	2,006,415	18.71%	2.75	194,963	0.0182	29,635,621	2.76
Village Green	1,895,545	500,198	26.39%	1.95	35,134	0.0185	3,724,088	1.96
Dixon Creek	10,646,477	3,323,804	31.22%	5.24	146,021	0.0137	55,921,019	5.25
Goodnight	1,476,668	547,907	37.10%	1.09	28,625	0.0194	1,636,157	1.11
Ryan Creek	554,022	207,322	37.42%	2.23	9,098	0.0164	1,241,848	2.24
Sequoia Creek	5,316,672	2,006,355	37.74%	3.81	95,922	0.0180	20,358,417	3.83
Mill Race	1,629,515	632,777	38.83%	1.45	40,868	0.0251	2,406,499	1.48
Garfield	2,231,949	923,815	41.39%	0.93	77,697	0.0348	2,159,474	0.97
Western	505,835	289,878	57.31%	0.64	10,111	0.0200	333,016	0.66
Madison	256,504	147,202	57.39%	0.80	8,709	0.0340	213,755	0.83
Fillmore	2,665,090	1,618,055	60.71%	1.09	55,259	0.0207	2,960,759	1.11
Adams Jefferson	687,242	443,755	64.57%	0.30	23,507	0.0342	230,888	0.34

Note: S_P_Value ($): Stormwater Purification Economic Value ($); E_Value ($): Ecological Economic Value ($); E_V ($\$/m^2$): Ecological Economic Value per Square Meter.

Table 13. Ecosystem Service Valuation for Each Subwatershed

The entire stormwater basin's monetary value of ecosystem service provision for the year of 2014 including nitrogen retention, phosphorus retention and carbon storage is $889,307,847. The ecological monetary value for each subwatersheds is listed in the Table 13. A strong power regression relationship at the subwatershed level is found between the total ecological monetary value per unit and the impervious surface percentage with correlation coefficient as 0.74 (see Figure 19), which indicates that the percentage of impervious surface could be used for ecological monetary values prediction.

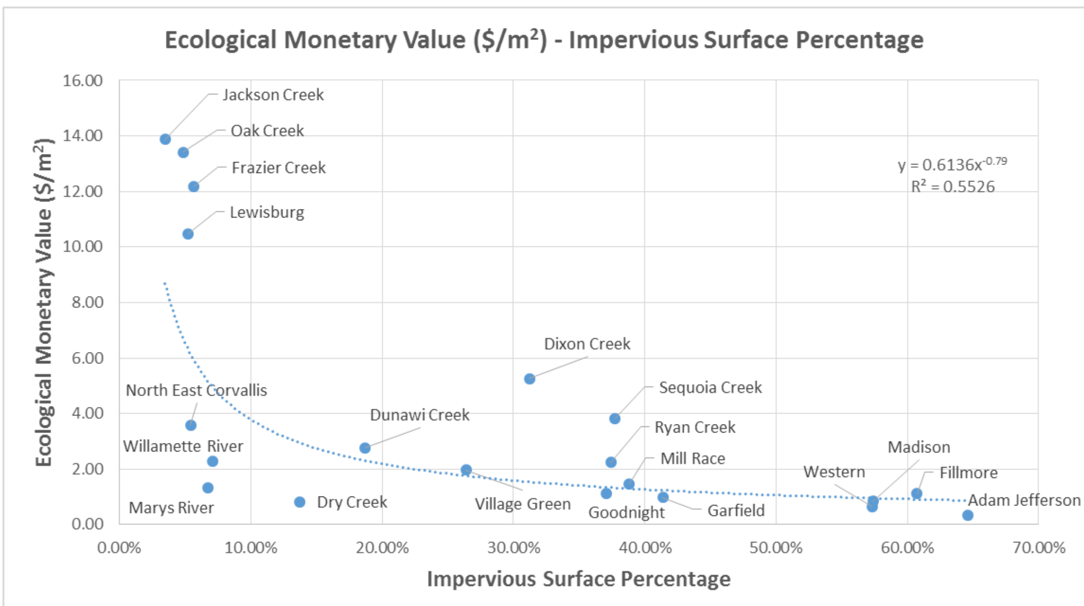
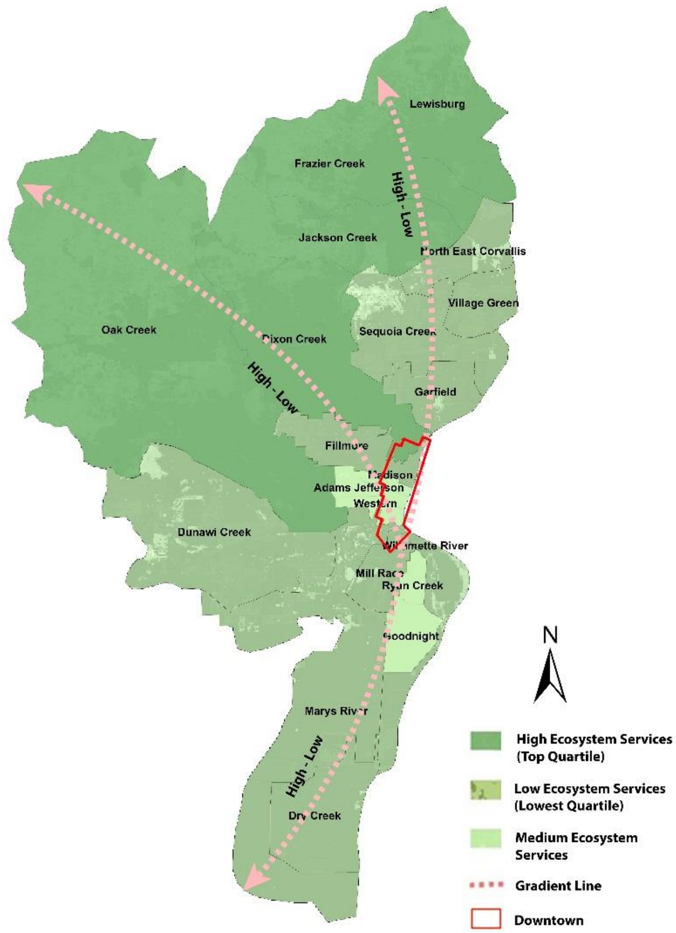


Figure 19. Correlation between Impervious Surface Percentage and Ecological Monetary Value



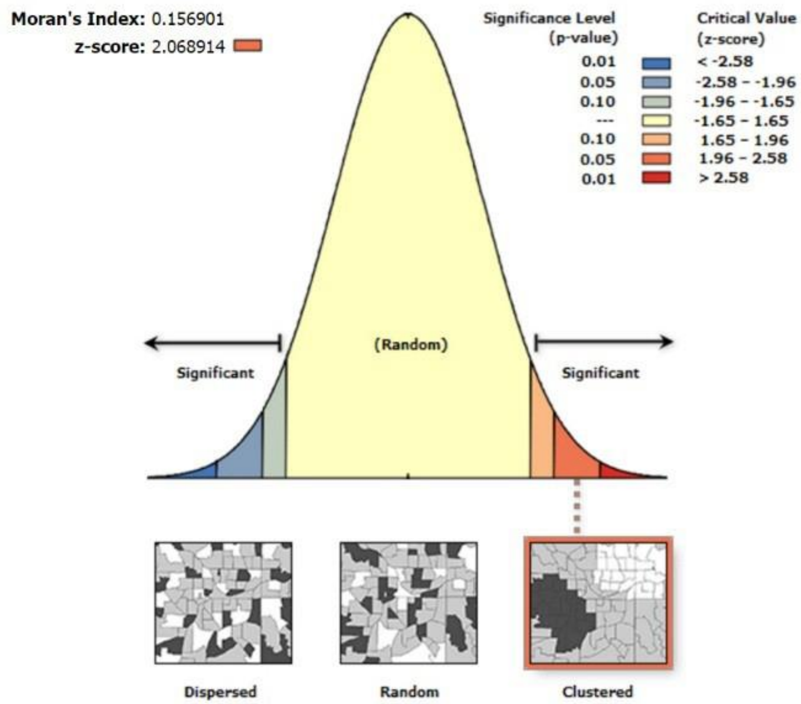
Note: This map is made based on Table 13-Ecological Economic Value

Figure 20. Qualitative Explanation of Ecological Monetary Value Gradient on Subwatershed Level

The five subwatersheds in the top quartile with highest ecological monetary value are Oak Creek, Jackson Creek, Frazier Creek, Lewisburg and Dixon Creek. They are all located on the undeveloped northwest edge of the watershed. The five subwatersheds in the lowest quartile with lowest ecological monetary value are Madison, Adams Jefferson, Western, Ryan Creek and Goodnight. All those subwatersheds with less ecological values are around the Downtown of the city (see Figure 20). Therefore there exists a gradient in providing ecosystem services from the city's center to the undeveloped subwatersheds. In order to confirm this gradient in a quantitative way, spatial autocorrelation of the ecological monetary value was tested on both the subwatershed and parcel levels. The results are shown in next section.

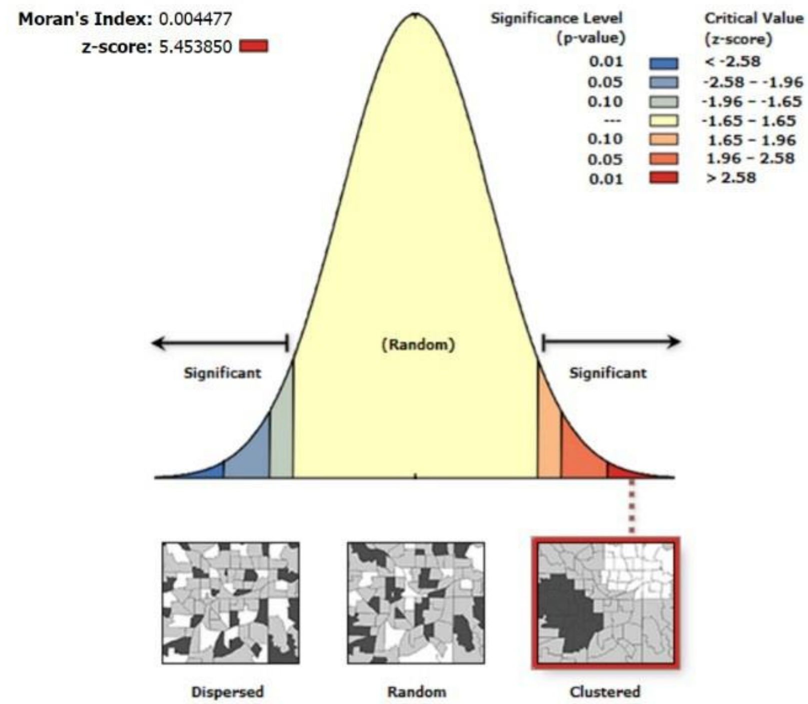
2.3 Spatial Autocorrelation Analysis

This research, first of all, explores what unit of analysis should be applied in proposing a new Comprehensive Plan. The previous analysis of the ecological monetary value for each subwatershed has demonstrated that there exists a gradient in providing ecosystem services from the urbanized center to the watershed edges. The research quantified the ecological monetary value for each parcel and the Global Morans I test for the ecological monetary values are used on both subwatershed and parcel levels in ArcGIS 10.2. The results show that both of the z-scores are bigger than 1.96 which indicates that there exists spatial autocorrelation on both the subwatershed and parcel level. However the autocorrelation on the parcel level is much stronger than it is on the subwatershed level (see Figure 21). Therefore this research probes how to revise the comprehensive plan to conserve more ecological values using unit of analysis on the parcel level in next section.



Given the z-score of 2.06891356627, there is a less than 5% likelihood that this clustered pattern could be the result of random chance.

Global Morans I Test on Subwatersheds



Given the z-score of 5.453849582, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Global Morans I Test on Parcels

Figure 21. Global Morans I Test on Subwatershed

3. Comprehensive Plan Revision

3.1 New Conservation Area

To create a revised comprehensive plan that reflects ecosystem services values a parcel-level analysis was utilized as explained in Section 2.3. All the parcels are ranked from low to high based on their ecological monetary values, then the parcels' size are kept aggregated starting from the first one with least ecological monetary values until the total size is bigger than 28 square miles, which is required in the City's current Comprehensive Plan to meet the City's land needs for future urbanization. The revised comprehensive map (see Figure 22) is generated by this principle, with green areas representing lands of higher ecological monetary values to be conserved and the red area representing lands of lower ecological monetary values for urbanization. Based on this conservation plan, the conservation area stores 1,847,725 ton carbon and retains 30,522 kg nitrogen and 4,533 kg phosphorus annually. The comparison of the proposed conservation plan with the City's existing comprehensive plan is shown in the Table 14. The revised comprehensive retains 103% more nitrogen, 270% more phosphorus and stores 19% more carbon than the comprehensive plan made by the City (see Table 14).

	Current Comprehensive Plan	Proposed Conservation Area	Difference
Nitrogen Retention	15,073kg	30,522kg	102.49%
Nitrogen Retention Value	$336,667	$681,732	102.49%
Phosphorus Retention	1,225kg	4,533kg	270.04%
Phosphorus Retention Value	$183,044	$677,338	270.04%
Carbon Storage	1,553,993Mg	1,847,725Mg	18.90%
Carbon Storage Value	$659,369,305	$784,001,697	18.90%

Table 14. Comparison of the Conservation Areas in Providing Ecosystem Services

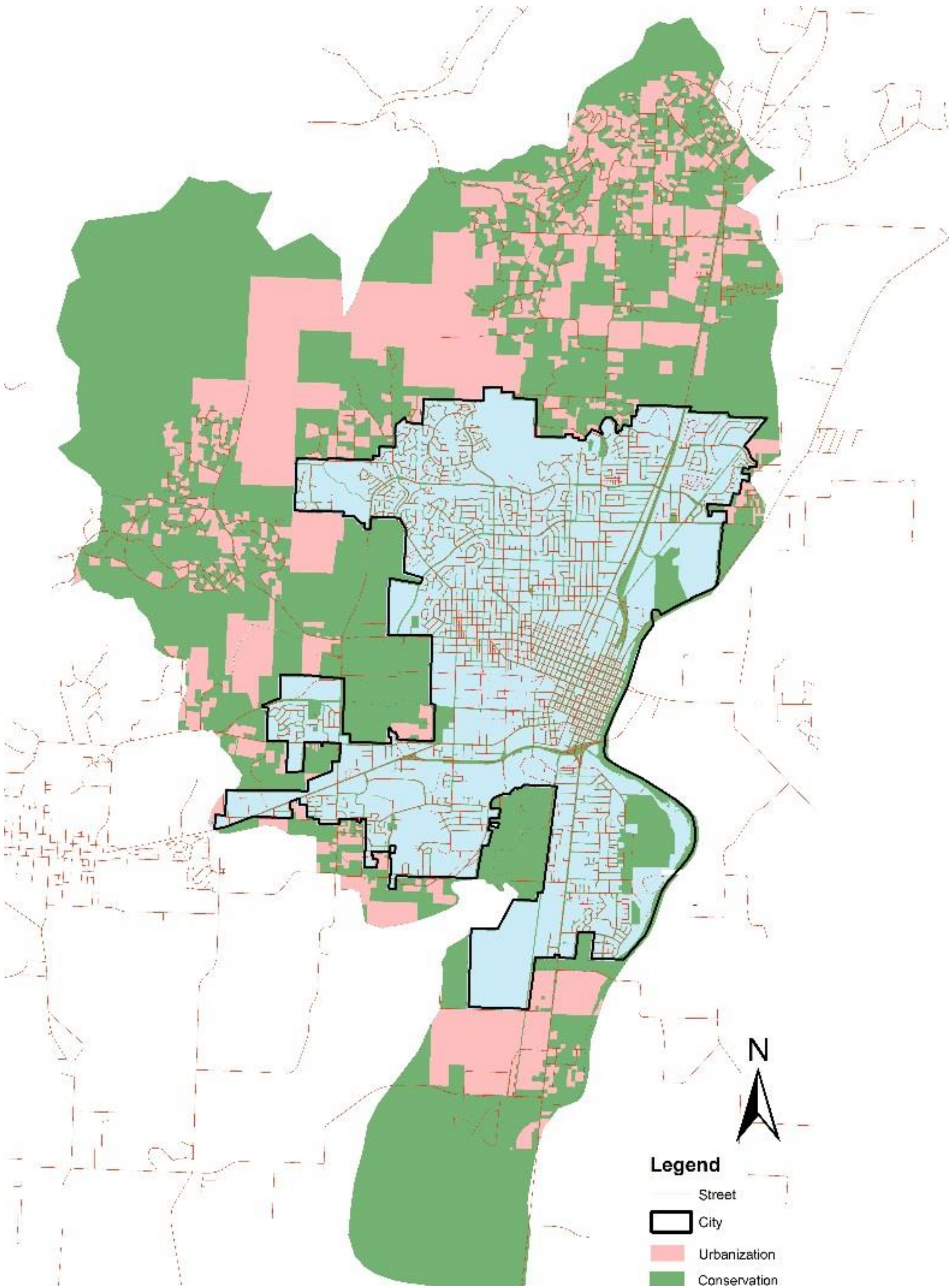


Figure 22. New Proposed Conservation

3.2 Modified Comprehensive Plan

According to the Comprehensive Plan proposed by the City, the City needs 12.65 square miles land outside the current City Limit and eleven main land use categories to meet future urbanization demands (see Figure 23). I propose a revision to the comprehensive plan with the goal of accommodating these eleven land use categories and conserving most ecological values. It is assumed that there is no land use change within the City Limit. Outside the City Limit, the method to develop such a comprehensive plan is based on the principle that the land use category affecting ecological values most should be developed on the land of lowest ecological values, therefore the lands with most ecological values could be conserved from the City's future sprawl.

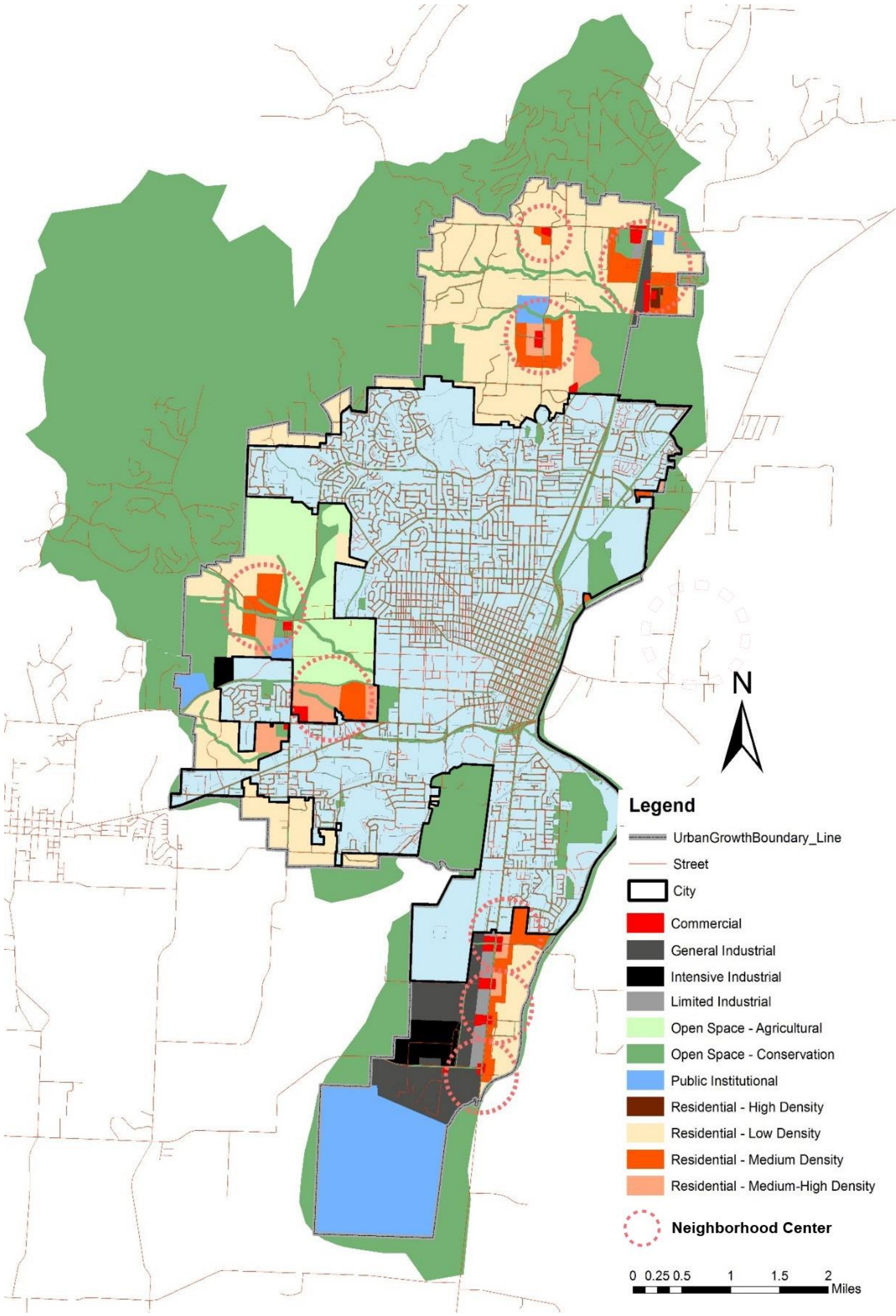


Figure 23. Current Comprehensive Plan (2014)

Land Use	Projected Size (m^2)	Impervious Percentage	New Urbanization Land Use	Projected Size (m^2)	Impervious Percentage
Commercial	438,296	76.80%	General Industrial	2,352,492	31.14%
Intensive Industrial	778,680	67.25%	Residential - Low Density	12,444,195	25.20%
Residential - High Density	309,608	53.88%	Limited Industrial	416,222	15.79%
Residential - Medium-High Density	1,377,225	42.76%	Open Space - Agricultural	3,174,064	4.26%
Public Institutional	4,966,187	37.93%	Open Space - Conservation	4,520,116	0.00%
Residential - Medium Density	1,987,273	37.28%	Total	32,764,358	25.36%

Table 15. Projected Future Land Use Size and Impervious Percentage

As analyzed in the previous section, there exists a negative power correlation between the percentage of impervious surface including building, roads and driveways, parking lots, and sidewalks and paths. Therefore the more impervious percentage of a land use, the more impacts it has on ecological quality and should be zoned for land uses with lower ecological value. It is assumed that the same land use category will have the same impervious percentage as it had in 2000. According to the comprehensive plan proposed by the City (see Figure 23), Table 15 summarizes the future land use categories, the projected size and the impervious percentage. All the parcels within the proposed urbanized area generated in the new conservation plan are ranked based on their ecological values from low to high (see Figure 24). Then the parcel size is kept aggregated from the first one until the total size is higher than the proposed land use size. For example, the City needs 438,296 square meters of land planned as commercial land use and the commercial area has the impervious surface percentage as high as 76.80%. So the first group of parcels with total size as 438,296 square meters in the low-high ecological value ranking list should be delineated as commercial land use. Following the same steps, all other eleven land uses for the future urbanization are delineated and the revised comprehensive plan is proposed (see Figure 25).

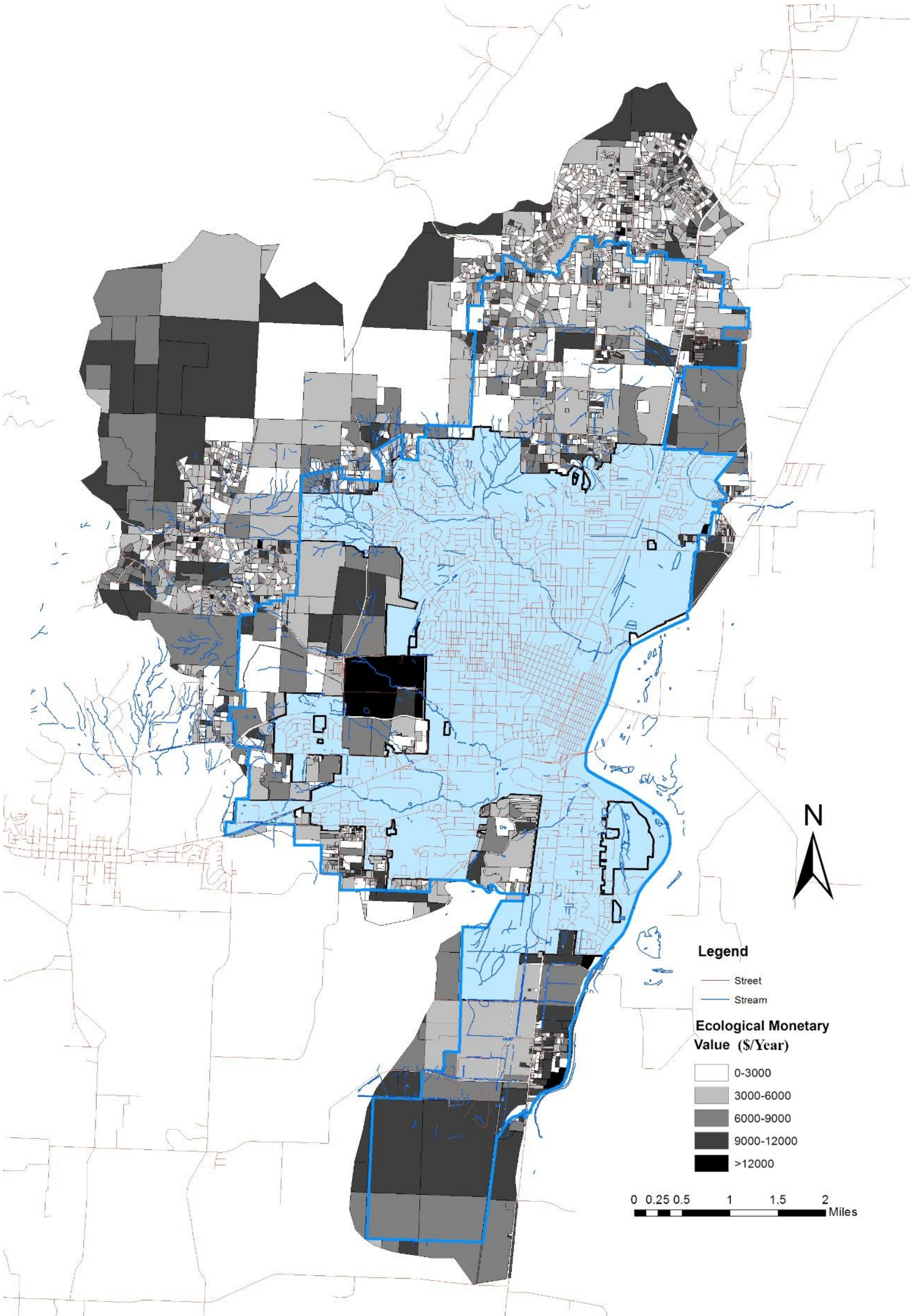


Figure 24. Ecological Value on the Parcel Level

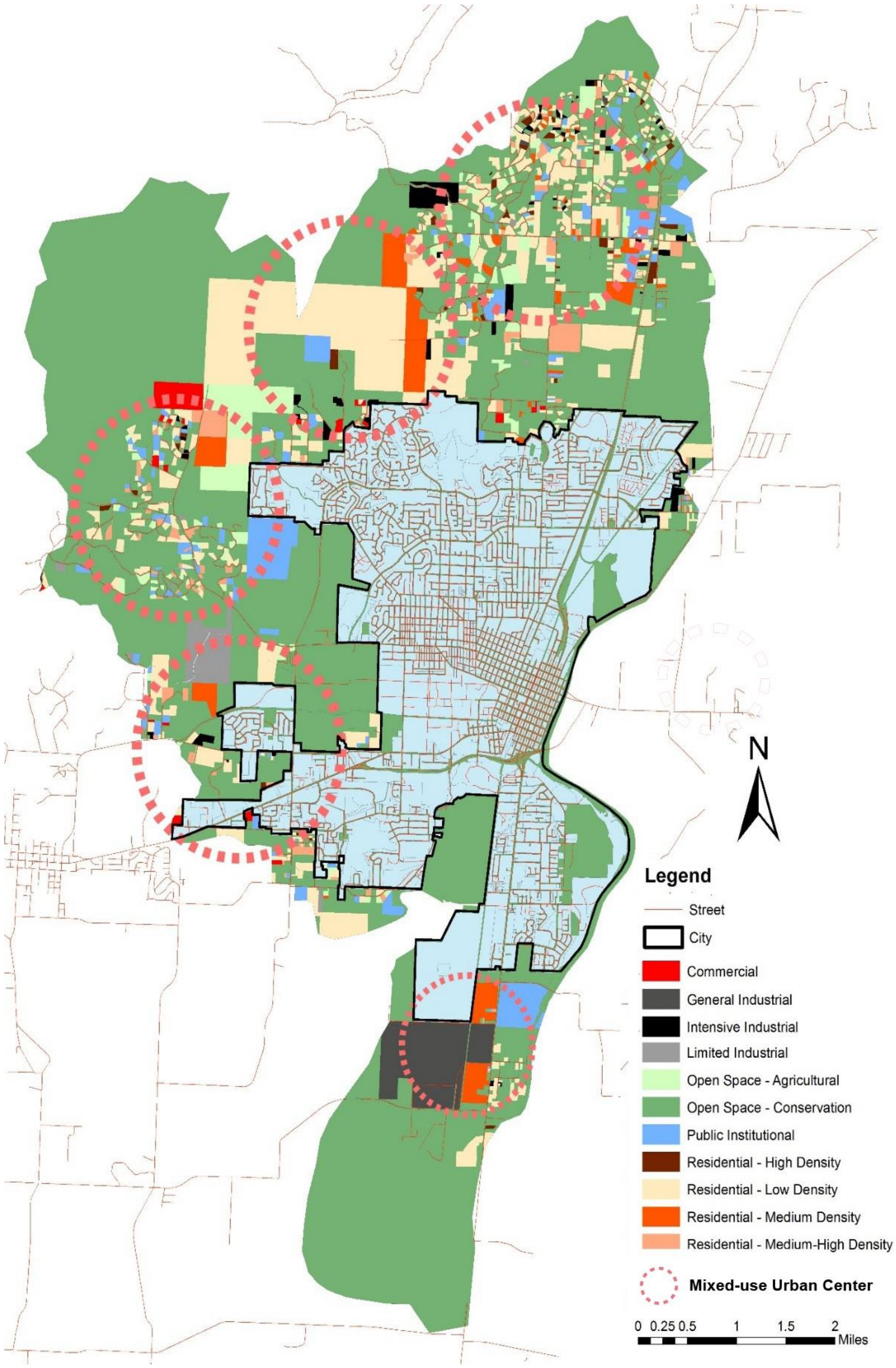


Figure 25. Revised Comprehensive Plan

Compared with the City's current Comprehensive Plan with several compact neighborhood centers in the Urban Fringes, the revised comprehensive plan proposes five mixed-use urban centers (see Figure 23 and Figure 25). Similar with the city's current Comprehensive Plan, new industrial areas are mainly located on the south edge of the city limit. However, different residential types, commercial-use land and new public institutions are evenly distributed outside the city limit.

Ecological Monetary Value	Total Parcel	Urbanized Parcel	Conserved Parcel	Percent Conserved
0-3000	801	801	0	0.00%
3000-6000	875	398	477	54.51%
6000-9000	839	0	839	100.00%
9000-12000	141	0	141	100.00%
>12000	112	0	112	100.00%

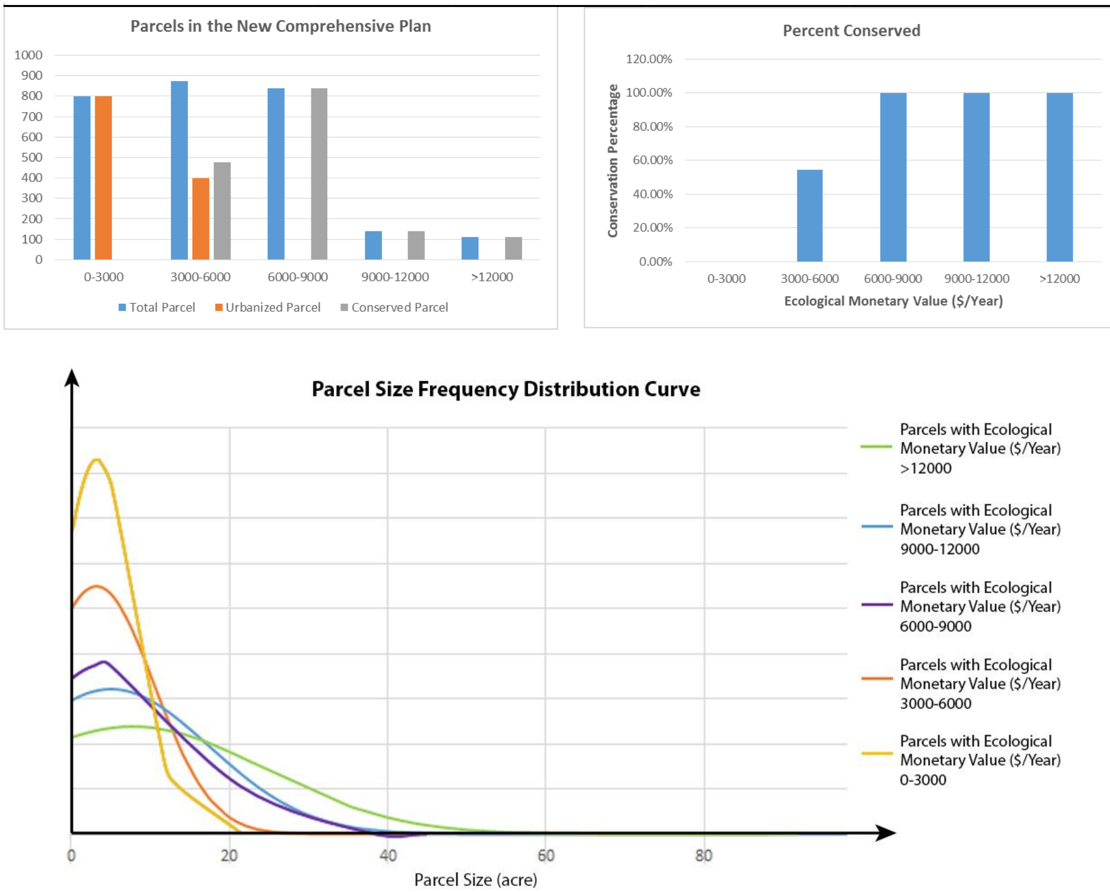


Table 16.Urbanized and Conserved Parcels in Revised Proposed Comprehensive Plan

In the new comprehensive pan, all the parcels that have the ecological monetary value higher than 6,000 $/Year and 54.51% of parcels that has the ecological monetary value ranging from 3,000 to 6,000 are conserved (see Table 16). Compared with the compact development proposed in the City's current Comprehensive Plan, the new comprehensive plan with spreading mixed-use developments would cost more money in urban infrastructure construction (e.g. streets, drainage pipe, power line) (see Figure 23 and Figure 25). Therefore, the new proposed comprehensive plan, by no means, is the most practical development plan for the City's future urbanization. However, as demonstrated by landscape ecologists, the natural lands setting among the spreading urbanization function as ecological stepping stones and corridors to strengthen local biodiversity (Dramstad et al 1996). The mixed-use urbanization spreading embedded in forests is favored by some landscape architects as well due to its less interruptions to the natural ecosystem and more recreational accessibility to people. For example, Mia Lehrer Associates responded to the lack of city action in Los Angeles in their City Tree-planting programs by intertwining forests and urbanization (Hough 2013). The forests provide more recreational opportunities to residents and alleviate some urbanization impacts, for example urban heat island effects (see Figure 26). It is necessary to comprehensively analyze the tradeoffs and to explore the feasibility in practice in future.

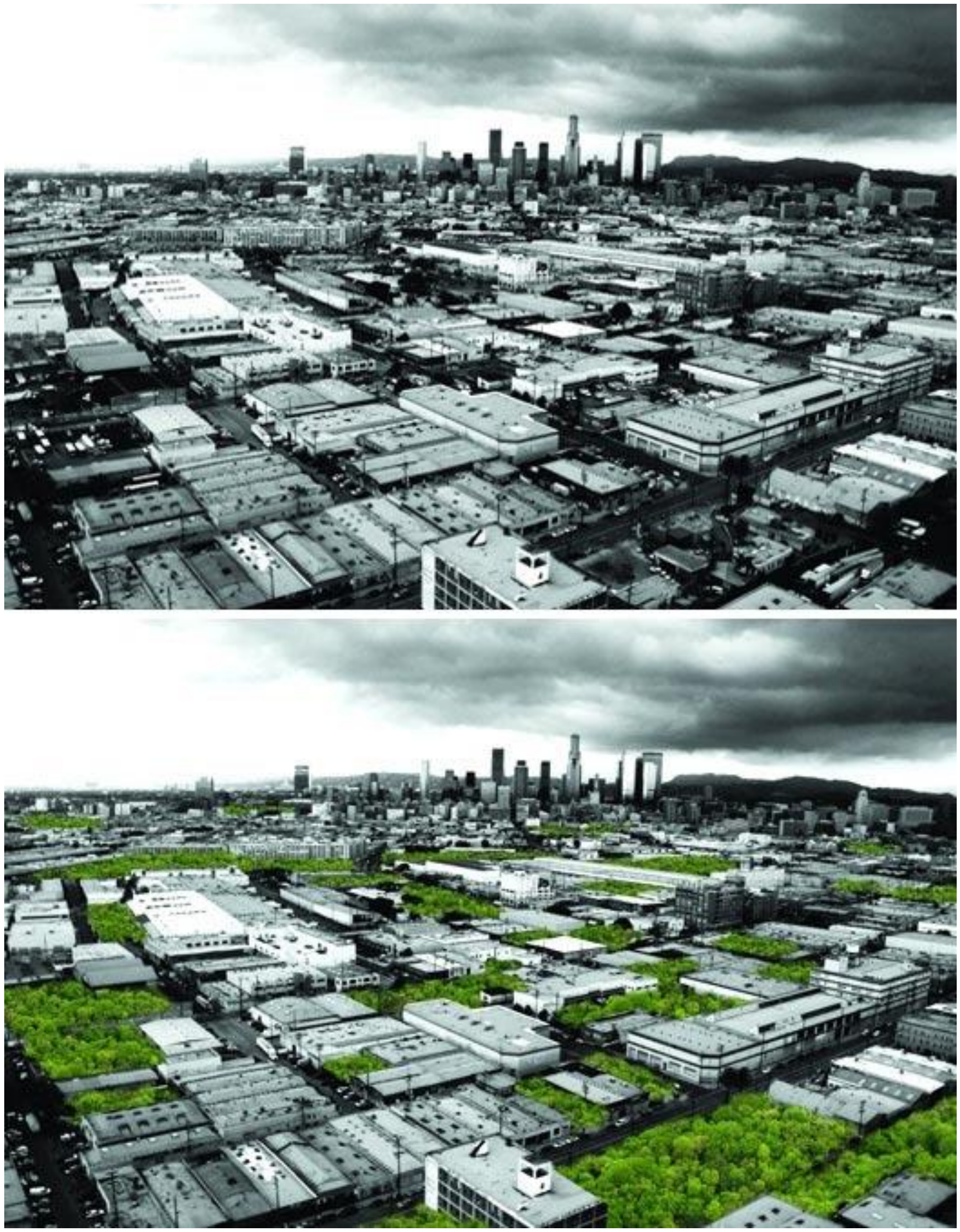


Figure 26. Urban Forest Los Angeles, before and after, a proposal by Mia Lehrer Associates. Source: Mark Hough, Champion Trees and Urban Forests. [*https://placesjournal.org/article/champion-trees-and-urban-forests/*](https://placesjournal.org/article/champion-trees-and-urban-forests/).

Chapter 6

Conclusion

Through land use and land cover change, urbanization has been posing threats to environmental quality at multiple scales. Urban growth management has been widely applied in managing urban growth and conserving natural resources. Enacting a locally appropriate urban growth management program requires a full understanding of different variables affecting urban growth and spatial distribution. However, in practice, planners used to make the comprehensive plan and delineate urban growth boundaries based on their hypothesis with scant supporting data and evidence.

As required by the State Land Conservation Act, the City of Corvallis implemented its first comprehensive plan in 1980 and it was updated in 1990, 1998, 2006 and 2014. Based on this Comprehensive Plan, the 14 square mile Urban Fringe zone is going to be filled with various industry, residential neighborhoods, and public institutions. This research models the urbanization impacts on environmental quality using indicators of nitrogen export, phosphorus export and carbon storage lost under the City's current Comprehensive Plan. Comparing the results with the City's development history from 1853 to 1998, we find that the current urban growth management strategy is effective in conserving the watershed's capacity in storing carbon, but it does not restrain the city's trend in increasingly exporting more nitrogen and phosphorus into urban runoff. We quantified the urbanization in each of the urban subwatersheds and the impacts on stormwater quality and carbon storage. Through statistical analysis, it is found that urban water yield and nitrogen export is strongly linearly-related with impervious surface size. The phosphorus export is also linear related with the impervious size, but it is not as strong as urban water yield and nitrogen export. There is no linear relationship existing between carbon storage and impervious surface size. This could be explained by the fact that most of the carbon in the urban watershed is stored in the soil and is less affected by the surface pavement.

Finally, this research quantifies the ecosystem services in purifying stormwater and storing carbon provided by each parcel within different zones (the area within the City Limit, Urban Fringe and the area outside the Urban Growth Boundary) under the City's current Comprehensive Plan. Compared with ecosystem services provided by the different areas on the entire watershed, it is found that the current urban growth management strategy conserves the land of high ecological value in carbon storage, but does not protect the land of high ecological value in stormwater purification. Using ecological unit monetary value from previous studies and the ecosystem service quantification result generated from InVEST, we monetized ecological values in retaining nitrogen and phosphorous, and storing carbon, and find a strong negative power regression relationship between the ecological monetary value per unit and the impervious surface percentage on the subwatershed level with a correlation coefficient as high as 0.74. The methodology used in this process could be applied to evaluate the performance of other cities' planning policy in preserving natural resources.

Based on the ecological monetary value for each parcel and demonstrated autocorrelation of the ecological monetary value on the parcel level, we propose a new conservation plan for the City. The new conservation plan directs future urbanization into the lands with least total ecological values and conserves the lands with most total ecological values. Finally this research proposes a new comprehensive plan retaining 103% more nitrogen, 270% more phosphorus and storing 19% more carbon than the city's current Comprehensive Plan. The new proposed comprehensive plan argues for spreading mix-used development types, which results in more overall higher ecological values and recreational opportunities, but more urban infrastructure construction cost. How to balance the tradeoffs and apply it into practice calls for further research.

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