WHAT'S IT WORTH? IMPROVING LAND USE PLANNING THROUGH THE MODELING AND ECONOMIC VALUATION OF ECOSYSTEM SERVICES

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ABSTRACT

The American landscape is urbanizing without full assessments of urbanization's true environmental costs and is endangering the delivery of critical ecosystem services. This is unintentional, resulting from a lack of known economic values for ecosystem services and ecosystem service delivery models and means for incorporating the results of such models into market-driven land use planning. Developing communities could benefit from the consideration of ecosystem services in land use planning, but lack relevant means for such analyses. This renders ecosystem services invisible in their planning. The three studies described here address the need to incorporate ecosystem services into planning by identifying local values for ecosystem services and illustrating how they, along with predictive models of ecosystem service delivery, can be used to evaluate land use policies' environmental impacts. The first study estimated the marginal implicit prices for changes in two ecosystem services, access to recreational open space and scenic quality, in an urban county, providing solid evidence of these services' values and suggesting how they could be used to inform policy making. The second study expanded the list of services, adding services provided by trees, and focused on a larger, two-county area. This study identified significant positive values for tree cover in local neighborhoods surrounding individual homes, but not on home parcels themselves. This suggests that tree cover provides neighborhood externalities that could be remedied using policies or incentives. The third study, which focused on a single, urbanizing city, illustrates a process for evaluating land use plans based on their environmental and economic consequences. This study identified ecosystem services' values and the likely impacts of land use change on them and used this information to evaluate a local land use plan, thus generating both information and methods to inform the land use planning process locally. These studies' results serve to inform local development, enabling it to occur in a more sustainable manner, and provide an example for later studies to follow in considering the environmental impacts of land transformation in planning. This research has great potential to improve the visibility of ecosystem services in local land use planning and, thus, to improve the ecological functioning of future landscapes.

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CHAPTER 1 – INTRODUCTION

Background and project rationale

Humans are dependent on goods and services from ecosystems. Termed ”ecosystem services” these include “supporting” services, such as soil formation and nutrient cycling; “provisioning” services such as providing clean drinking water and food production; “regulating” services, such as flood control and climate regulation; and “cultural” services, such as the provision of areas for outdoor recreation and aesthetic or educational experiences (Millennium Ecosystem Assessment, 2005a). Although these services contribute to our well-being, our decisions often negatively impact them by altering the structure and function of ecosystems. Land-use change is one of the key drivers of change in ecosystem service delivery. To reduce the negative impacts of land-use decisions on service provision, we need a means for considering ecosystem service impacts in land-use decisions.

Land-use changes, such as the urban and suburban development that occurred in the United States over the last fifty years and continues today, often reduce the delivery of important ecosystem services. A number of negative impacts on ecosystem services resulting from urbanization have been identified. These include the loss or disruption of nutrient cycling, loss of species habitat and diversity, increased surface runoff, and modifications in energy flow (Alberti, 2005). As a result of these and other ecological impacts associated with urbanization, urban areas may experience increased rates of disease transmission, urban heat island effects, reduced air and water quality, increased flooding, as well as limited access to recreation areas and reduced scenic quality (Millennium Ecosystem Assessment, 2005b). It is clear that such impacts may have deleterious effects on human health and welfare, yet, land-use decisions related to urbanization that sacrifice these and other services are frequently made. Planners and policy-makers do not set out to make such decisions with the intention of causing damage to the natural environment; rather, they make these decisions with the information that they have available, which typically does not include impacts on ecosystem services. Because the effects of land-use change on ecosystem service delivery are poorly understood even in scientific communities and methods for forecasting them tend to be complicated and fraught with uncertainty, basic predictions about the impacts of proposed land-use changes on ecosystem services are rarely available to those making decisions relative to urbanization. Thus, land-use decisions are typically made without such considerations and may have unforeseen negative consequences. Additionally, even where such information is available to communities, the presence of externalities and the public good aspects of many ecosystem services may still lead individual landowners or communities to make decisions that degrade these services.

Community land-use planning, which is used to design local-level comprehensive or master plans that, in turn, are used to set zoning and other land-use regulations and determine if variances are granted, also tends to be a market-driven activity. That is, it is based upon estimates of the expected economic benefits resulting from a land-use change, as well as the expected costs. This system may work well when one is considering benefits and costs with well-known or easily-estimated monetary values, for instance, when the costs of constructing infrastructure such as roads and sewers for an area are compared to the likely increases in a community's tax base resulting from residential construction in that area. However, it tends to fail where the monetary values of costs and benefits are largely unknown. This is the case with ecosystem services as their economic values are very rarely readily available or estimable. Thus, even if those involved in the approval of land-use plans and policy were equipped with forecasts of the changes in ecosystem service delivery likely to result from a proposed land-use change, they would find it difficult to incorporate this information into the benefit-cost analyses involved in such decisions or to design other incentives to induce landowners to make land-use decisions that do not negatively impact ecosystem services. As such, these services typically become "invisible" in the land-use decision making processes associated with urbanization and are sacrificed as a result.

As development rates accelerate and landscapes become increasingly urban, it is likely that the failure of current policy-setting practices to adequately consider the full economic and ecological costs and benefits of such development will result in large reductions in ecosystem service delivery levels. Thus, because ecosystem services are underpriced, they will tend to be underprovided without better recognition of their value. In order to remedy this situation, studies that improve our ability to forecast changes in ecosystem service delivery levels as a function of land-use change and that advance economic valuation techniques to make them practical for community planning are necessary. Because local planners and policy-makers generally lack the means for conducting such studies themselves, this suggests a role for partnerships between local communities and researchers. These studies will offer a means for providing valuable information about the likely impacts of land-use change on ecosystem service delivery and the economic values of such changes that would improve land-use decision making. If changes in ecosystem service delivery due to land-use change could be predicted during the planning process and could be translated into economic terms for use in benefit-cost assessments associated with policy making, land-use planners could minimize the negative environmental impacts of development. As a result, the environmental quality and ecological sustainability of future landscapes might not only be preserved, but also improved.

The studies contained in this dissertation focus on the generation of economic values for ecosystem services, on the prediction of the impacts of land-use changes on these services, and on identifying ways in which these values and predictions could be used to evaluate local land-use plans and policies. As such, they generate useful approaches and information that may be used to inform land-use planning and may, indeed, be used to alter the land-use decision making process so that adequate consideration is given to ecosystem services in urbanizing communities. Its goals are as follows:

1. To identify the economic values associated with changes in the delivery of ecosystem services and amenities in order to generate baseline information about these values in the study area,
2. To predict the environmental impacts of land-use change using spatial models of ecosystem services and amenities in order to identify how levels of ecosystem services are likely to change under different land uses,

3. To provide a novel general environmental modeling and economic valuation framework centered on land use that can be used to evaluate local-level land-use plans and policies.

In achieving these goals, this project will provide an example of the manner in which ecosystem services may be forecast and valued so as to inform the decision-making process used to set zoning and other land-use regulations and incentive programs which influence on-the-ground land-use decisions. Such examples are largely lacking from the present literature. Thus, this study fills a critical gap that impedes the incorporation of ecosystem services in local land-use planning. As such, this project will facilitate improvements in land-use planning and policy-making and will thus promote more ecologically-sustainable communities.

Literature review

Economic valuation techniques

Ecosystem services and amenities could be made visible in local land-use planning and policy making using a combination of ecological models and economic valuation techniques. Critics of the economic valuation of ecosystem services argue that ecosystem services and amenities have intrinsic value and that assigning monetary values to these services cheapens them, poses the risk of generating competition between the needs of local populations and conservation, and may actually be counter-productive if the values estimated for ecosystem services are insufficient to secure their conservation. Such critics suggest that such valuations are thus to be avoided (McCauley, 2006). However, few other means exist for incorporating ecosystem services into market-driven local decision-making and, as we make decisions that impact ecosystems and environmental quality almost daily, failure to adequately value ecosystem services is likely to result in their under-consideration in such decisions. By explicitly valuing ecosystem services and stating the limitations of such valuations, we make clear the importance of such services in a manner that policy-makers can readily interpret. Thus, economic valuation remains a promising means for incorporating ecological services and amenities into land-use decision-making.

A variety of economic valuation techniques exist for valuing ecosystem services. One group of techniques, household production functions (HPF), are used to value environmental amenities based on the sale prices of marketed goods related to these amenities. HPF approaches include hedonic pricing which estimates the economic values associated with changes in the delivery of an ecosystem service based on the differences in sales prices of similar goods, typically homes, with different delivery levels of that service; averting behavior models which estimate the values of ecosystem services based on the expenditures of individuals seeking to avoid undesirable conditions; and travel cost approaches which measure a service's value based on the expenditures individuals make to use it. Hedonic pricing has been used to value many environmental amenities including open space (e.g., Bolitzer and Netusil, 2000; Geoghegan, 2002; Irwin, 2002), specific land-cover types (e.g., Doss and Taff, 1996; Tyrvainen and Miettinen, 2000), and water quality (e.g., Leggett and Bockstael, 2000; Wilson and Carpenter, 1999). The economic values of recreational fisheries (Phaneuf et al., 1998), and recreation areas (Lew and Larson, 2005; Siderelis et al., 1995) have been assessed using the travel cost approach. Averting behavior models have been used to estimate the value of the provision of drinking water by ecosystems (Abdalla et al., 1992; Harrington et al., 1989). HPF models are particularly useful in estimating the values of ecosystem services that contribute to the production of a marketed good, but are inapplicable in situations where no such contribution exists. Additionally, these studies provide only partial estimates of the values of ecosystem services and amenities, those that accrue to users of these goods. As such, the full values of these goods are likely to be higher than those estimated.

Production function (PF) methods and replacement cost analyses are also used to estimate the economic values of ecosystem services with market surrogates. In using PF methods, an ecological service or amenity is seen as an input into a marketed good's production. Wetlands, for example, may be seen as inputs into fish production that impact fish populations and thus harvests. Wetland values may therefore be estimated based on the market values of fish harvested under different conditions. This approach has been used to value wetland fishery production (Barbier and Strand, 1998; Bell, 1997) and storm protection produced by coastal erosion control (Sathirathai and Barbier, 2001).

Replacement cost analyses use the price of the least-cost alternative to an ecosystem service to indicate that service's value. This technique was utilized in the decision to protect New York City's watershed to provide quality drinking water instead of building an expensive water treatment facility (Ashendorff et al., 1997; National Research Council, 2000). As with HPF methods, PF methods do not generally provide full estimates of a service or amenity's value and cannot be used for services that have no market surrogate.

Many ecosystem services lack market surrogates and are difficult to value using these methods. These services have neither indirect nor direct use values, but have non-use values that current markets fail to measure. Stated preference approaches, like contingent valuation which assesses values via surveys to estimate individuals' willingness-to-pay for a service or willingness-to-accept compensation for decreases in that service and conjoint analysis which asks individuals to make a series of trade-offs, often by rating or ranking different choices corresponding to different service delivery levels, can provide measures for services without market surrogates. This approach was used to estimate values for oil spill damages (Carson et al., 1992) and groundwater protection (Boyle et al., 1994). Stated preference analyses have the benefit of being usable in situations where data on ecosystem service delivery are limited. However, they suffer from potential problems related to the accuracy of individuals' claims regarding what they would or would not pay for ecosystem services and amenities in hypothetical situations which may not match closely with what they would actually pay if asked to do so (More et al., 1988).

Benefit transfer approaches, which use economic values estimated in one site to identify economic values in a comparable site in a different location, have also been used to identify values for services and amenities in cases where they are unavailable and cannot be estimated in a reasonable amount of time. For example, a recent study estimated ecosystem service delivery and identified economic values for ecosystem services in three locations distant from one another using a benefit transfer approach (Troy and Wilson, 2006) and, indeed, one of the most cited studies of ecosystem service valuation, a study that attempted to generate values for all ecosystem service globally, also used this method (Costanza et al., 1997). Although the use of this method may provide economic values where none are available, a number of concerns about its use exist. These include errors in the estimation of economic values that are likely to occur when the characteristics of the area from which economic values are transferred match poorly with those of the area to which they are transferred (Plummer, 2009). Additionally, as cultures and ecosystem service availability differ with geographic region, the values individuals hold for ecosystem services are also likely to vary with region. As such, estimates generated for one region may be inaccurate for another.

The studies encompassed in this dissertation make use of the hedonic pricing method to assess the values of environmental amenities as indicated by the sale prices of single-family homes. Using this method in this way enables one to identify the values of environmental amenities and ecosystem services as they accrue to the owners of these homes. As noted above, hedonic pricing provides only a partial estimate of an ecosystem service's value (i.e., that which accrues to the users of the goods used in valuation), but it does provide a tangible estimate of value that can be readily applied in land-use decision-making. Because home sale prices are directly related to community tax bases, these values could be readily used by urbanizing communities to identify some of the potential economic costs and benefits associated with land-use changes that impact ecosystem services that accrue to the owners of single-family residential property owners. Although hedonic pricing has its weaknesses, for instance, it assumes that buyers are aware of the environmental quality attributes being valued when, in fact, they may not be, it has previously proven sufficient for generating estimates of marginal values. As such, the values generated using this method could be straightforwardly incorporated into benefit-cost analyses associated with land-use policy-making with the caveat that they represent the partial, not full, values of ecosystem services to the community.

Previous studies of the economic value of ecosystem services and amenities

Interest in valuing ecosystem services and amenities has grown in recent years. As a result, a number of recent studies have sought to identify the economic values of ecosystem services and amenities. These studies vary in their focus. Some studies center on assessing the value of a single service while others look at multiple services. Some studies take a local or regional focus while others focus on the earth as a whole. Regardless of their focus, these studies provide valuable lessons for the advancement of ecosystem service valuation.

Most existing studies have examined a single or a selection of ecosystem services and did not estimate the total economic value of the ecosystems studied. A pioneering assessment that is often noted for its flaws in combining results from studies with varied approaches and objectives (Pimm, 1997), assessed earth's ecosystems' total value by combining estimates from multiple studies (Costanza et al., 1997). This study illustrates the pitfalls of studies that claim to consider all ecological values, but omit many, and that transfer values for services calculated in limited global areas to the entire earth, assuming values to be comparable in all global regions. Despite these pitfalls, this study advanced ecosystem service valuation significantly simply by generating a greater interest and awareness of these services, their possible values, and the methods used to assess them.

Other studies have examined multiple ecosystem services without claiming to estimate an ecosystem's total economic value. In Wisconsin, economic analyses of ecosystem services provided by a Madison area lake determined the costs and benefits of management to reduce eutrophication relative to recreational fishing, local food production, and drinking water provision (Stomborg et al., 2001). Similar studies valued select services for the Columbia River Basin in the Pacific Northwest (National Research Council, 2004a) and for Wake County, North Carolina, USA (Phaneuf et al., 2008). In all of these cases, assessments and valuations of the delivery of multiple services of high regional importance generated data that could inform economically and ecologically efficient regional management policies and that provide justification for considering ecosystem service impacts in planning and policy making.

Several studies have evaluated the impacts of potential land-use change on multiple services and their associated economic impacts. Among these are a series of studies conducted in the Swiss Alps resort community of Davos that identified not only the values associated with four ecosystem services relevant to the area, but also modeled changes in these services as a result of possible future land-use change and estimated the economic impacts of these changes (Gret-Regamey and Kytzia, 2007; Gret- A. Gret-Regamey et al., 2007; Gret-Regamey et al., 2008a; Gret-Regamey et al., 2008b; Lundstroem et al., 2007), a study conducted in the Philadelphia, Pennsylvania, USA metropolitan area that evaluated the impacts of two potential development patterns in the region on ecosystem services (Phaneuf et al., 2008), and a study that predicted changes in a series of ecosystem services in the Willamette Basin of Oregon, USA, providing economic values for some of them and metrics for comparison for others (Nelson et al., 2009). These studies illustrate the utility that combining predictive models of ecosystem service delivery based on land-use change with economic valuation techniques may have for assessing the trade-offs among different ecosystem services and between ecosystem services and development in land-use policy making. The current study will have a similar impact, but operates at the more local, city level, thus enabling local policy-makers to consider ecological impacts in community land-use planning.

The studies described above and others have begun to lay the ground work for incorporating ecosystem services and amenities and their values into land-use planning and policy making. They are not, however, sufficient to make consideration of these services simple or routine in local-level land-use decision making. First, nearly all existing studies involving the economic valuation of ecosystem services are academic exercises with minimal applicability to real world decision making (National Research Council, 2004b) and, as a result, it is difficult to apply their findings to local land-use decision making. Additionally, the scientific basis required for incorporating ecosystem services into land-use policies is currently lacking such that the tools and knowledge required for forecasting both the environmental and economic impacts of land-use change are largely unavailable at scales relevant to decision-making (Daily et al., 2009). The research described in the following chapters adds to the existing literature and takes significant steps towards addressing some of these issues so that ecosystem services may be better considered in local land-use decisions.

Summary of Chapters

The following chapters consist of three separate studies aimed at identifying the economic values of select ecosystem services and at making these values useful in identifying both the environmental and economic impacts of land-use change in local communities. These studies focus on local counties and cities in the Minneapolis-St. Paul metropolitan area of Minnesota, USA. In generating economic values for ecosystem services in this area and in forecasting the changes in these services and their values likely to occur with land-use change, these studies collectively strive to improve and inform land-use decision-making regionally. They also function as examples that future studies could follow to incorporate environmental values and impacts in land-use planning. As such, they may help to remedy many of the methodological and conceptual shortfalls associated with incorporating ecosystem services and amenities in land-use planning and to increase our understanding the environmental sustainability ramifications of human activities. At the practical level, these studies provide information and illustrate a method that might be used to increase the visibility of ecosystem services and amenities in local planning, thus offering the potential to improve both the environmental condition of future landscapes and the economic condition of future communities. The studies detailed in these chapters are described briefly below.

Chapter 2 summarizes a study that examined the economic values of two environmental amenities provided by local ecosystems, open space access and scenic quality, in Ramsey County Minnesota. In this preliminary analysis, hedonic pricing is used to elicit values for these amenities as they accrue to single-family homeowners. The results of this study demonstrate the economic valuation of environmental amenities using this methodology and provide information about the economic importance of these environmental amenities that can be used to inform local planning and policy making.

The study described in Chapter 3 focuses on identifying the economic values associated with tree cover which provides a collection of ecosystem services and amenities to local communities. This study was executed in both Ramsey and Dakota Counties in Minnesota and used hedonic pricing to identify the values associated with tree canopy cover as they accrue to single-family homeowners. These most notably include values related to local climate regulation through shading and screening as well as to the local environmental aesthetics. As with the study described in Chapter 2, this study demonstrates both the use of hedonic pricing to elicit the economic values of environmental services and amenities. It also goes further in identifying the spatial areas over which these relationships extend. This study's results might also be used to guide planning and policy making.

Chapter 4 details the methods and results of a case study example of the use of environmental modeling and economic valuation to predict both the environmental and economic impacts of planned future land use in an urbanizing community, Farmington, Minnesota, USA. Using hedonic pricing to elicit economic values in combination with geographic information systems (GIS) based spatial models for ecosystem service delivery under a planned land-use scenario for the city, this analysis provides an example of a method that could be used to generate information to inform land-use planning and policy in local level land-use planning. As such, it represents an advance in generating policy-relevant information and techniques for predicting the environmental impacts of land-use change that could substantially improve the visibility of ecosystem services and amenities in local land-use planning.

Conclusions

At present, the development of the American landscape is occurring without full consideration of its damage to the delivery of vital ecosystem services and environmental amenities. This damage is, in many ways, an inadvertent consequence of the paucity of available methods for forecasting and incorporating presently invisible ecosystem amenities and services in land-use decision making. In conceptual terms, the studies encompassed in this dissertation help to remedy these methodological and conceptual shortfalls by creating a modeling and economic valuation framework that communities, in conjunction with researchers, may use to inform their land-use decisions. By implementing the valuation of ecosystem services in a real-world context, this research develops a novel application of ecosystem service valuation to policy evaluation. As such, it represents a major step forward in the larger move towards understanding the ecological sustainability ramifications of human activities.

At a practical level, this project has great potential to increase the visibility of ecosystem services and amenities in local planning and thus to improve both the environmental condition of future landscapes and the economic condition of future communities. The significance of projects such as those incorporated in this dissertation is highlighted by a National Research Council publication that examined the current incorporation of ecosystem service valuation in planning (National Research Council, 2004b). One of this study's key findings was that, although existing valuation methods are adequate for improving decision-making, they are used largely in academic exercises and methods for their application to real-world policy are essentially non-existent. As a result, this committee set forth a mandate for projects like this one that improve the real-world applicability of ecosystem service valuation.

Collectively, the studies of which this dissertation is comprised contribute to our understanding of both the economic value of ecosystem services and of the impacts of urbanization on ecosystem service and amenity delivery. This research is significant not only in the generation of methods for predicting and valuing ecosystem services and environmental amenities, but also in the novel and practical application of environmental modeling and valuation to the evaluation of local land-use policy. These studies thus represent a major research advance in human-environment modeling that, with some modification and expansion, will enable policy makers in the study area and in other regions struggling with rapid urbanization to minimize negative ecological impacts and to create more ecologically sustainable future landscapes.

CHAPTER 2 – THE VALUE OF VIEWS AND OPEN SPACE: ESTIMATES FROM A HEDONIC PRICING MODEL FOR RAMSEY COUNTY, MINNESOTA, USA

This chapter presents the results of a study that addressed dissertation goal 1, to identify the economic values associated with changes in the delivery of environmental services and amenities, by using a hedonic pricing model to estimate the marginal implicit prices associated with changes in ecosystem service delivery. This study focuses on two ecosystem services, provision of access to areas for outdoor recreation and scenic quality, using highly urbanized Ramsey County, Minnesota, USA as its study area. The values that it identifies shed light on how individuals in the study area values these ecosystem services and provide information that, in itself, could be used to inform planning and policy-making. Additionally, this study's results provide a basis upon which the two studies described in the following chapters build. The material in this chapter is published in Sander and Polasky, 2009.

Introduction

Development decisions in the United States frequently fail to consider the values of environmental amenities. As a result, development may occur in ways that greatly reduce these amenities with negative environmental, economic, and social consequences. Communities rarely intentionally omit such amenities from their planning, rather, they fail to consider them because they lack means for incorporating them into market-driven land-use decision-making or because they are unaware of their values. If the values of these amenities were better recognized and incorporated into land-use planning, negative impacts associated with urbanization could be minimized. In this way, greater recognition of the economic impacts of environmental amenities could provide justification for actions that seek to preserve them.

Open space areas provide communities with numerous amenities, among them opportunities for recreation, scenic views, and even a simple absence of development

(Irwin, 2002). Open space also benefits human health by providing a location for outdoor exercise or to escape the stresses of urban environments (Giles-Corti et al., 2005; Krenichyn, 2006; Maller et al., 2006; Roemmich et al., 2006; Song et al., 2007) and may provide ecological benefits, for example, by acting as habitat for wildlife or improving water or air quality. Open space is frequently reduced as communities urbanize and along with it go the public goods it provides. Recognition of the economic benefits of open space access could enable planners to accurately assess the trade off between protecting open space and allowing land to develop (Hobden et al., 2004).

While the open space benefits described above are clearly of importance to people, their value may be difficult to quantify. As a result, communities may overlook such benefits in their planning. The benefits of open space and other environmental amenities, however, may be capitalized in the sales prices of homes in a community. If so, estimates of the dollar value of these benefits can be derived by careful analysis of home prices. Indeed, the effect of open space on residential property values has been the subject of much study in the last decade and numerous studies have found that increased proximity to open space increases home sale prices. Crompton (2001) reviewed 30 studies that investigated the impact of parks on property values, finding that all but five reported positive impacts on property values. These impacts varied considerably with park attributes (e.g., area, type), but generally could be considered to be 10%-20% of property values. Crompton also found general agreement among studies that the impact of parks on home values extends at least 500 feet and, in some cases, up to 2,000 feet into surrounding neighborhoods.

Studies completed since the writing of Crompton's review support the ideas that parks positively contribute to home sales prices and that this effect varies with open space type, protection status, and size (Bolitzer and Netusil, 2000; Hobden et al., 2004; Lutzenhiser and Netusil, 2001; Wu et al., 2004). For example, recent studies found that larger parks increase property values more than smaller parks (Lutzenhiser and Netusil, 2001; Tajima, 2003), natural area parks have a greater impact on home sale prices than most other park types (Lutzenhiser and Netusil, 2001), and permanently protected open space increases property values more than developable open space (Geoghegan, 2002;

Irwin, 2002). Increased proximity to open space with specific natural habitat types, for instance, forest and wetland, also significantly increases home sale prices (Mahan et al., 2000; Thorsnes, 2002). In these recent studies, the impacts of open space on home sale prices vary and are difficult to compare largely because studies used different methodologies, focused on different regions and time periods, measured open space access differently, and calculated marginal implicit prices for open space access in different manners. For example, Lutzenhiser and Netusil (2001) calculated marginal implicit prices of between $342 and $13,916 depending on park type and distance in Portland, Oregon; Wu et al (2004) calculated an increase in home value per foot of $0.24 for a 1000 foot decrease in distance to parks in Portland, Oregon; and Anderson and West determined that the value of the average home increased by between $246 and $1,790 depending on park type when the distance between a home and park were halved in the Minneapolis-St. Paul, Minnesota area. Recent studies also indicate that other landscape conditions may influence the degree to which open space impacts property values. For example, open space was found to be of greater value in neighborhoods that were dense, high-income, high-crime, highly urban, or that had many children in the Minneapolis-St. Paul metropolitan area (Anderson and West, 2006). Because open space access is often reduced as communities develop, recognition of the positive value of such open space could be an important component of landscape planning in urbanizing communities.

The scenic quality of a landscape is also altered as urbanization occurs with consequent affects on values. Changes in scenic amenities may also be reflected in property values. Bourassa et al (2004) reviewed 35 studies that examined the impact of views on home values. Although these authors found some variation in study conclusions, particularly in earlier studies, they noted that the bulk of studies reported that views positively impacted the values of residential homes. This impact varied widely from 1% (Beron et al., 2001) to as much as 147% (Benson et al., 1997). The authors suggest several reasons for this variation, among them that studies used different variables, types of views, and methods and were conducted in different cities at different points in time. A closer look at the studies reviewed and the few studies published since reveals that views including certain land-use and land-cover types impact property values considerably. These include water (Benson et al., 1998; Bishop et al., 2004; Bourassa et al., 2004; Jim and Chen, 2006; Loomis and Feldman, 2003; Luttik, 2000), urban green space areas (Bishop et al., 2004; Jim and Chen, 2006), and forests (Tyrvainen and Miettinen, 2000), all of which have been found to positively impact property values. Indeed, ocean views have been found to increase property values by as much as 60% (Benson et al., 1998). Conversely, views of industrial lands and roads have been found to negatively impact home values (Lake et al., 2000b). View structure or composition may also influence land sale prices. For example, views with more diversity (i.e., more land-cover types) were found to increase property values in the state of Wyoming, U.S.A. (Bastian et al., 2002).

Some studies, however, have reported the impacts of views on property values to be insignificant. A study conducted in Glasgow, Scotland, concluded that views containing parks, water, and vegetation did not significantly influence property values (Lake et al., 2000a, 2000b). Similarly, Paterson and Boyle (2002) found the impacts of views of agricultural land and water on property prices to be inconsequential. Thus, although views with certain characteristics do appear to positively impact property values, no general consensus exists as to the extent of these impacts (Yu et al., 2007) and the values calculated by studies are difficult to compare given that they used different methods, study areas, time frames, and means for quantifying views. Given the potentially large changes in views that occur with development, an important research question is the value of such changes as perceived by community residents. Assessing the impacts of land-use and land-cover changes on views is likely to become increasingly important to land-use and natural resource planners. Here again, recognition of the value of this amenity could be an important component of landscape planning in urbanizing communities.

As environmental amenities are frequently negatively affected by urbanization and because this is often reflected in home sale prices, estimates of the monetary value of these impacts would serve to improve land-use planning. This study identifies the degree of influence of the two environmental amenities discussed in the preceding paragraphs, view quality and open space access, on residential property values in Ramsey County, Minnesota using a hedonic pricing model. In estimating the values of these amenities, we hope not only to illustrate their importance to residential property owners, but also to provide planners and policy makers with estimates of values that would permit them to better evaluate the impacts of land-use change before decisions are made and landscape changes become irreversible. Our results may thus be used to inform land-use planning so as to minimize the negative economic, social, and environmental outcomes associated with urbanization.

The hedonic price model

The hedonic price model applied in this paper uses data on housing prices along with observable characteristics of the house and the environment to estimate the marginal implicit price of each characteristic. The marginal implicit price of individual characteristics can be estimated using a multiple regression model with housing price as the dependent variable and various characteristics as explanatory variables (see Freeman, 2003 for a complete description of the hedonic pricing model). Under the assumptions that the housing market is in equilibrium and that the area studied lies within a single housing market, the estimated marginal implicit prices derived from regression coefficients represent the price an individual would be willing to pay for an additional unit of a particular characteristic holding all other characteristics constant. So, for example, the estimated value of proximity to open space could be derived from the coefficient on proximity to open space in the regression model.

We use ordinary least squares regression analysis to estimate the hedonic pricing model to relate home sale price to the parcel, structural, neighborhood, and environmental characteristics of each property. This model may be written as:

$$\ln P_i = \beta_0 + \beta_1 S_i + \beta_2 N_i + \beta_3 Q_i + \varepsilon_i$$

where P_i is the price of property i, S_i is a vector of parcel and structural characteristics of property i (e.g., lot size, number of rooms, age, house style), N_i is a vector of neighborhood characteristics (e.g., neighborhood crime rate, population density, household income), Q_i is a vector of environmental characteristics (e.g., proximity to lakes, proximity to open space, views), and ε_i is an error term. The natural log of home sale value is the dependent variable. Natural logs were also used for distance variables and for lot acreage, finished square feet, and view area variables since the effect of these variables on home sale price was expected to decline with increased levels of these characteristics. Details on the estimation procedure and variables are described below.

It is important to note that although the hedonic pricing method may be used to estimate some of the value associated with environmental amenities, it typically does not provide a full estimate of value. The value estimated using the hedonic model reflects only the value of environmental amenities that accrue to the owners of single family homes. Such benefits are typically highly localized. For example, in the case of open space, benefits valued by homeowners include access to recreational space and increased scenery and wildlife viewing opportunities (Thorsnes, 2002). Other less localized benefits, for instance pollution filtration, carbon sequestration or more general provision of public goods, are not likely to be captured by the hedonic pricing method because they are less likely to be capitalized in the values of nearby homes. As such, the hedonic pricing method can be used to provide a partial, not total, estimate of the value of many environmental amenities.

Study area and data

The study area, Ramsey County, Minnesota, USA, is located in the east-central portion of the state (Figure 1) in the Minneapolis-St. Paul metropolitan area. It is a largely urban county with a population of nearly 500,000. The county encompasses an area of 441 km^2 and contains 19 cities, including St. Paul, the state capital of Minnesota. The Mississippi River runs along the south and southwestern borders of the county.

Figure 1. Location of the study area, Ramsey County, MN.

Real estate, structural and sales data used in this study came from the Metro GIS Regional Parcel Dataset. This dataset contains spatially-referenced ownership, tax, structural, and sale data for all parcels in the seven county Minneapolis-St. Paul metropolitan area. Using this dataset, we identified 5,364 single-family residential properties that sold in Ramsey County in 2005. Data were screened to remove properties with incomplete or questionable attribute data. After screening, the final dataset consisted of 4,918 single-family residential properties.

Both estimated market values for taxation purposes and actual sales values were available for all properties in the data set. We used actual sales values as the dependent variable in this study. Actual sales values are preferable in hedonic pricing studies as assessment values may not accurately match market prices (Freeman, 2003). The mean and median sale prices for single-family residential properties sold in 2005 were $255,955 and $222,000, respectively. Home sale prices ranged from $65,000 to $1,740,000.

We collected information on a set of structural, neighborhood, environmental variables for each property in the dataset using a geographic information system (GIS). These variables are summarized in Table 1 along with the expected impact of each variable on home sales prices. Descriptive statistics for each variable may be found in Table 2. Data for all structural variables came from the Metro GIS Regional Parcel Dataset described above with two exceptions. Because the elevation of the land on which a property sits has previously been found to influence its sales price (Mahan et al., 2000; Wu et al., 2004), we determined the lot elevation for each property using a 10 meter digital elevation map (DEM) available from the Twin Cities Metropolitan Council and GIS techniques. We also estimated a dummy (categorical) variable for each property to identify whether it was situated within the boundaries of a flood zone as determined by the Federal Emergency Management Agency (FEMA) and as indicated by a polygon dataset available from the Minnesota Department of Natural Resources. We included this variable because we felt that properties that were more prone to flooding would experience reduced sales prices due to the risk of property damage and higher insurance rates (Bin and Polasky 2004).

Table 1. Definitions for study variables and their expected relationship to home sale values.

Variable Name	Definition	Expected Impact on Sale Price
Structural Variables		
age	Year home was built subtracted from 2005	Positive
sqft	Finished square feet in home	Positive
acres	Lot area in acres	Positive
basement	Dummy variable indicating presence (1) /absence (0) of basement	Positive
elevation	Elevation of lot on which the home sits in feet	Positive
flood	Dummy variable indicating whether lot is in a FEMA floodway (1) or not (0)	Negative
Neighborhood Variables		
busyrd	Distance to closest road with high traffic volume in meters	Positive
cbd	Distance to closest central business district (Minneapolis or St. Paul) in meters	Negative*
shop	Distance to closest shopping center in meters	Positive
college	Distance to closest college or university in meters	Negative*
mca_3rd	Average 3rd grade Minnesota Comprehensive Assessment score for local elementary school	Positive
mca_5th	Average 5th grade Minnesota Comprehensive Assessment score for local elementary school	Positive
mca_ms	Average 7th grade Minnesota Comprehensive Assessment score for local middle school	Positive
tax_rate	Tax amount divided by estimated market value of home (times 100)	Negative*
View Variables		
viewarea	Viewshed area in square meters	Positive
elev_std	Standard deviation of elevations in a viewshed (measure of relief)	Positive
view_rich	View richness calculated as percentage of possible land-use and land-cover types present in a viewshed	Negative*
per_forest	Percentage of a viewshed composed of forest	Positive
per_grassy	Percentage of a viewshed composed of grassy land covers	Positive
per_water	Percentage of a viewshed composed of water	Positive
dtstp_view	Dummy variable indicating if property has view of downtown St Paul (0 if no, 1 if yes)	Positive
Open Space Variables		
lgpkrd	Road distance to closest park in meters	Negative*
traileuc	Euclidean distance to closest trail in meters	Negative*
lake	Euclidean distance to closest lake in meters	Negative*
stream	Euclidean distance to closest stream in meters	Negative*
Market Segment Variables (reference location is east St. Paul)		
nw_stpaul	Home location dummy variable (1 if northwest St. Paul, otherwise 1)	Positive
sw_stpaul	Home location dummy variable (1 if southwest St. Paul, otherwise 1)	Positive
c_stpaul	Home location dummy variable (1 if central St. Paul, otherwise 1)	Positive
sd282623	Home location dummy variable (1 if St. Anthony-New Brighton/Roseville school districts, otherwise 1)	Positive
sd621	Home location dummy variable (1 if Mounds View school district, otherwise 1)	Positive
sd622	Home location dummy variable (1 if N St Paul-Maplewood school district, otherwise 1)	Positive
sd624	Home location dummy variable(1 if White Bear Lake school district, otherwise 1)	Positive

* For distance variables, a negative expected relationship indicates that individuals pay more to live closer to a feature.

Table 2. Descriptive statistics for quantitative variables.

Variable Name	Mean	Standard Deviation	Median	Minimum	Maximum
Structural Variables					
sale_value	255,954.79	127,018.48	222,000.00	65,000.00	1,740,500.00
age	60.02	28.59	55.00	1.00	141.00
sqft	1,399.74	635.84	1,226.00	440.00	7,040.00
acres	0.24	0.24	0.17	0.04	4.42
elevation	919.74	44.82	921.00	720.00	1,068.00
Neighborhood Variables					
busyrd	137.07	138.43	110.00	0.00	1,880.00
cbd	5,457.53	4,063.68	4,418.59	0.00	18,577.96
shop	1,372.99	730.59	1,297.88	30.00	5,750.24
college	2,583.69	1,940.50	2,115.78	8.42	9,594.02
mca_3rd	1523.09	94.54	1518.15	1335.58	1732.40
mca_5th	1558.49	105.60	1563.06	1391.93	1735.23
mca_ms	1,461.55	110.14	1,464.28	1,383.76	1,525.22
tax_rate	1.00	0.16	1.00	0.52	4.32
View Variables					
Viewarea	160,039.60	19,1502.81	97,402.76	7,087.36	2,153,152.83
elev_std	12.28	10.37	9.69	0.00	114.73
view_rich	30.73	13.71	31.58	5.26	73.68
per_forest	4.21	10.25	0.00	0.00	93.00
per_grassy	0.79	4.41	0.00	0.00	63.00
per_water	2.34	9.88	0.00	0.00	93.18
Open Space Variables					
lgpk_rd	609.46	432.37	524.30	0.00	2,853.41
traileuc	612.18	256.69	452.93	0.00	4,315.34
lake	958.24	758.54	721.11	0.00	3,500.00
stream	1,041.62	781.87	825.65	0.00	3,907.86

n = 4,918

Neighborhood variables were estimated for each property using several data sources. First, as access to certain amenities and disamenities may impact home sale prices, Euclidean distances from each parcel centroid to the closest shopping center, central business district, road with a high traffic volume, and college or university were calculated using a GIS. We located shopping centers using GIS polygon files available from the Twin Cities Metropolitan Council depicting major shopping centers and central business districts using Twin Cities Metro Transit downtown fare zones for Minneapolis and St. Paul. College and university locations were identified using the Metro GIS Regional Parcel Dataset described previously and high traffic volume roads were identified from the Met Council and The Lawrence Group Functional Class Roads dataset. As home sale prices may be also influenced by the quality of neighborhood schools, we calculated the average Minnesota Comprehensive Assessment test scores for each neighborhood school at the third, fifth, and seventh grade levels to indicate school quality. We obtained test scores for the year 2005 from the Minnesota Department of Education (http://education.state.mn.us/MDE/Data/index.html) and averaged scores for each school and grade level and linked them to each residential property by their 2005 elementary and middle school district in a GIS. Because the level of taxation in a property's community has been found to impact sales prices in past studies (Mahan et al., 2000), we calculated an additional variable, tax rate, using estimated market values and tax rates from the parcel dataset.

To include the impacts of a property being located in different Ramsey County submarkets, we divided the Ramsey County housing market into a series of market segments. Initially, we delineated market segments using major school districts. This division proved reasonable for the suburbs, where there were relatively few sales and there was relatively little diversity within each district, but not for St. Paul, which has only one major school district, contained more than half of all properties sold in 2005, and has large diversity across neighborhoods. As such, we further divided St. Paul based on middle school districts, then merged adjacent school districts with similar attributes. This resulted in the creation of eight housing submarkets, listed here in order of mean residence sale price from lowest to highest: east St. Paul (reference location), central St. Paul, North St. Paul-Maplewood School District, northwest St. Paul, White Bear Lake School District, St. Anthony-New Brighton and Roseville School Districts, Mounds View School District, and southwest St. Paul. Dummy variables were used to identify each parcel's market segment.

Open space access may be assessed in several ways in hedonic pricing studies. Some studies use dummy variables to indicate the presence or absence of open space areas within a specified distance of a property (Lutzenhiser and Netusil, 2001; Netusil, 2005). More commonly, however, studies utilize continuous measurements that identify the land area or percent of open space within a specified buffer distance from sampled properties (Geoghegan et al., 1997; Acharya and Bennett, 2001; Geoghegan, 2002; Irwin, 2002; Ready and Abdalla, 2005; Kong et al., 2007), the distance or travel time from a property to the nearest open space area (Bolitzer and Netusil, 2000; Lake et al. 2000a; Shultz and King, 2001;Tajima, 2003; Wu et al., 2004; Anderson and West, 2006; Kong et al., 2007) or the size of a property's nearest open space area (Lutsenhiser and Netusil 2001). We chose to use the distance to each property's nearest open space area to indicate access to these areas in this study for two reasons. First, previous studies in the study area found that such distance variables contributed significantly to home sales prices (Doss and Taff, 1996; Anderson and West, 2006). Second, we felt that open space areas were likely to be accessed using road networks or, where possible, by crossing other parcels in a roughly as-the-crow-flies manner and that distance measurements would thus best approximate homeowners' perceptions of their access to open space. We believed that open space proximity would thus provide the best measure of open space access for residential parcels in the study area.

We calculated each residential parcel's proximity to open space features of interest in a GIS. These included terrestrial parks 1 ha or larger in area, recreational greenway trails, lakes, and streams as these features are often the sites of outdoor recreational activities in the Minneapolis-St. Paul Metropolitan area. To locate parks, we used a parks polygon layer created by combining data from two datasets including parks, The Lawrence Group Landmarks and Twin Cities Metropolitan Council Regional Recreation Open Space Features, and selected those parks with areas of 1 ha or greater. In this case, parks included recreational parks, wildlife refuges, nature reserves, and wildlife management areas. We identified trails using two GIS datasets, Metropolitan Council Regional and State Trails and a bikeways dataset from the Minnesota Department of Transportation. Following screening of both datasets to remove trails that used city streets and planned or proposed trails, we merged them to produce a single recreational trails dataset that included paved and unpaved recreational greenway trails.

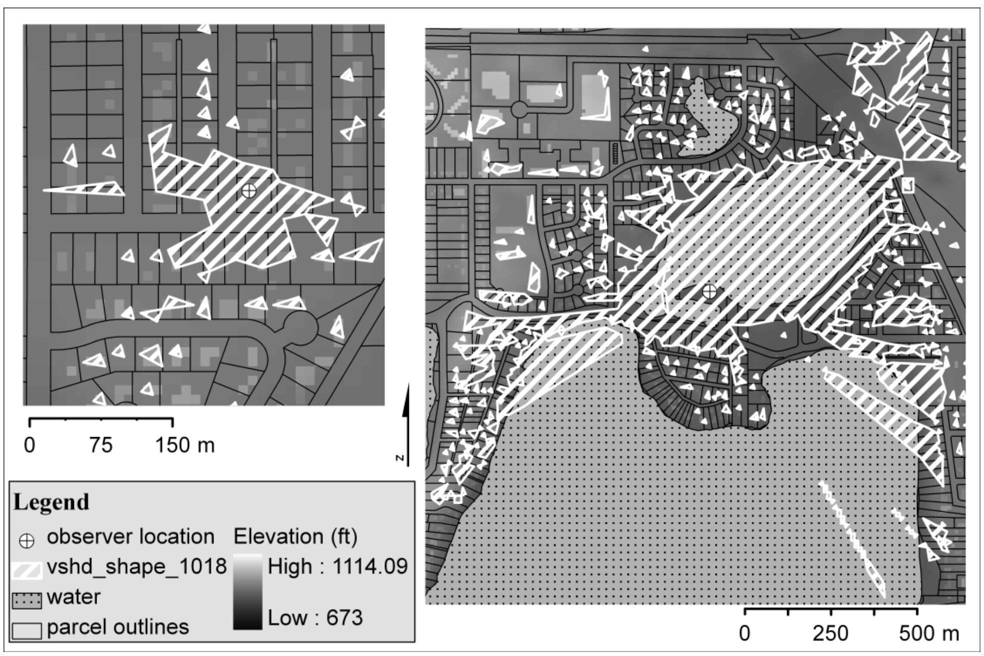
Lakes and streams were identified using GIS datasets available from the Minnesota Department of Natural Resources.

Distances were calculated within a GIS in two ways. First, we calculated Euclidean distances between the centroid of each subject residential property and the closest trail, lake, and stream. We then calculated road distances between each property and the closest large park. We calculated road distances to parks because we felt that they would better approximate homeowners perceptions of their access to open space as they would likely access these areas on roads rather than by cutting across other parcels in an as-the-crow-flies fashion. Initial model runs indicated that this was indeed the case as none showed significant results for the impact of Euclidean distance to parks on home sales prices. Thus, four open space access variables were used in the final analysis: Euclidean distances to the closest (1) trail, (2) lake, and (3) stream, and road distances to the closest (4) park.

To provide a measure of the scenic quality of the landscape surrounding each residential property, we calculated viewsheds using the VIEWSHED function in ArcGIS. This function computes the locations in a DEM that are connected to an observation location, in this case, each home sold in 2005, by a line-of-sight within a specified distance accounting for the location, height, and angle of view of the viewer in three dimensions. Because existing DEMs for the area did not include aspects of the built environment likely to obstruct views, we constructed a DEM for use in viewshed calculation using the following steps. First, we obtained a GIS dataset containing the footprints and locations of all Ramsey County buildings over 7.5 m^2 in area from the Ramsey County Surveyor's Office. We assigned a height to each building based on its land-use type, if a parcel's land-use classification was not residential, or based on its dwelling type, if a parcel was classified as residential, as indicated by the parcel dataset. The mean number of stories in buildings of each type was identified via visual surveys of 20 buildings of each type and multiplied by three, assuming stories to be 3 m on average, and adding 2 m to account for roof and basement offsets. Based on previous studies, we considered building heights assigned using this methodology to be representative of actual building heights (Lake et al., 2000a; Sander and Manson, 2007) so that calculated viewsheds would accurately approximate actual views. We generated a final DEM for use in viewshed calculation by converting the resulting vector layer to raster format and summing this with an existing 10 m DEM for the area available from the Twin Cities Metropolitan Council.

We calculated a viewshed for each property using the DEM created above and locating observer points at the top story of each home in each sampled parcel such that one observer point was located on each exterior surface. We specified a maximum view radius of 1000 m. Viewsheds calculated in this manner identified areas that would be visible from top story windows in each home and would likely represent each property's best view. Example viewsheds are provided in Figure 2.

Figure 2. Sample viewsheds.



In order to incorporate the estimated viewsheds in the hedonic analysis, we calculated a series of view quality metrics for each property. The first, areal extent, quantified the overall area encompassed by each view and was calculated using simple GIS techniques. We also computed metrics to quantify the composition of each property's viewshed. To identify the composition of each viewshed in term of land covers of interest, we calculated the areas of three, more natural land-cover classes, forest (including areas of contiguous tree cover with minimal amounts of impervious surface), water (e.g., lakes, streams), and grassy areas (e.g., lawns, golf courses, playing fields, prairie patches), in each viewshed using a 2005 land-cover map available from the University of Minnesota's Remote Sensing and Geospatial Analysis Laboratory and computed the percentage of each viewshed composed of each of these land covers. We also computed the richness of each viewshed as the percentage of possible land-cover classes it contained. For instance, a home with a viewshed containing 10 of 15 possible land-cover types would have a calculated richness of 67%. This provided a measure of complexity for each view. Because views of urban cityscapes may impact property values, we also located properties with views of downtown St. Paul, that is, views that intersected Metro Transit's downtown St. Paul fare zone, and identified these using a dummy variable. Lastly, we used GIS techniques to identify the standard deviation of landscape elevations present in each view. This provided a measure of the relief, or elevation range, present in a view.

Results and Discussion

Table 3 presents the results of this analysis. Residuals were examined for spatial autocorrelation by calculating Moran's *I* statistic. The resulting Moran's *I* estimate, 0.0015, was not significant ($p > 0.05$), so we did not correct for spatial autocorrelation in this estimation. We tested for heteroskedasticity using a Breusch-Pagan test. The resulting test statistic was significant at the 1% level. We corrected for this by generating heteroskedasticity-consistent standard errors using White's method (White, 1980).

Table 3. Regression results.

Variable Name	Est. Coefficient	Standard Error	*t*-value
Structural Variables			
Constant	5.7963376**	0.28979233	20.001694
age	-0.0015039**	0.00015373	-9.782596
ln_sqft	0.5717987**	0.01005176	56.8854
ln_acres	0.1332237**	0.00834667	15.961286
basement	0.0791416**	0.03252299	2.4334057
elevation	0.0005768**	0.00007040	8.1926345
flood	-0.0812112*	0.04175447	-1.944971
Neighborhood Variables			
ln_busyrd	0.0161386**	0.00219182	7.3631064
ln_cbd	0.0026645*	0.00124222	2.1449754
ln_shop	0.0229511**	0.00417394	5.4986527
ln_college	-0.0384366**	0.00426684	-9.0082033
mca_3rd	0.0004524**	0.00004938	9.1612123
mca_5th	0.0001652**	0.00004545	3.63545
mca_ms	0.0009389**	0.00018689	5.0239398
tax_rate	-0.0852605**	0.02683265	-3.1774923
View Variables			
ln_viewarea	0.015095**	0.00443820	3.4011562
elev_std	0.0002878	0.00024630	1.1683778
view_rich	-0.0011095**	0.00025271	-4.3905254
per_forest	0.0001723	0.00028385	0.6071164
per_grassy	0.0021555**	0.00063264	3.4072016
per_water	0.0028978**	0.00042755	6.7777689
dtstp_view	-0.0466663**	0.01513651	-3.0830259
Open Space Variables			
ln_lgpkrd	-0.0053214**	0.00212533	-2.5037749
ln_traileuc	-0.0046619**	0.00151491	-3.0773717
ln_lake	-0.0084211**	0.00242615	-3.4709679
ln_stream	-0.0049768*	0.00235806	-2.1105395
Market Segment Variables (Reference location is east St. Paul			
nw_st_paul	0.0530447*	0.02384070	2.2249629
sw_st_paul	0.3070399**	0.01607988	19.09466
c_st_paul	0.0322594**	0.00897607	3.5939302
sd282_623	-0.177884**	0.02671403	-6.6588224
sd621	-0.1930452**	0.02298509	-8.3987143
sd622	-0.1806954**	0.01886870	-9.5764628
sd624	-0.1818687**	0.02151404	-8.453491

**$p < 0.01$, *$p < 0.05$

Dependent variable = ln_price

R^2 = 0.7915

Adjusted R^2 = 0.7901

F = 579.460

All structural and neighborhood variables were statistically significant at the 5% level. All signs for structural variables and most signs for neighborhood variables were as predicted. The signs for two neighborhood variables were not as expected, those for distance to the closest central business district and distance to the closest shopping center. We had expected these variables to indicate the ease with which homeowners could access shopping and places of business. However, our results indicate that proximity to these features has other negative consequences that reduce property values. It thus seems likely that these features may have nuisance values, perhaps as a result of increased noise levels, congestion, and crime rates in their vicinities that outweigh the amenity value.

Our results clearly indicate that both open space proximity and view attributes influence home sale prices. The coefficients for most view variables were significant and positive, among them those for view area and view percent composition of water and grassy areas. The marginal implicit price of increasing the area of a home's viewshed by 100 m^2 evaluated at the mean home sale price ($255,955) and initial area of 1000 m^2 is $386. The marginal implicit prices of increasing the percentage of a home's view composed of grassy surfaces or water by 10%, evaluated at the mean home sale price, are $5,517 and $7,417, respectively. This illustrates a preference on the part of single family homeowners for homes with large views including these land-cover types.

Surprisingly, although the sign of the coefficient for the percentage of a view composed of forest was positive, this variable did not significantly impact home sales values, indicating that forested areas are not particularly desirable in residential views. This may be a result of the tendency for trees to restrict views. It is still possible that views that include a high proportion of tree cover, for instance, views of heavily treed residential streets, might positively influence home sale prices. However, this study examined only the influence of views of forest land cover on home sale prices and did not examine the influence of views including varying amounts of tree cover in non-forested environments such as residential areas. This should be the subject of future study as the amount of tree cover visible from a property may influence its sale price.

The standard deviation of elevations found within a viewshed indicates the amount of relief in a view and was expected to positively influence home sale prices.

Although this variable's coefficient had the expected sign, it was not significant (p = 0.242711). This indicates that the degree of relief in views does not influence home sale prices in the study area. However, the range of elevations in the study area is fairly low (less than 300 feet), so this may also be the result of low variation in this attribute in the region.

The sign of the dummy variable indicating that a property has a view of downtown St. Paul was negative, the opposite of what was expected. This relationship was significant at the 0.001 level. Calculating the marginal implicit price of downtown St. Paul views at the mean home sale price indicates that views of downtown St. Paul actually reduce home sale prices by $11,944. This, however, may result from the way in which this variable was measured and may not actually indicate negative values. Because this study used a maximum view distance of 1 km, properties located further than 1 km from downtown St. Paul were assumed not have views of the downtown area. It is possible that some of these properties actually do have views of downtown St. Paul, but this analysis identified only properties in close proximity to the downtown area as having these views. As properties near the downtown area tend to have low property values because of a number of factors, among them high crime rates, this would also explain this negative result.

The coefficient for view richness, which measures the number of land types visible, was also negative and significant. The marginal implicit price for increasing the richness of a view by 10% evaluated at the mean home sale price indicated a price decrease of $2,834. This suggests a preference on the part of homeowners for views with low diversity, that is, a low number of land-cover types in view. We had expected this variable to positively impact home sale prices based on the results of a previous study that found increased diversity in views to be highly valued (Bastian et al., 2002). However, that study was conducted in Wyoming, a rural land market, where increased diversity likely corresponds to an increase in natural and agricultural land-cover types visible in a view. In the Ramsey County area, where most land-use and land-cover classes are urban, higher view richness likely increases the number of different urban land-use classes in view, making it more likely that undesirable urban land uses will be visible from a home.

The signs of all open space access variables were as expected, although not all variables were significant. This indicates that, in general, decreasing the distance to the nearest open space feature increases home sale prices. Homes located near both lakes and streams have significantly increased sale values. Evaluated at the mean home sale price and an initial distance of 1000 m, the marginal implicit price for reducing the distance to the nearest lake by 100 m produces a $216 increase in home sale value, the highest marginal implicit price of all open space feature types. Proximity to streams influenced home values to a lesser degree. The marginal implicit price for reducing the distance between a home and the closest stream by 100 m evaluated at the mean home sale price and a starting distance of 1000 m suggests a home sale price increase of $127. Thus, although it is desirable to live near a stream, it is more desirable to live near a lake.

Our results indicate that parks and trails are highly desirable features. The marginal implicit price for decreasing the road distance to the closest park by 100 m, when evaluated at an initial distance of 1000 m and the mean home sale value, indicates an increase in home sale value of $136 while the marginal implicit price for decreasing the Euclidean distance from a home to the closest trail evaluated in the same manner indicates an increase of $119. Thus, close proximity to parks on roads and to trails as-the-crow-flies increases home values. This suggests that individuals may be more inclined to access parks by roads, either by driving or walking, and perceive proximity to them on a road network. Conversely, individuals appear to consider proximity to trails in terms of straight-line distance and may not access them via roads, possibly because these features have more continuously-located access points than parks. Thus, although both parks and trails do increase home sale prices, people appear to perceive and access them differently and this is reflected in the amount they pay to live near them.

Conclusions and Policy Implications

As urbanization intensifies in many parts of the United States, planners and policy makers will be forced to make important decisions about the arrangement and type of urban land uses in their communities. These decisions will determine the composition and arrangement of future landscapes. This, in turn, will influence the availability and condition of environmental amenities both locally and regionally. The values of these amenities should be given adequate consideration in making such decisions. Our results indicate that people value access to open space and scenic amenities. These values should be used to inform land-use planning so that decisions minimize the negative economic, social, and environmental outcomes associated with urbanization.

This study provides quantitative estimates of the value of two environmental amenities that are often reduced in urbanizing communities, scenic quality and open space. Our results, like those of previous studies, clearly indicate that a preference exists for living near parks, trails, streams, and lakes. People are willing to pay more for increased proximity to these features as indicated by higher home values. In agreement with past studies, we also found that many aspects of views significantly influence home sales prices. Our findings indicate that residential home owners pay more for views that encompass larger areas, include fewer land-cover types, and include higher percentages of water and grassy land covers. Conversely, highly urban views of the downtown St. Paul cityscape significantly reduce home sale prices, although this may be an artifact of the process used in measuring this variable and may not indicate actual negative value. The values calculated for the amenities studied here alone may be enough to provide communities and developers with grounds for preserving them, but it is important to recognize that the values calculated here do not represent the total values of the amenities in question. Rather, they represent the values of these amenities as they are reflected in single family home sales prices. As such, they do not include the values of these amenities that accrue to visitors or businesses nor are they likely to include ecological values that residents may fail to perceive directly. The total values of these amenities are thus likely to be higher than those estimated here.

These results have implications for land-use planning in urban areas. Because open space access and view attributes, particularly those related to more natural land covers, positively influence home sale prices, they should be considered as communities plan their future land use. Failure to do so will not only impact the environmental amenities themselves, but will also result in negative economic, social, and ecological outcomes. Using the values calculated here could help planners to assess the tradeoffs inherent in developing to different densities and in different landscape configurations. Communities using such values in their planning could not only justify the preservation of open space features and scenic quality, but could also avoid negative economic consequences associated with lost tax revenues.

This study suggests a number of directions for future research. First, we examined the impact views with varying percent compositions of a variety of natural land-cover types on home sale prices. We did not examine the impacts of views with different degrees and types of vegetated areas on home values. Although this might be difficult to accomplish on a large scale or with a large number of properties, the increasing availability of LIDAR (Light Detection and Ranging) data, from which vegetation may be extracted, may facilitate such studies. As the arrangement and type of vegetation in a home's view on a fine scale is likely to impact not only the home's sale price, but the environmental quality of its neighborhood, such studies could provide more detailed information for planners and policy makers. Also, this study did not examine the impacts of different urban land uses in views or of different combinations thereof on home sale prices and this should be explored in future studies. Additionally, it should be noted that the values of amenities will likely change over time. If development increases the scarcity of open space and other environmental amenities, these amenities may have increased value for nearby residents. On the other hand, increased provision of parks and open space may lower the marginal value of additional amenities. Studies across different regions with different scarcity of open space and other amenities would help to uncover the changing marginal value of amenities with scarcity. This subject warrants further examination in order to better inform land-use planning. Lastly, this study did not look at how open space value as capitalized in home sale prices varies with neighborhood characteristics like density or distance from central business districts. Studies that examine these relationships will further serve to inform land-use planning and policy so that urbanization may occur in a manner that minimizes its negative economic, social, and environmental impacts.

CHAPTER 3 –THE VALUE OF URBAN TREE COVER: A HEDONIC PROPERTY PRICE MODEL IN RAMSEY AND DAKOTA COUNTIES, MINNESOTA, USA

As in Chapter 2, the study detailed in this chapter also addresses dissertation goal 1, to identify the economic values associated with changes in the delivery of environmental services and amenities, but goes further in its analysis of these values. Like Chapter 2, this study uses a hedonic pricing model to elicit the values associated with changes in the delivery of several ecosystem services, including access to outdoor recreation suitable and scenic quality. However, it uses an expanded study area that includes both Ramsey and Dakota Counties in the metropolitan Twin Cities area and investigates the values of additional services provided by tree cover. As such, it provides a picture of the economic values of these services in both urban and suburban areas of the metropolitan area and identifies the values of a larger list of services, thus providing more insight into the way in which individuals value these services regionally that could be used to inform planning and policy. This study also makes strides methodologically, addressing issues related to spatial autocorrelation using a more complex regression model and identifying how the values of some services vary spatially. As such, the study detailed in this chapter provides the foundation for the study described in the next chapter which not only elicits the economic values for ecosystem services in a portion of this study area, but predicts how these services and their values will changes under planned future land-use conditions.

Introduction

Trees in urban areas provide a wide range of benefits. The environmental benefits of urban tree cover include protection against soil erosion, provision of habitat for wildlife, reductions in ozone and other air quality improvements, reductions in the urban heat island effect, energy savings through building shading and insulation, carbon sequestration, and stormwater runoff reductions (Beckett et al., 2000; Brack, 2002;

Dwyer et al., 1992; Laverne and Lewis, 1996; Maco and McPherson, 2003; McPherson et al., 1999; McPherson et al., 2005; Nowak and Crane 2002; Nowak et al., 2006a; Sailor, 1995; Scott et al., 1998; Simpson, 1998; Simpson and McPherson, 1996; Xiao et al., 2000). Trees also provide also cultural benefits that lead to improved quality of urban life as tree cover may improve the scenic quality of a city neighborhood, provide privacy, reduce stress, shelter residents from the negative effects of undesirable land uses, and improve retail areas by creating environments that are more attractive to consumers (Dwyer et al., 1991; Hull, 1992; Ellis et al., 2006; Laverne and Winson-Geideman, 2003; Sheets and Manzur, 1991; Westphal, 2003; Wolf, 2005). While the environmental and cultural benefits of urban trees are well documented, less is known about how urban residents value these non-market benefits.

Some of the environmental and cultural benefits generated by trees in may be capitalized into the values of residential and commercial properties and documenting these effects can provide evidence of the value of trees to urban communities. This study examines the impact of urban tree cover on home sale prices in the Minneapolis-St. Paul metropolitan area, Minnesota, USA. In particular, we examine how these effects vary spatially by estimating the relative effects of tree cover on a home's parcel and in several neighborhood areas around that parcel. Our results indicate that, although buyers pay more for homes in neighborhoods with higher tree cover, they do not pay more for homes with higher parcel tree cover. These conflicting impacts of tree cover are not well documented in previous studies and will help local governments recognize the barriers to producing optimal tree cover and to promote higher levels of tree cover using policy instruments such as zoning restrictions and tree planting subsidies.

Previous studies of the value of urban trees

A number of prior studies have estimated the monetary benefits provided to communities by urban forests (Table 4). These studies focus on different geographic locations and forest benefits and use different methods to identify urban forest value making direct comparison of results difficult. Nonetheless, these studies indicate that forests provide a positive economic benefit to local landowners and communities.

Table 4. Summary of previous studies of the economic value of urban trees.

Study	Measurement used	Location	Method	Results
Anderson and Cordell, 1988	Number of large, small, pine, and hardwood trees in front yards of residential single family properties	Athens, Georgia, USA	Hedonic pricing	Trees were found to be associated with a 3.5%-4.5% increase in homes sales price
Brack, 2002	Number, health, and size of trees planted in streets and parks	Canberra, Australia	Calculated dollar value of trees in terms of energy reduction, pollution mitigation, and carbon sequestration	Planted trees were estimated to have a combined value in terms of energy reduction, pollution mitigation, and carbon sequestration of US$20-67 million during the 2008-2012 time period
Dombrow et al., 2000	Dummy variable to indicate single-family residential properties that had mature trees	Baton Rouge, Louisiana, USA	Hedonic pricing	The presence of mature trees on a parcel contributed about 2% to home sales prices
Garrod and Willis, 1992	Percentage of forested areas of broadleaved trees; larch, Scots pine, and Corsican pine; and other conifers on Forestry Commission lands for homes located in 1km squares that contained these homes	Great Britain	Hedonic pricing	Broadleaved trees positively impacted home sales prices while coniferous trees negatively impacted home sales prices

Study	Measurement used	Location	Method	Results
Holmes et al., 2006	estimated exotic forest pest damages as indicated by hemlock health and percent deciduous, coniferous, and mixed forest types on parcels and within 0.1km, 0.5km, 1km buffers on parcels	Sparta, New Jersey, USA	Hedonic pricing	Deciduous cover within 0.5km and 1 km of homes positively impacted property values, conifereous cover within 0.5km enhanced property values, and mixed forests within 0.5km and 1km of homes negatively impacted property values; hemlock health significantly impacted property values with healthy hemlocks positively impacting values (no MIPs)
Jim, 2006	Detailed data related to size, species, health, structure, appearance, rarity, and habitat of heritage trees	Hong Kong	Formulatic expert method (developed by author)	Values for individual heritage trees ranged from HK$3.0 million to HK$4.39 million depending on tree species and characteristics
Maco and McPherson, 2003	Tree survey data	Davis, California, USA	Calculated total annual expenditures for urban forest management (e.g., planting, tree maintenance, damage mitigation) and total benefits (through direct and implied valuation) of urban forests (energy savings, atmospheric carbon reduction, stormwater runoff reductions, air quality improvement, aesthetic) for use in benefit-cost analysis	Benefits ($1.7million) exceeded costs ($449,353) by $1,248,464 annually for an average benefit of $52.43 per publicly maintained tree. The benefit-cost ration was 3.78:1.

Study	Measurement used	Location	Method	Results
Mansfield et al., 2005	Percentage of residential single family parcel that was forested, acres of forest on a parcel, percentage of forested land within 400m, 800m, and 1600m buffers around parcel, distances to private and institutional forests	Research Triangle, North Carolina, USA	Hedonic pricing	Proximity to both forest types and proportion of parcel that was forested both increased home sales prices, increasing forest cover on parcel by 10% adds less than $800 to home sales prices while adjacency to private forests add more than $8000
McPherson et al., 1999	Survey data for street and park trees	Modesto, California, USA	Calculated total annual expenditures for urban forest management (e.g., planting, tree maintenance, damage mitigation) and total benefits (through direct and implied valuation) of urban forests (energy savings, atmospheric carbon reduction, stormwater runoff reductions, air quality improvement, aesthetic) for use in benefit-cost analysis	Benefits exceeded costs by a factor of 1.89. Benefits were valued as follows: aesthetic -- $1,455,636, air quality improvement -- $1,442,036 ($15.82/tree), energy savings -- $1,000,560 ($10.97/tree), stormwater runoff reductions -- $616,139 ($6.76/tree), carbon sequestration -- $449,445 ($4.93/tree), net-- $4,964,816 ($54.44/tree). Costs totaled $2,623,384.
McPherson et al., 2005	Tree survey data for each city	Fort Collins, Colorado; Cheyenne, Wyoming; Bismark, North Dakota, Berkeley, California; and Glendale, Arizona, USA	Calculated total annual expenditures for urban forest management (e.g., planting, tree maintenance, damage mitigation) and total benefits (through direct and implied valuation) of urban forests (energy savings, atmospheric carbon reduction, stormwater runoff reductions, air quality improvement, aesthetic) for use in BENEFIT-COST ANALYSIS for each city	Benefits exceeded costs in all cities with benefit cost ratios ranging from 1.37-3.09. Benefits were valued as follows: aesthetic -- $21-$67/tree, stormwater runoff reduction -- up to $28/tree, energy savings -- up to $15/tree, carbon reduction -- $1-$2/tree, air quality improvement -- $-0.57-$1.52/tree, total -- $31-$89/tree.

Study	Measurement used	Location	Method	Results
Morales et al., 1976	Binary variable to indicate whether home had good or poor tree cover	Manchester, Connecticut, USA	Hedonic pricing	Tree cover increased property values by 6% of total price ($2,686)
Morales et al., 1980	Binary variable to indicate whether a property has good tree cover or not	Manchester, Connecticut, USA	Hedonic pricing	Tree cover increased property values by 6%
Morales et al., 1983	Binary variable to indicate whether a property had mature tree cover or not	Greece, New York, USA	Hedonic pricing	Trees on wooded lots added 10%-17% to home sales prices
Nowak et al., 2006b	Number of trees, species, and canopy cover	Minneapolis, MN	Calculated dollar value of trees in terms of air pollution mitigation and carbon sequestration	Minneapolis' urban forest's carbon storage is valued at $46 million and removes approximately $164,000 worth of carbon per year. Tree and shrubs together remove $1.9 million worth of air pollution per year. Total structural value of the area's forests is estimated at $756 million.
Nowak et al., 2006c	Number of trees, species, and canopy cover	Washington, D.C.	Calculated dollar value of trees in terms of air pollution mitigation and carbon sequestration	Washington D.C.'s urban forest's carbon storage is valued at $9.7 million and removes approximately $299,000 worth of carbon per year. Trees remove $2.5 million worth of air pollution per year. Total structural value of local forests is estimated at $3.6 billion.
Nowak et al., 2007	Number of trees, species, and canopy cover	New York, NY	Calculated dollar value of trees in terms of air pollution mitigation and carbon sequestration	New York City's urban forest's carbon storage is valued at $24.9 million and removes approximately $779,000 worth of carbon per year. Trees remove $10.6 million worth of air pollution per year. Total structural value of local forests is estimated at $5.2 billion.

Study	Measurement used	Location	Method	Results
Thompson et al., 1999	forest density and health	Lake Tahoe, California, USA	Hedonic pricing	Forest density and health contribute 5-20% to values of properties location at urban-wildland interface
Thorsnes, 2002	proximity of vacant building lots to forest preserves	Grand Rapids metropolitan area, Michigan, USA	Hedonic pricing	Lots that directly bordered a forest preserve sold at 19%-35% high prices than other lots, but effects were highly localized
Treiman and Gartner, 2006	willingness to pay a tax to establish a tree care fund for the local area	44 Missouri, USA communities	Contingent valuation	Residents of communites with populations greater than 50,000 strongly supported establishment of a trees care fund with a tax of $14-$16 per household per year.
Tyrväinen, 2001	willingness to pay to avoid construction on forested land and for wooded recreation areas	Joensuu and Salo, Finland	Contingent valuation	Half of respondents were willing to pay to avoid construction on forested land (average WTP of 74 - 206 FIM/year -- $19.23-$53.56) and more than two-thirds were willing to pay for use of wooded recreation areas (average WTP of 42 - 53 FIM/month -- $10.92-$13.78)
Tyrväinen and Miettinen, 2000	distance to closest forest and existence of forest view for terraced homes	Salo, Finland	Hedonic pricing	Property values decrease 5.9% on average with a 1 km increase in distance to forest and properties with forest views are 4.9% more expensive that properties that are otherwise similar
Vesely, 2007	willingness to pay to avoid 20% decrease in urban tree estate	Aotearoa, NZ	Contingent valuation	Household average annual WTP to avoid 20% reduction in urban tree estate was (2003) NZD 184 for a three year period ($143)

Several recent studies used contingent valuation (CV) to estimate the economic value of tree cover in urban areas (Treiman and Gartner, 2006; Tyrväinen, 2001; Veseley 2007). This survey-based method is frequently used to calculate individuals' willingness-to-pay for public goods. Typically, survey questions ask individuals whether they would be willing to pay a specified amount to provide for an increase in the public good of interest or to avoid a decline in that good. In applying CV to the valuation of urban trees, researchers generate a scenario in which some aspect of an urban forest changes and ask individuals how much they would pay to avoid this change or to cause this change to occur. CV studies may be conducted with little or no data about local forests, which can be an advantage as tree cover data are limited or non-existent in many areas and may also capture benefits not captured by other methods, for instance, environmental benefits accruing to large populations. However, values estimated using CV are often questioned because they represent only what individuals claim they would pay in a hypothetical situation and may not correspond closely with what they would actually pay in a real situation (More et al., 1988). Although CV studies of the value of urban tree cover conducted to date monetized different aspects of forest cover and thus are not directly comparable, their results all show that individuals in urban environments are willing-to-pay to maintain urban forests.

Hedonic pricing models can be used to calculate the value of urban trees based on the property characteristics and sale prices or assessed values of properties. Such studies require varying amounts of data on urban trees depending on the metrics used. Thus, they may be applied in a series of data rich and data poor environments.

Some hedonic pricing studies have used very simple and somewhat subjective measures of urban forest character. Among these are several studies that developed hedonic pricing models using binary dummy variables to identify parcels with good or mature forest cover. These studies found that good tree cover increased home sales prices by between 2% in Baton Rouge, Louisiana, USA (Dombrow et al., 2000) and 6% in Manchester, Connecticut, USA (Morales et al., 1976; Morales, 1980). This indicates that homeowners will pay more for properties that have good tree cover. However, because the binary variable used by these studies is subjective, it is difficult to generalize their conclusions as definitions of "good" and "mature" tree cover are likely to vary.

A number of hedonic pricing studies used more well-defined metrics to quantify urban forest characteristics. Some of these studies used proximity to forested areas to identify the value of urban forests, finding that increased proximity to forested areas increases home sale prices. For example, a study conducted in the area around Grand Rapids, Michigan, USA found that housing lots that directly bordered a forest preserve sold for 19%-35% higher prices than other lots (Thorsnes, 2002). A study conducted in Finland found that the values of terraced homes decreased by an average of 5.9% with a 1 km increase in their distance from the closest forest, and homes with forest views were 4.9% more expensive than otherwise comparable properties (Tyrvainen and Miettinen, 2000). A similar study in North Carolina, USA found that proximity to both private and institutional forests increased home sale prices (Mansfield et al., 2005). Thus, these studies indicate that homeowners will pay more for homes that are closer to forests. However, they tell us little about the value of trees that are not part of contiguous urban forests, for instance street and yard trees.

To address this problem, some hedonic pricing studies have examined the impact of tree cover on property values using counts of tree numbers or estimates of percent tree cover. These studies generally found that increasing tree cover increases home sales prices, although only within certain areas and for certain tree types. A North Carolina, USA study found that increasing forest cover on a parcel by 10% increased home sales prices by $800 (Mansfield et al., 2005). Anderson and Cordell (1988) found that homes with more than five front yard trees sold for 3.5%-4.5% more than comparable homes with fewer trees, with a mean value of $343 per tree, $376 for each hardwood tree and $319 for each pine. Other studies have also noted a similar difference in value with increases in broadleaved and deciduous cover in the area surrounding a home producing greater price increase than increases in conifer cover, and, in some cases, increases in conifer cover or in mixed cover types were actually found to reduce sale prices (Garrod and Willis, 1992; Holmes et al., 2006). For example, a study conducted in New Jersey, USA found that deciduous tree cover within 0.5 km and 1 km of homes positively impacted property values as did coniferous cover within 0.5 km, while mixed forests within 0.5 km and 1 km of homes negatively impacted property values (Holmes et al., 2006). Thus, higher percentages of tree cover increase home sales values, although this effect varies with tree species and distance from homes.

Some studies have used hedonic pricing to examine the impact of tree health on home values. In general, these studies found that healthier, better maintained forests increased home sale prices while less healthy forests could actually decrease home sale prices. A 1999 study conducted in the Lake Tahoe Basin of California, USA found that the degree of disease infection in trees near a home negatively impacted home sale prices and that thinning and removing infected trees increased home sales prices by between $19,800 and $109,300 (Thompson et al., 1999). Another study found that measures of hemlock health significantly impacted property values in New Jersey, USA, although this study did not calculate marginal implicit prices for this impact (Holmes et al., 2006).

Some studies have valued urban trees based on the values of the ecological services they provide (Brack, 2002; Maco and McPherson, 2003; McPherson et al., 2005; McPherson et al., 1999; Nowak et al., 2006b; Nowak et al., 2006c; Nowak et al. 2007). In such studies, the values of a series of benefits provided by urban tree cover are estimated for an area and are then summed to produce more comprehensive estimates of value. Such studies are useful in quantifying the economic costs and benefits of urban tree cover and thus help in management and policy decision-making. However, they require detailed data on tree populations and community forestry expenditures that are currently unavailable in most urban areas. Thus, these studies may be impractical or impossible to conduct in many locations.

In sum, studies have shown that urban trees provide valuable benefits to urban communities, but leave many aspects of the value of urban tree cover unknown. Additional studies that assess value using similar methodologies and measures or that value similar benefits of tree cover will help to increase our understanding of the value of urban trees and as will studies that examine the patterns that exist in these values geographically and contextually. This study strives to improve our understanding of human values for urban trees by eliciting information about the spatial extent in which single-family homeowners value tree cover as well as about the manner in which their values vary with different levels of tree cover. In so doing, we can determine whether tree cover affects home prices beyond the local parcel and thereby uncover evidence of an externality. Our results offer insights into the manner in which humans value urban tree cover and may be used to inform policy meant to optimize levels of urban tree cover.

Methods

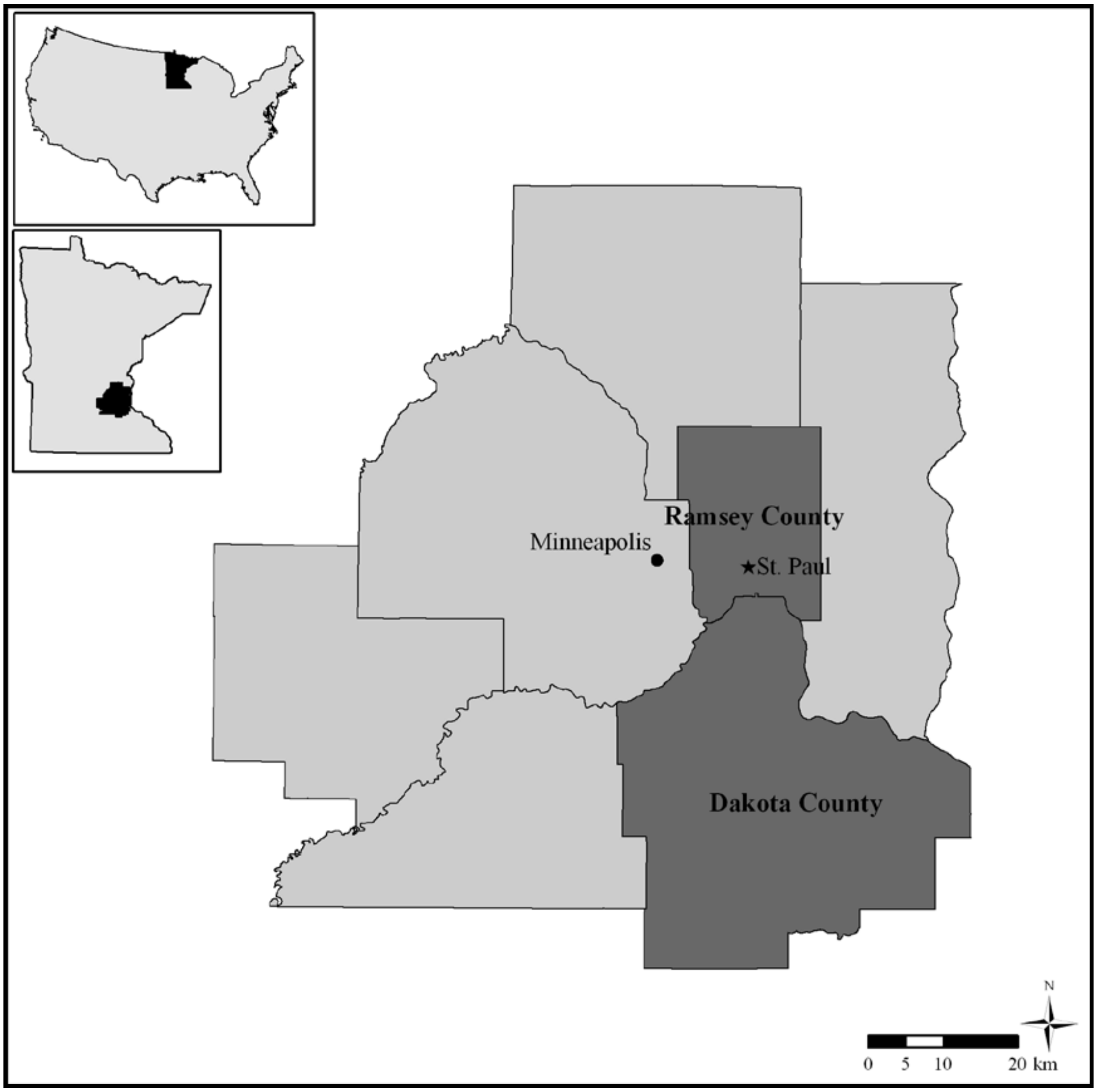
Study area

Our study area included Ramsey and Dakota Counties, part of the Minneapolis-St. Paul metropolitan area, located in east central Minnesota, USA (Figure 3). Ramsey County, which consists of eighteen cities and one township, is dominated by urban and suburban land uses while Dakota County, with 21 cities and 13 townships, is less urbanized and consists of a mix of urban, suburban, and agricultural land uses. Ramsey County is the most densely populated of the two counties with a population of approximately 500,000 in an area of 441 km^2. Dakota County's population of approximately 360,000 occupies a land area of 1,475 km^2. Ramsey County has been largely urbanized for decades, while Dakota County's urbanization occurred more recently, with rapid urbanization occurring in the last 20 years and continuing today.

Hedonic pricing overview

Hedonic pricing models are widely used to estimate the contributions of different attributes (structural, neighborhood, and environmental characteristics) to the value of a property as measured by its sales price or assessed value (Freeman, 2003). Hedonic pricing models can be used to estimate the marginal implicit price of an attribute, the change in the amount an individual would be willing-to-pay for a property if there is a small change in an attribute, holding all other attributes constant. In this paper, we estimate the marginal implicit prices of various aspects of homes using a hedonic pricing model that relates home sale prices to structural, neighborhood, and environmental attributes, including tree cover, using ordinary least squares (OLS) regression and spatial

Figure 3. Location of the study area.



simultaneous autoregressive (SAR) error modeling. The OLS hedonic pricing model can be written as follows:

$$\ln P_i = \beta_0 + \beta_1 S_i + \beta_2 N_i + \beta_3 Q_i + \varepsilon_i$$

where the dependent variable, ln P_i, represents natural log of the sales price of property i; S_i is a vector of parcel and structural characteristics (e.g., finished square feet, home age, lot acreage); N_i is a vector of neighborhood characteristics (e.g., distance to shopping centers, school quality); Q_i is a vector of environmental characteristics (e.g., proximity to lakes, percent tree cover on parcel); and ε_i is an error term. We used natural logs for proximity variables, lot acreage, and home finished square footage as we expected the effect of these variables to decline as their values increase, assuming elasticity to be constant.

Estimation of the hedonic pricing model may be complicated by heteroscedasticity and spatial autocorrelation of the error term. We used Moran's I to check for significant spatial autocorrelation in our OLS residuals. As this test was significant, we then used Lagrange multiplier tests test whether the particular form of spatial autocorrelation was better explained by assuming spatial autocorrelation in the error term, by assuming a spatial lag in which a functional relationship exists among nearby properties, or by assuming autocorrelation in both the lag and error terms. We found that spatial autocorrelation in the error term was dominant and that spatial autocorrelation in the lag term was not significant. We account for spatial autocorrelation using a spatially autoregressive (SAR) error model and estimate this model using a maximum likelihood (MLE) approach (see Cressie, 1993 and Anselin and Bera, 1998 for a full description of this modeling approach). We then tested for heteroscedasticity using a Breusch-Pagan test and, as the result was significant, calculated White's standard errors (White, 1980) using a method designed for use with SAR error models to adjust for heteroscedasticity (R. Bivand, *personal communication*).

The SAR error model belongs to a family of models (simultaneous autoregressive models) that are used to address spatial autocorrelation in data by augmenting OLS regression models with an additional term to represent the spatial structure of the autocorrelation in the dataset. These models make the assumption that the value of the dependent variable at each location is a function of both the explanatory variables used in the model and of the values of the dependent variable for its neighbors (Cressie, 1993; Haining, 2003; Kissling and Carl, 2008). Three types of SAR models exist and are implemented when different spatial autoregressive processes occur: lag models that are applied in situations where spatial autocorrelation occurs in the response variable (inherent spatial autocorrelation), error models that address spatial autocorrelation occurs in the error term (induced spatial dependence), and mixed models that are used in situations where spatial autocorrelation impacts both the response and error terms (Anselin, 1988; Cliff and Ord, 1981; Haining, 2003; Kissling and Carl, 2008). As stated above, our data were complicated by significant spatial autocorrelation in the error term only. Thus, we used a SAR error model to address this. When a SAR error model is implemented in a hedonic pricing study, the OLS expression above is modified to include an additional term (λW*u*) to represent spatially-dependent error term's (*u*) spatial structure (λW). This modified expression may be written

$$\ln P_i = \beta_0 + \beta_1 S_i + \beta_2 N_i + \beta_3 Q_i + \varepsilon_i + \lambda W u$$

Here, λ represents the spatial autoregression coefficient, W represents an *n* x *n* spatial weights matrix used in estimating the model (see Anselin and Berra, 1998; Fortin and Dale, 2005 for a discussion of methods for specifying weight matrices), and *u* is the spatially-dependent error term.

Data

We assembled a dataset with a series of structural, neighborhood, and environmental variables for each sample residence using GIS techniques. These variables are summarized in Table 5 and descriptive statistics for them are given in Table 6. Property sales and most structural data used in this study originated in the Metropolitan Twin Cities parcel dataset. This dataset is available from the Twin Cities

Metropolitan Council and includes spatially-referenced information related to property ownership, taxation, and use for all parcels in the seven county Twin Cities metropolitan area. From this dataset, we identified 9,992 single family, residential properties that sold in the year 2005 in Ramsey and Dakota Counties and that had valid, complete data for all fields of interest. We excluded parcels in the cities of Randolph and Cannon Falls in extreme southern Dakota County from this dataset as preliminary analyses indicated that these were part of a different submarket. We used these 9,992 properties as our sample in this analysis.

Using a geographic information system (GIS), we assembled information for each property related to its sale, structural, neighborhood, and environmental attributes (Tables 2-3). Sale prices for all homes in the sample came from the parcel dataset. We chose to use sale prices rather than values assessed for taxation purposes because they may more accurately reflect actual market values (Freeman, 2003). Home sale prices in our sample ranged from $65,000 to $2,870,250 with a mean sale price of $287,637.

Almost all of our structural variables came from the parcel dataset. These included the finished square footage, age, and tax rate for each home. Because we believed that the effect of age on home sale prices would lessen or that older homes would, at some age, become more valuable, we calculated a squared term for home age as well. We also calculated a dummy variable to indicate the month in which sales occurred as sale month influences sale price in the Twin Cities area. An additional variable, the elevation of the home's lot in feet, was also calculated in a GIS using a digital elevation model (DEM) for the region obtained from the Twin Cities Metropolitan Council. All of these variables have been found to significantly impact home sale prices in previous studies (Anderson and West, 2006; Doss and Taff, 1996; Sander and Polasky, 2009). The parcels database did not contain other structural variables often used in hedonic studies, such as number of rooms, number of bathrooms, and features of the house (presence of fireplaces, hardwood floors, etc.), which prevented us from including such variables in the analysis.

Table 5. Study variable descriptions and expected relationship to the dependent variable, home sale price.

Variable Name	Definition	Expected relationship to sale price
Structural variables		
PRICE	Home sale price (dependent variable)	
ACRES	Lot size in acres	Positive
FINSQFT	Finished square feet in home	Positive
HOME_AGE	Year home was built subtracted from 2005	Negative
TAX_RATE	Property taxation rate	Negative
ELEV_FT	Elevation of lot on which the home sits in feet	Positive
Neighborhood variables		
BUSYRD	Distance to closest road with high traffic volume in meters	Positive*
CBD	Distance to closest central business district (Minneapolis or St. Paul) in meters	Negative*
SHOP	Distance to closest shopping center in meters	Positive*
COLLEGE	Distance to closest four-year college or university in meters	Negative*
MEAN_MCA	Average Minnesota Comprehensive Assessment score for local elementary and middle schools	Positive
IMPERVIOUS	Mean impervious surface in 500 m buffer around parcel	Negative
Environmental variables		
LAKE	Euclidean distance to closest lake in meters	Negative*
LGPKRD	Road distance to closest park in meters	Negative*
TRAIL	Euclidean distance to closest non-park trail in meters	Negative*
VIEW_AREA	Area of a home's viewshed in square meters	Positive
Tree cover variables		
TREE_PARCEL	Percent tree cover on parcel	Positive
TREE_100	Percent tree cover in 100m buffer around parcel	Positive
TREE_250	Percent tree cover in area 100 m – 250 m around parcel	Positive
TREE_500	Percent tree cover in area 250 m – 500 m around parcel	Positive
TREE_750	Percent tree cover in area 500 m – 750 m around parcel	Positive
TREE_1000	Percent tree cover in area 750 m – 1000 m around parcel	Positive
Market segment variables (reference location is South St. Paul)		
APPLEVALLEY	Home location dummy variable (1 if northwest Apple Valley school district, otherwise 0)	Positive
BURNSVILLE	Home location dummy variable (1 if southwest Burnsville school district, otherwise 0)	Positive
CENTRAL	Home location dummy variable (1 if Central school district, otherwise 0)	Positive
COMO_ARL	Home location dummy variable (1 if Como-Arlington school district, otherwise 0)	Positive
EAGAN	Home location dummy variable (1 if Eagan school district, otherwise 0)	Positive
EASTVIEW	Home location dummy variable (1 if Eastview school district, otherwise 0)	Positive
FARMINGTON	Home location dummy variable (1 if Farmington school district, otherwise 0)	Positive
HARDING	Home location dummy variable (1 if Harding school district, otherwise 0)	Positive

Variable Name	Definition	Expected relationship to sale price
HASTINGS	Home location dummy variable (1 if Hastings school district, otherwise 0)	Positive
HIGHLANDPK	Home location dummy variable (1 if Highland Park school district, otherwise 0)	Positive
HUMBOLDT	Home location dummy variable (1 if Humboldt school district, otherwise 0)	Positive
STANT_IRONDL	Home location dummy variable (1 if St. Anthony-Irondale school districts, otherwise 0)	Positive
LAKEVILLE	Home location dummy variable (1 if Lakeville school district, otherwise 0)	Positive
MOUNDSVIEW	Home location dummy variable (1 if Mounds View school district, otherwise 0)	Positive
NORTH	Home location dummy variable (1 if North school district, otherwise 0)	Positive
NORTHSOUTH	Home location dummy variable (1 if North-South school district, otherwise 0)	Positive
ROSEMOUNT	Home location dummy variable (1 if Rosemount school district, otherwise 0)	Positive
ROSEVILLE	Home location dummy variable (1 if Roseville school district, otherwise 0)	Positive
SIMLEY	Home location dummy variable (1 if Simley school district, otherwise 0)	Positive
WSTPAUL	Home location dummy variable (1 if West St. Paul school district, otherwise 0)	Positive
Sale month variables (reference month is February)		
JAN	Sale month dummy variable (1 if January, otherwise 0)	Positive
MAR	Sale month dummy variable (1 if March, otherwise 0)	Positive
APR	Sale month dummy variable (1 if April, otherwise 0)	Positive
MAY	Sale month dummy variable (1 if May, otherwise 0)	Positive
JUNE	Sale month dummy variable (1 if June, otherwise 0)	Positive
JULY	Sale month dummy variable (1 if July, otherwise 0)	Positive
AUG	Sale month dummy variable (1 if August, otherwise 0)	Positive
SEPT	Sale month dummy variable (1 if September, otherwise 0)	Positive
OCT	Sale month dummy variable (1 if October, otherwise 0)	Positive
NOV	Sale month dummy variable (1 if November, otherwise 0)	Positive
DEC	Sale month dummy variable (1 if December, otherwise 0)	Positive

* For distance variables, a negative coefficient indicates that, as the distance between a home and a given feature decreases, home sale prices increase.

Table 6. Descriptive statistics for quantitative study variables.

	Mean	Std. Deviation	Minimum	Maximum
PRICE (2005 US$)	287,636.65	137,852.92	65,000	2,870,250
ACRES	0.34	0.86	0.04	43.31
FINSQFT	1,811.21	836.19	440	11,471
HOME_AGE	41.49	31.50	0	153
TAX_RATE (%)	0.95	0.23	0.03	4.32
ELEV_FT	925.55	60.89	686	1,151
BUSYRD (m)	184.09	182.42	0	2,678
CBD (m)	13,774.42	10,781.58	0	42,935
SHOP (m)	1,847.30	1,555.88	10	16,594
COLLEGE (m)	8,974.76	7,654.66	20	39,592
MEAN_MCA	1539.86	62.41	1372.67	1652.67
IMPERVIOUS (%)	32.75	19.51	0	100
LAKE (m)	917.19	771.14	0	9,305
LGPKRD (m)	711.91	863.79	0	13,643.82
TRAILEUC (m)	442.50	805.405	0	14,095.82
VIEW_AREA (ha)	24.16	25.66	0	246.58
TREE_PARC (%)	15.44	22.10	0	93.00
TREE_100 (%)	14.55	15.70	0	90.00
TREE_250 (%)	14.67	15.84	0	88.57
TREE_500 (%)	14.81	16.18	0	90.00
TREE_750 (%)	15.02	16.17	0	89.29
TREE_1000 (%)	15.44	16.20	0	100.00

n = 9,992

We used GIS techniques to estimate neighborhood variables from several sources. First, because neighborhood school quality may influence home sale prices, we calculated a mean Minnesota Comprehensive Assessment (MCA-II, a standardized test across multiple subjects) test score for each home's neighborhood schools using third, fifth, and seventh grade MCA-II scores for each school available from the Minnesota Department of Education (http://education.state.mn.us/MDE/Data/index.html). Access to amenities and undesirable land uses and areas may also influence home sale prices, so we calculated four additional variables to identify the distance from each sample parcel to each amenity or disamenity. We calculated proximity to the closest four-year college or university and to the closest shopping center using a dataset produced by the Lawrence Group available from the Twin Cities Metropolitan Council. We also calculated distances to high traffic volume roads based on a functional class roads dataset from the Metropolitan Council and The Lawrence Group and distance to the central business districts of Minneapolis and St. Paul based on a Twin Cities Metro Transit downtown fare zones GIS dataset, also available from the Metropolitan Council. Based on the results of a previous study conducted in the region (Sander and Polasky, 2009), we believed that proximity to four-year universities and colleges would have a positive effect on home sale price (such that increasing distance would have a negative effect), while proximity to busy roads would have a negative relationship to home sale prices (such that increased distance would have a positive effect). Distance to shopping centers and to the central business districts of Minneapolis and St. Paul could have either sign. Being closer to work or shopping is more convenient and so might increase home prices while at the same time shopping centers and the downtown area could be associated with more crowded conditions, noise, pollution and other possible disamenities that might decrease home prices. Lastly, we calculated the mean percent impervious cover within 500 m of each sample parcel using a dataset available from the University of Minnesota's Remote Sensing and Geospatial Analysis Laboratory to identify neighborhood development intensity such that higher impervious surface levels correspond to more intense development. We believed that this variable would be negatively related to home sale prices.

We divided the housing market in the two counties into a series of submarkets and assigned dummy variables to account for the impacts of different submarkets on home sale prices. We examined a number of means for identifying housing submarkets, including using zip codes, city boundaries, and elementary, middle, and high school districts. We found that housing submarkets defined using high school districts were most robust to the changing geographic scope of the market and used these to define housing submarkets in the two counties. As a result, we identified a total of twenty-three market segments, twelve in Ramsey County and eleven in Dakota County.

Natural areas, trails, and lakes have previously been found to impact property values in the study area (Anderson and West, 2006; Doss and Taff, 1996; Krizek, 2006; Sander and Polasky, 2009). To account for these impacts, we calculated distances from sample properties to each of these features. We calculated Euclidean distances to lakes using datasets available from the Twin Cities Metropolitan Council and to trails using two GIS datasets, Metropolitan Council Regional and State Trails and a bikeways dataset from the Minnesota Department of Transportation. We screened these datasets to remove planned and proposed trails as these trails are highly tentative and trails that used the city streets. We calculated proximity to large natural area parks, including recreational parks, wildlife refuges, nature reserves, and wildlife management areas with areas of 1 ha or greater as indicated by two datasets, the Lawrence Group Landmarks and Twin Cities Metropolitan Council Regional Recreation Open Space Features, both available from the Twin Cities Metropolitan Council. We calculated Euclidean distances to lakes and trails because these features generally have nearly continuous access points in the region and road distances to parks because these features typically have discrete access points that intersect roadways. Thus, individuals are more likely to access trails and lakes in an as-the-crow-flies manner and large natural area parks using the road network (Sander and Polasky, 2009).

The scenic quality of the landscape around a home may also impact property values (Sander and Polasky, 2009). To account for this, we included an additional variable, view area, to identify the areal extent of the view from each property. We calculated this variable using the viewshed function in ArcGIS 9.2 and a DEM that included both natural topography and buildings, a GIS dataset containing Ramsey County building footprints available from the Ramsey County Surveyor's Office, and a GIS planimetric dataset for Dakota County available from the Dakota County Office of Geographic Information Systems. We calculated viewsheds for each property in the sample and calculated the area of the identified viewshed for each property. For a detailed description of the techniques used in calculating viewsheds, see Sander and Manson, 2007 and Sander and Polasky, 2009.

We used the National Land Cover Database (NLCD) 2001 to identify tree coverage for the study area. The NLCD 2001 includes three datasets generated using remotely-sensed imagery for the extent of the United States: land cover, impervious surface, and tree canopy (Homer et al., 2004). For our analysis, we used only the tree canopy dataset. This 30-m raster dataset depicts the percent canopy cover in each pixel in the study region estimated from Landsat Thematic Mapper imagery using regression tree techniques (for a detailed description of the creation of this dataset, see Huang et al. 2003). These data have been found to have mean absolute errors of 14.1% and a correlation coefficient between actual and predicted values of 0.78 for the study area's mapping zone (Homer et al., 2004). Although there is a temporal mismatch of four years between this dataset and our sale data, the NLCD tree canopy dataset is the only comprehensive tree canopy cover dataset for the study area and provides the most accurate assessment available of the region's tree cover. We considered using sale data from 2001, but found that the Metropolitan Twin Cities Parcel Dataset was largely incomplete for the study area until 2005. Additionally, tree cover in much of the study area is fairly stable and changes little in the short-term. Thus, although we acknowledge that a temporal mismatch exists between the sale and tree cover data and that this may impact data accuracy in some areas, we feel that this impact is likely to be slight and that these data are sufficiently accurate for the time-period represented in this study. Using this dataset, we calculated mean tree cover for each parcel and, to identify the sphere of influence for neighborhood tree cover on parcels, in neighborhoods with radii of 0-100 m, 100-250 m, 250-500 m, 500-570 m and 750-1000 m around each parcel in a GIS environment. We expected tree cover to be positively related to home sales prices on the parcel and in each neighborhood radius.

Results

We calculated two hedonic pricing models using the above data. The first (Model 1) included all variables described in the previous section, among them the raw values for tree cover within each parcel neighborhood. The second model (Model 2) included all of these terms as well as squared terms for all tree cover variables as we were concerned that the relationship between tree cover might vary with increasing levels of tree cover. We first ran each model using OLS regression. Even though the fit for these models was high, with adjusted R^2 values of 0.8073 and 0.8078 and Akaike's information criterion (AIC) values of -7,508.10 and -7,527.40, for Models 1 and 2 respectively, we were concerned about the presence of spatial autocorrelation and heteroscedasticity in the data. We calculated statistics to quantify the degree and cause of spatial autocorrelation in our data using 2500 m weights. The calculated Moran's *I* statistic for both models was significant at the 0.001 level providing compelling evidence of spatial autocorrelation in the data. We calculated Lagrangian multiplier diagnostics for our residuals to identify the nature of this spatial autocorrelation. Our results indicated that both error and lag processes were present in each model, but robust tests indicated that the error process was dominant and significant in these models ($p < 0.001$) and that the lag process was not significant in either ($p > 0.05$). As such, we calculated SAR error models for each variable set using an MLE approach. SAR model fit was an improvement over OLS fit for each model as evidenced by reduced AICs of -8,534.10 for Model 1 and -8,550.20 for Model 2. In these models, the extent of the spatial relationship in the residual variation across sample parcels is identified by the coefficient λ which was significant in each model, indicating a significant error process that was accounted for using the SAR error models. The estimated values of λ are high for both models (0.97795 for model 1, 0.97806 for model 2) and the p-values for their likelihood ratio tests, which compare the OLS model with and assumption of no spatial autocorrelation to the fitted model with the non-zero autocorrelation parameter, are significant ($p < 0.001$), indicating that significant spatial autocorrelation is present in the OLS model that is accounted for in the SAR model. We then calculated a Breusch-Pagan test statistic for each model. These were significant at the 0.001 level, indicating the presence of heteroscedasticity. To address this issue we calculated heteroscedasticity-corrected standard errors for the SAR model following White's method (R.Bivand, *personal communication*). The results of the estimation of the SAR error models with heteroscedasticity-corrected standard errors are presented in Table 7.

Coefficients for structural variables were significant and of the expected sign in both models. Increases in the size of the lot, finished square feet, and elevation along with sale months as compared to February were associated with higher home sales prices. Increases in home age were associated with lower sales prices to about 75 years of age and thereafter were associated with sale price increases.

All coefficients for neighborhood variables in both models were of the expected sign and statistically significant. Higher neighborhood education testing scores, proximity to a four year college or university, and greater distance from a busy road and central business districts of Minneapolis and St. Paul were all associated with higher home sales prices. Increasing distance to shopping centers was associated with higher home sale prices, but this relationship was not statistically significant. The mean percent impervious surface in a 500 m neighborhood surrounding each home was negatively related to home sales prices such that homes with higher levels of impervious surface and thus higher development intensities in this neighborhood experienced lower sale prices.

In both models, all signs for the coefficients of environmental variables (exclusive of tree cover variables) were as expected, but not all were significant. Proximity to lakes significantly increased home sale prices in the study area, but proximity to trails and large parks did not. Additionally, properties with larger view areal extents had higher home sales prices than comparable properties with smaller view extents.

Table 7. SAR error model results with heteroscedasticity-consistent standard errors.

	Model 1 (2500m)				Model 2 (2500m)			
Variable	**Coefficient**	**White's Std. Error**	**t-value**		**Coefficient**	**White's Std. Error**	**t-value**	
Structural variables								
(Intercept)	7.960800	0.149000	63.514	***	7.968100	0.149010	63.59	***
LN_ACRES	0.132090	0.004376	29.5	***	0.131250	0.004378	29.249	***
LN_FINSQFT	0.522250	0.005926	89.579	***	0.522900	0.005926	89.534	***
HOME_AGE	-0.007209	0.000246	-25.113	***	-0.007183	0.000246	-25.057	***
HOME_AGE_SQ	0.000041	0.000002	17.291	***	0.000041	0.000002	17.312	***
TAX_RATE	-0.123310	0.008329	-12.603	***	-0.122600	0.008345	-12.624	***
ELEV_FT	0.000330	0.000055	6.53	***	0.000324	0.000055	6.378	***
Neighborhood variables								
LN_BUSYRD	0.001558	0.000659	3.212	*	0.001495	0.000659	3.192	*
LN_CBD	0.001831	0.000607	6.391	**	0.001836	0.000606	6.354	**
LN_SHOP	0.006832	0.003635	1.201		0.006738	0.003638	1.273	
LN_COLLEGE	-0.050212	0.006359	-9.545	***	-0.050394	0.006354	-9.513	***
MEAN_MCA	0.000532	0.000061	20.641	***	0.000525	0.000061	20.489	***
IMPERVIOUS	-0.000564	0.000113	-4.666	***	-0.000569	0.000114	-4.569	***
Environmental variables								
LN_LAKE	-0.004674	0.000514	-8.889	***	-0.004676	0.000515	-8.723	***
LN_LGPKRD	-0.000300	0.000227	-2.023		-0.000311	0.000227	-2.136	
LN_TRAIL	-0.000765	0.000666	-3.378		-0.000763	0.000666	-3.323	
VIEW_AREA	0.000742	0.000079	7.467	***	0.000741	0.000079	7.531	***
Tree cover variables								
TREE _PARCEL	0.000165	0.000091	2.533		-0.000731	0.000224	-2.775	**
TREE_100	0.000477	0.000150	3.622	**	0.001056	0.000324	4.348	**
TREE_250	0.000291	0.000135	2.595	*	0.000594	0.000306	2.195	*
TREE_500	-0.000038	0.000136	0.341		-0.000375	0.000300	-0.374	
TREE_750	0.000180	0.000129	2.186		-0.000140	0.000290	0.309	
TREE_1000	0.000006	0.000121	1.586		0.000478	0.000280	2.789	
TREE_parcel2					0.000016	0.000004	4.132	***
TREE_100_2					-0.000012	0.000005	-3.306	*
TREE_250_2					-0.000005	0.000005	-1.222	
TREE_500_2					0.000006	0.000004	0.565	
TREE_750_2					0.000005	0.000004	0.638	
TREE_1k_2					-0.000008	0.000004	-2.327	
Submarkets (reference location is South St. Paul)								
APPLEVALLEY	0.122480	0.048479	-10.511	*	0.124970	0.048456	-10.351	**
BURNSVILLE	0.068981	0.047131	-14.014		0.068646	0.047113	-14.031	
CENTRAL	0.601000	0.048141	16.427	***	0.603600	0.048133	16.487	***
COMO_ARL	0.651700	0.052989	9.591	***	0.655380	0.052996	9.617	***
EAGAN	0.092995	0.046037	-8.652	*	0.097503	0.046008	-8.548	*
EASTVIEW	0.091950	0.046107	-10.448	*	0.093249	0.046080	-10.356	*
FARMINGTON	0.121950	0.051978	-8.504	*	0.124450	0.051961	-8.282	*
HARDING	0.527910	0.061668	1.083	***	0.530890	0.061739	1.043	***
HASTINGS	0.181040	0.101880	-7.284		0.183430	0.101860	-7.167	
HIGHLANDPK	0.437890	0.048234	27.664	***	0.440930	0.048205	27.684	***
HUMBOLDT	0.145210	0.041083	7.188	***	0.146490	0.041059	7.111	***
JOHNSON	0.582760	0.058961	5.304	***	0.585940	0.058997	5.258	***
LAKEVILLE	0.126120	0.050486	-11.046	*	0.128140	0.050464	-10.888	*
MOUNDSVIEW	0.448130	0.063491	-3.508	***	0.453250	0.063540	-3.451	***

	Model 1 (2500m)				Model 2 (2500m)			
Variable	**Coefficient**	**White's Std. Error**	**t-value**		**Coefficient**	**White's Std. Error**	**t-value**	
NORTH	0.491060	0.061092	-4.984	***	0.496000	0.061149	-4.989	***
NORTHSOUTH	0.409720	0.063960	-3.77	***	0.414560	0.063994	-3.835	***
ROSEMOUNT	0.077320	0.047319	-11.844		0.079598	0.047302	-11.477	
ROSEVILLE	0.467510	0.056886	-0.582	***	0.470770	0.056935	-0.652	***
SIMLEY	-0.131210	0.030025	-7.326	***	-0.131710	0.030007	-7.336	***
STANT_IRONDL	0.379760	0.070625	-4.124	***	0.383230	0.070658	-4.182	***
TARTAN	0.473240	0.064798	-3.112	***	0.477280	0.064898	-3.198	***
WSTPAUL	0.035443	0.037030	-5.283		0.038680	0.037022	-5.27	
Month of sale (reference month is February)								
JAN	0.028921	0.009420	3.097	**	0.029185	0.009413	3.101	**
MAR	0.022638	0.009095	2.705	*	0.022839	0.009088	2.703	*
APR	0.032279	0.008935	3.918	***	0.033112	0.008931	3.987	***
MAY	0.041470	0.008670	4.962	***	0.042463	0.008665	5.057	***
JUNE	0.050296	0.008420	6.396	***	0.050932	0.008413	6.457	***
JULY	0.056588	0.008605	6.668	***	0.057695	0.008603	6.786	***
AUG	0.058387	0.008505	6.926	***	0.058919	0.008501	6.968	***
SEPT	0.062647	0.008759	7.402	***	0.063125	0.008753	7.436	***
OCT	0.054718	0.009118	6.422	***	0.055801	0.009114	6.512	***
NOV	0.043627	0.009292	5.143	***	0.044273	0.009286	5.208	***
DEC	0.032482	0.009628	3.42	***	0.033342	0.009622	3.502	***
dep. var	LN_PRICE				LN_PRICE			
adj R2 (OLS)	0.807300				0.807800			
lambda	0.977950				0.978060			
LR test value	1028.00	***			1024.800000	***		
Log likelihood	4325.03				4339.09			
AIC (OLS)	-7508.10				-7527.40			
AIC (SAR)	-8534.10				-8550.20			

The coefficients of the tree cover variables varied in both the direction of their sign and their significance with the neighborhood considered and model. In model 1, which included just the raw mean tree cover values for each neighborhood, the coefficient for tree cover at the parcel level was positive, but not statistically significant, and was considerably lower than the coefficients for tree cover in the 100 m and 250 m buffers around parcels, which were statistically significant and positive. Evaluated at the mean home sale price of $287,637 and mean tree cover of 14.55%, the marginal implicit price of a 10 percentage point increase in tree cover within the 100 m buffer (e.g., increasing tree cover from 14.55% to 24.55%) was $1,371 or a 0.477% price increase.[1] The marginal implicit price of a 10 percentage point increase in tree cover within the 250 m buffer calculated in the same manner was $836, or about 0.291% for the mean home. While the percentage of tree cover within the 500 m buffer was negatively related to sales price, this relationship was not statistically significant at a 95% percent confidence level (p=0.7790). Tree cover in neither the 750 m and 1000 m neighborhood areas did not contribute significantly to home sale prices. The signs for both were positive, but the coefficients were small. These results indicate that the owners of single family residences will pay more for homes with higher levels of tree cover in the local (100-250 m) neighborhood of their property. However, they provide much less evidence that owners of single family residences will pay more for homes with higher tree cover on their own lot or in neighborhoods beyond 250 m from their parcels.

Model 2, which included raw as well as squared terms for all tree cover variables, sheds further light on the relationship between tree cover and home sale prices. In this model, the coefficient for parcel level tree cover was negative and significant while the coefficient for its squared term was positive and significant. This indicates that increasing levels of parcel level tree cover actually decrease home sales prices to a certain point (~47%) and thereafter increase home sale prices. The marginal implicit price for a

[1] The marginal implicit price for percent tree cover is ∂ sale price/∂ percent tree cover. This is calculated as the sales price times the percent tree cover coefficient. For example, to calculate the marginal implicit price of tree cover within 100 m, we multiply its coefficient, 0.000477, by the mean home sale price, $287, 637, which generates a marginal implicit price of $137.08. To estimate the impact of a ten percent change in tree cover, multiply the marginal implicit value by ten to get a value of $1,370.84.

10% tree cover increase at the parcel level calculated as above corresponds to a large decrease in home sale prices of $2,103 or 0.731% to 47% tree cover and a small increase in home sale prices of $45 or 0.0016% at higher levels of tree cover. The coefficient for parcel level tree cover in the 100 m neighborhood was positive for the raw term and negative for the squared term, indicating that the effect of 100 m tree cover on home sale price is positive to a point (~87%) and thereafter is negative. Evaluated as stated above, the marginal implicit price of a 10 percentage point increase in tree cover within the 100 m buffer was quite large and positive, $3,036 or 1.056% for the mean home to 87% tree cover, and was small and negative, -$35 or -0.012% above that level. As in model 1, the coefficient for the percentage of tree cover within the 250 m buffer was significant and positive, although greater, such that a 10% increase in tree cover corresponds to a 0.594% or $1,708 increase in home sale price. The coefficient for this variable's squared term was not significant, indicating that this effect does not decrease or switch direction with increasing tree cover percentages. As in Model 1, the coefficients for both the raw and squared terms for tree cover in the 500, 750, and 1000 m buffers were not significant, indicating that tree cover in these neighborhoods does not significantly impact home sale prices in the study area.

Discussion and conclusions

The results of this study provide interesting insights into how people value urban trees. As in previous studies, these results indicate that local tree cover is valued by the purchasers of residential single family properties in urban areas such that individuals are willing to pay more for properties with higher amounts of tree cover in areas around their home. Specifically, they indicate that higher percentages of tree cover within 100 m and 250 m radii of a parcel increase home sale price significantly, although very high levels of tree cover in the 100 m radius (>87%) may negatively impact home sale prices, and that lower percentages of tree cover on the parcel itself negatively impact home sale prices until a parcel has nearly 50% tree cover, when this impact becomes positive. Tree cover beyond these levels has a small or no impact on home sale price.

These results generally agree with the findings of previous studies that found positive relationships between tree cover in these neighborhoods and home sale prices (Garrod and Willis, 1992; Holmes et al., 2006). They disagree, however, about the distance over which this relationship extends. For example, Holmes et al. (2006) found that in Sparta, N.J., USA, tree cover within 100 m of properties did not significantly impact home sale prices and that tree cover at greater distances (500 m, 1000 m) did. Our result disagree with this finding and indicate that the distance over which tree cover influences home sale price is much more local, extending only to 250 m. Our result also disagree with other previous studies that found that tree cover at the parcel level positively impacted home sale prices (Anderson and Cordell, 1988; Dombrow et al., 2000; Mansfield et al., 2005; Morales et al., 1976; Morales, 1980) as we found that parcel level tree cover has a negative or very slight positive impact on sale price. These studies, however, did not examine tree cover beyond the extent of the parcel and did not include terms to assess non-linearities in the relationship between parcel level tree cover and home sale prices. Since tree cover is somewhat spatially correlated (e.g., parcels with greater tree cover are likely to be in neighborhoods with greater tree cover), it may be that controlling for neighborhood tree cover more accurately pinpoints the value of own parcel tree cover. It seems probable that, had these studies included additional variables reflecting tree cover within different neighborhoods, the significance of tree cover on the parcel itself would have been reduced.

The present study dealt with both spatial autocorrelation and neighborhood effects, factors that have been ignored by most other analyses. Additionally, other environmental factors such as development intensity, access to natural areas, and view quality were controlled for in this analysis, more so than in many previous analyses. This suggests that this study's results may be more reliable than those of some previous studies because factors that frequently complicate hedonic pricing studies were more thoroughly dealt with in this study than in previous studies of the value of urban tree cover.

A picture of the way in which urban residents value tree cover emerges from our results. Parcel-level tree cover did not significantly influence home sale prices in Model

1 and negatively impacted sale prices to about 47% tree cover and had only a small, positive impact at levels above 47% in Model 2. This suggests that single-family home owners in the study area are not particularly concerned about the amount of tree cover on their own lots per se unless the levels of tree cover are below 47%, in which case they actually place a negative value on tree cover. This indicates that either homeowners are unconcerned with own parcel tree cover or prefer parcels that have either very low or very high amounts of tree cover, possibly as a result of the feelings of safety and privacy provided by well or unscreened properties. However, because tree cover in radii of 100m and 250 m around a parcel did significantly contribute to home sales prices, it seems that home owners do value trees in their local neighborhoods. As this distance roughly corresponds to the length of a city block, this may reflect a preference for tree-lined streets and the shading and aesthetic environment they offer. The negative relationship between tree cover in the 100 m buffer at values above 87% indicates that homeowners may avoid homes with extremely high levels of tree cover in this neighborhood, possibly because they reduce visibility and decrease feelings of safety. Homeowners' preference for different levels of tree cover becomes insignificant at greater distances as evidenced by the decline in influence of tree cover as the buffer is increased to 500 m and greater around homes. Thus, our results suggest that the owners of single family homes value tree cover because it enhances the environment in their local neighborhoods and may negatively value levels of tree cover in close proximity to their homes as they may reduce visibility and security.

Due to limits in data availability, this study did not estimate the value of individual trees, trees of different sizes, or of different species of trees and thus cannot address the impact of canopy composition on home sale prices. As more detailed data related to urban forest stocks become available over the coming years, it would be well-worth repeating this type of study to investigate the value of specific tree species and forest conditions in more detail.

It should be stressed that the values calculated using the hedonic property price model are only partial estimates of the value of urban tree cover in that they capture only the portion of value that accrues to the owners of single family residential properties. As such, they are likely to include largely aesthetic and cultural values of trees and omit many of the other benefits provided by urban trees. Carbon sequestration, air pollution reduction, reductions in peak stormwater runoff, and wildlife habitat provision, benefits accrue to the wider public, are unlikely to be adequately measured using the hedonic property price approach. In addition, benefits that accrue to entities other than individual homeowners are not measured in this study. Thus, the total economic value of urban forests may be substantially larger than indicated by these results.

These results provide incentives for communities to preserve or augment their urban tree stocks. The fact that property values are increased by neighborhood tree cover much more so than tree cover on the property itself and that parcel-level tree cover level below 47 % are negatively valued by home owners suggests that tree cover provides neighborhood externalities. If so, home owners might all benefit if everyone in the neighborhood planted more trees, but no individual property owner may have an incentive to do so. In such cases, there may be a positive role for municipal governments to play in promoting tree planting as a way to overcome the externalities that may prevent optimal tree cover. For example, the owner of parcels with tree cover below 47% (most of the study area) actually have a disincentive to plant trees unless they are planting enough trees to increase their parcel's tree cover above 47%. As the average parcel in the study area has only 15% tree cover, this means that most homeowners are unlikely to plant trees, even though they value them in their larger local neighborhood and benefit when their neighbors plant trees. Zoning restrictions or incentives to plant trees on privately-owned single family parcels would help to overcome this disincentive. Consideration of even the partial value of tree cover measured here, with recognition that it serves as a minimum estimate of the value of urban tree cover, may provide an incentive for improved tree cover that would therefore serve to enhance social, economic, and environmental conditions in urban environments.

Clearly, more research is needed into the value of urban trees. Although a number of studies including this one have generated such values, they are difficult to compare because of differences in their study regions, analysis methods, and means for quantifying urban tree cover. This study adds to this literature and makes new contributions in identifying the neighborhoods in which homeowners value tree cover as well as the variation in these values with different tree cover levels. It also highlights the need for more standardized studies of the value of urban trees so that values may be better compared and general conclusions may be reached. Completion of these studies will greatly enhance both our understanding of the value of urban tree cover and our ability to produce cities with urban forms that maximize this value.

CHAPTER 4 -- PREDICTING AND VALUING THE IMPACTS OF LOCAL LAND-USE CHANGE ON ECOSYSTEM SERVICES AND AMENITIES: A CASE STUDY IN AN URBANIZING COMMUNITY

This chapter details a study that addresses dissertation goals 1, 2, and 3, to identify the economic values associated with changes in the delivery of environmental services and amenities, to predict the environmental impacts of land-use change using spatial models of ecosystem services and environmental amenities, and to provide a novel general environmental modeling and economic valuation framework centered on land use that could be used to evaluate local level land-use plans and policies. To achieve these goals, this study first builds upon the foundation provided by the studies detailed in Chapters 2 and 3, constructing a hedonic pricing model to estimate the marginal implicit prices associated with changes the delivery of the ecosystem services of provision of access to areas for outdoor recreation and scenic quality as well as the services provided by tree cover in Dakota County, Minnesota, USA. It then identifies the 2005 delivery levels for these services for all single family residences in a rapidly-developing city in the county, Farmington, and models changes in these services under the city's planned land use for 2030. These changes are then valued economically using the marginal implicit prices estimated by the hedonic pricing model and are used to evaluate Farmington's 2030 land-use plan. As such, this study achieves goals 1-3 by generating information about the values of these ecosystem services, identifying how they are likely to be impacted by land-use change, and using this information to evaluate a local land-use plan, thus generating both information and a methodology that could be used to inform the land-use planning process in local communities.

Introduction

Humans depend on ecosystem services and environmental amenities for their well-being. However, in developing the landscape to, ostensibly, improve our living conditions, we frequently alter ecosystems and reduce the delivery of these services.

Planners and policy makers do not intentionally make land-use decisions that negatively impact ecosystem services and environmental amenities. Rather, they lack means for forecasting the environmental impacts of land-use change and find incorporating them into market-driven land-use decision-making difficult as the economic values of these services and amenities are often poorly recognized or unknown. Because of this, ecosystem services and environmental amenities are rendered invisible in local land-use decision-making and land-use policies based upon such incomplete assessments of the true environmental costs of development often have negative environmental impacts. If the impacts of land-use changes on ecosystem services and their associated economic impacts were better known to local policy-makers, the visibility of ecosystem services and amenities in local planning would be much increased and the environmental quality of future landscapes and the economic condition of future communities could be preserved or improved. Combining environmental modeling with economic valuation techniques would provide a means for doing this.

Environmental modeling and the economic valuation of ecosystem services have been applied in a number of global and large region analyses of ecosystem service delivery (see Chapter 1). However, only a limited number of studies have used these techniques to identify the impacts of future land-use change at local scales. This is problematic as the preponderance of land-use decisions are made by local jurisdictions. In particular, few studies have focused on the use of ecosystem services in local level land-use planning and decision-making in urban and urbanizing areas. Some studies have examined the impacts of potential land-use change on ecosystem services without estimating economic values or have estimated service delivery and values under present conditions only. These studies have, for example, evaluated the impacts of different landscape management options and policies in terms of the actual delivery or a scaled metric of delivery for a series of ecosystem services, finding that, even without solid economic values, changes in ecosystem services under the different regimes may provide sufficient information to inform the selection of land-use policies and management practices (Farber et al., 2006; Guzy et al., 2008; Mehaffey et al., 2008; Nelson et al., 2008). An additional study (Nelson et al., 2009) evaluated alternative future land uses for ecosystem service delivery as well as economic values for services that produced marketed commodities. The findings of this study indicated that this method was particularly useful for assessing the tradeoffs between services and suggesting means for alleviating these tradeoffs. Other studies have generated economic values for services related to urban ecosystems in present landscapes or in both present and past landscapes, but used these only to provide evidence that, because these services are valuable and are frequently sacrificed by urbanization, they should receive consideration in land-use planning (Bolund and Hunhammar, 1999; Hu et al., 2008). These studies illustrate the utility of analyses that include assessments of either the impacts of future landscape conditions on environmental quality or of current economic values for services for planning and decision-making. As such, they represent valuable contributions to ecosystem services-based landscape management. Their usefulness to local planners and policy-makers is weakened, however, in the first case by the lack of economic values as such values are required to evaluate the trade-offs inherent in selecting future land uses, and, in the second case, by the lack of comparisons between present and alternative future landscapes.

Other studies geared towards evaluating the impacts of land-use change in urban and urbanizing areas have generated economic values for services that might remedy this problem. A study conducted in the Philadelphia metropolitan region of Pennsylvania, USA evaluated the impacts of two land-use scenarios on a series of ecosystem services and used a benefit transfer approach to estimate the economic values of changes in some of these services (Sorrentino et al., 2008). In this case, findings were sufficient to make recommendations for policies to generate more sustainable development patterns in the area. A series of studies conducted in the resort region of Davos in the Swiss Alps combined spatially-explicit models of the delivery of four key ecosystem services with economic models and valuation techniques to evaluate alternative future landscape scenarios in the region (Gret-Regamey and Kytzia, 2007; Gret-Regamey et al., 2007; Gret-Regamey et al., 2008a; Gret-Regamey et al., 2008b; Lundstrom et al., 2007). Their results show clearly the usefulness of such linked models in making land-use decisions as well as in locating the best areas for future development. More such studies that focus on local, rather than regional planning jurisdictions and that make methods and results accessible to local planners and policy-makers would improve the incorporation of ecosystem services in land-use planning in urban areas.

This study combines spatial-environmental modeling with economic valuation techniques to predict the impacts of planned future land use in a developing community, Farmington, MN, USA, on selected ecosystem services and environmental amenities as well as their associated economic impacts. We focus on services whose values are capitalized in the sale prices of residential homes as changes in these services will readily translate into impacts on community tax bases, thus enabling city planners and policy makers to better understand the effects of these changes. This research thus not only generates methods for predicting change in and valuing ecosystem services, but also provides a practical and novel application of environmental modeling and valuation to the evaluation of community-level land-use planning that is lacking in the current literature. In so doing, this study provides valuable information to inform the land-use decision making process and identifies key areas where combined economic and environmental modeling techniques may improve the sustainability of local land-use decision making. It further identifies areas where refinement and improvement are needed and makes suggestions for the application of similar methods in the future.

Past estimates of values for focal services

This study focuses on three ecological amenities and services of particular concern in the study area: the provision of areas for outdoor recreation, scenic quality, and tree cover. The first two of these may be classified as cultural ecosystem services. The last of these, tree cover, is not a service per se, but, rather provides a series of cultural, supporting, regulating, and provisioning services, among them carbon storage, local and regional climate regulation, enhancement of the aesthetic environment, and air pollution mitigation (Beckett et al., 2000; Brack, 2002; Dwyer et al., 1991; Dwyer et al., 1992; Ellis et al., 2006; Laverne and Lewis, 1996; Laverne and Winson-Geideman, 2003; McPherson et al., 2005; Nowak and Crane, 2002; Nowak et al., 2006; Sailor, 1995; Scott et al., 1998; Simpson and McPherson, 1996; Simpson, 1998). The present study estimates the values of two of the services provided by tree cover: local climate regulation and enhancement of the local aesthetic environment, with percent tree canopy cover acting as a proxy for these services. All three of the services and amenities on which this study focuses have received previous attention in the economic valuation literature and have been found to be valuable to humans, so it was expected they would be readily valued in our study.

Open space, which provides many services including areas for outdoor recreation and enhanced scenic quality, has been found in prior studies to contribute positively to property values. A literature review that examined 30 studies of the impact of parks on residential property values found that parks nearly always positively impacted property values for surrounding homes (Crompton, 2001). Although these benefits varied considerably with the characteristics of parks, they were generally found to be 10-20% of total property values and extended between 500 and 2000 feet from parks. More recent studies have supported these conclusions (Bolitzer and Netusil, 2000; Hobden et al., 2004; Lutzenhiser and Netusil, 2001; Wu et al., 2004). In general, these studies indicate that the impact of open space on property values is greater for natural area parks (Lutzenhiser and Netusil, 2001), larger parks (Tajima, 2003), and permanently protected parks (Geoghegan, 2002; Irwin, 2002) than for other park types. Although many studies have examined the values of open space, these studies are difficult to compare because of differences in their methodologies, study areas, and temporal coverage. However, nearly all studies of open space value indicate a positive economic value for these features. As such, their loss or creation is likely to impact local communities economically.

The scenic quality of the environment has also been found to be of value to humans and is commonly assessed by examining the characteristics of views. Previous studies that assessed scenic quality in the form of view quality found that this value is often reflected in property values and that it varies with view characteristics. A recent review of the economic values associated with views (Bourassa et al., 2004) found that the impact of views varied, but that, in most cases, views had positive impacts on residential home values. Examination of the studies reviewed in Bourassa et al. 2004 as well as subsequent studies indicates that the presence of certain land-use and cover types, notably water (Benson et al., 1998; Bishop et al., 2004; Bourassa et al., 2004; Jim and Chen, 2006; Loomis and Feldman, 2003; Luttik, 2000; Sander and Polasky, 2009), forests (Tyrvainen and Miettinen, 2000), grassy areas (Sander and Polasky, 2009), and urban parks (Bishop et al., 2004; Jim and Chen, 2006), positively impact home sale prices as do views with larger areal extents (Sander and Polasky, 2009). Views of built and industrial land-use types may negatively impact property values (Lake et al., 2000a; Lake et al.,2000b) while views of other land-use and cover types may have little or no impact on property values. Thus, view characteristics impact the values of single-family homes and, as such, are likely to impact community tax bases. Additionally, views are readily and irreversibly impacted by land-use change. For these reasons, they should receive consideration in land-use planning and policy making.

Tree cover in urban areas provides multiple ecosystem services, some of which, most notably provision of local scenic quality and local climate regulation, have been found in previous studies to be capitalized in home sale prices. In general, these studies have found that tree cover enhances local home sale prices and that impacts vary with geographic location, tree species, and tree health (Dombrow et al., 2000; Holmes et al., 2006; Mansfield et al., 2005; Morales et al., 1976; Morales, 1980; Thompson et al., 1999). Additionally, studies have found that the level of tree cover within different neighborhood areas around homes impacts sale prices, with higher levels of tree cover in neighborhood areas close to parcels (i.e., within 250 m) having relatively high and positive impacts on home sale prices (Sander et al., *in revision*) while tree cover in more distant neighborhoods has little impact. Because tree cover is readily altered by development and has a quantifiable impact on home sale prices, these values could be used to improve land-use decision-making and policy.

In incorporating these three ecosystem services and amenities in our study, we hope to both shed light on their values in our study area and to identify how they are likely to change under planned future land-use conditions. This will not only enable us to better understand how humans value ecosystem services and amenities, but will distinguish the ways in which land-use change may impact them. Thus, this study has great potential to improve the incorporation of ecosystem services in local land-use planning and to improve the sustainability of local land-use decisions.

Methods

Hedonic Pricing

Overview of Hedonic Pricing

A number of methods exist for valuing ecosystem services and environmental amenities. These include production function methods in which an ecosystem service or amenity is viewed as an input into the production of a marketed good and its value is estimated based on that good's price, replacement cost analyses that use the price of the least-cost alternative means for providing a service as a proxy for its value, stated preference approaches that use survey results to determine the monetary value individuals will pay for an increase in a service or will accept to allow a decrease in a service, and household production functions that value environmental goods and services based on the sale prices of marketed goods related to these amenities. This study uses hedonic pricing, a household production function technique that estimates the partial economic value of changes in an ecosystem service or amenity based on the sale prices of similar properties (e.g., residential homes) with different levels of that amenity, to estimate the economic values of the three target services and amenities in the year 2005. These values are then used to project the economic impacts of land-use changes occurring in the study area between 2005 and 2030 based on the results of environmental models.

Hedonic pricing models are typically used to estimate the marginal implicit prices associated with a change in the attributes of a property by estimating the relationship between these attributes and the property's sale price or assessed value (Freeman, 2003). Most commonly, these studies focus on the values of single-family residential homes in estimating value, but may also utilize lease values for commercial or residential rental units. The present study uses the sales prices of single-family residential homes to construct a hedonic pricing model that relates sale price to the structural, neighborhood, and environmental aspects of homes through the use of ordinary least squares (OLS) regression and spatially simultaneous autoregressive (SAR) error modeling. The OLS model used may be written as:

$$\ln P_i = \beta_0 + \beta_1 S_i + \beta_2 N_i + \beta_3 Q_i + \varepsilon_i$$

Here, ln P_i represents the natural log of property i's sale price, S_i represents a vector of property i's structural characteristics (e.g., lot size, home age), N_i is a vector of neighborhood characteristics (e.g., development intensity), Q_i is a vector of environmental characteristics (e.g., recreation area access, percent tree cover on parcel), and ε_i is an error term. Because we expected the impact of some variables (e.g., distance variables, home square footage, lot acreage) to decline as their values increased, we used their natural logs in our model. We also included a squared term for home age because we expected its impact to become insignificant or change direction at some value, such that newer homes would decrease in value with increasing age to a certain age and then would increase in value.

Two issues, heteroscedasticity and spatial autocorrelation, may complicate the estimation of hedonic pricing models, and, indeed, any model generated using OLS regression with spatial data. To identify whether these issues complicate a particular model, one may test for spatial autocorrelation using Moran's I statistic. If the result is significant, one may then use Lagrangian multiplier diagnostics to assess whether this autocorrelation is best explained by assuming spatial autocorrelation in the error term, which occurs, for example, when a spatially-structured predictor variable has been omitted from the model; in the lag term which occurs when spatial autocorrelation is present only in the dependent variable; or in both terms. Once the likely source of spatial autocorrelation has been identified, a number of methods exist to address it. One of these is the use of spatial regression models, for example, SAR models which augment standard OLS models by adding a term to incorporate the spatial structure of the autocorrelation in the dataset (Cressie, 1993; Haining, 2003). In these models, a user-defined spatial weights matrix that identifies the weight of each neighbor to a given observation is used to implement the added term. This weights matrix may be defined in a number of ways (Anselin and Bera, 1998; Fortin and Dale, 2005), most commonly based on distance such that closer neighbors receive higher weights in accounting for patterns in the dependent variable not accounted for by the independent variables.

Three types of SAR models exist: error, lag, and mixed (Anselin, 1988; Cliff and Ord, 1981; Haining, 2003). SAR error models are used to address autocorrelation in the error term. These models add an additional term, λWμ, to the OLS expression to represent the spatially-dependent error term's spatial structure. The SAR error model may be summarized as:

$$Y = X\beta + \varepsilon_i + \lambda Wu$$

where Y is the dependent variable, X is a matrix, β is a vector that represents the slopes associated with the explanatory variables in the original predictor matrix, λ is the spatial autoregression coefficient, W represents a spatial weights matrix used in model estimation, and *u* represents a spatially-dependent error term. The SAR lag model, which is used to address spatial autocorrelation in the lag term, adds a term to account for spatial autocorrelation in the dependent variable to the standard OLS regression such that:

$$Y_i = X\beta + \varepsilon_i + \rho WY$$

where ρ is the autoregression coefficient and Y is the response variable. When spatial autocorrelation exists in both the lag and error terms, a SAR mixed or Durbin model may be used. This model adds an addition term, WXγ, to represent the autocorrelation coefficient of the lagged independent variables, where γ is the autoregression coefficient. SAR mixed models may thus be represented as follows:

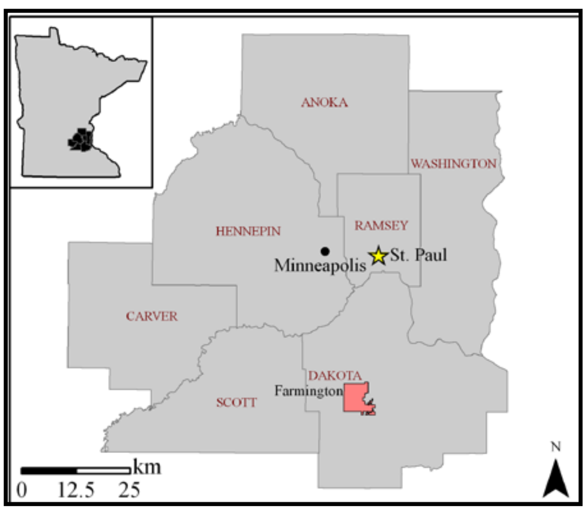
$$Y_i = X\beta + \varepsilon_i + \rho WY + WX\gamma$$

In implementing our hedonic pricing model and other regression models used in this analysis, we use these models in cases where statistical tests indicate they are appropriate.

Study Area

The main study area for this analysis is the City of Farmington in Dakota County, MN located approximately 25 miles south of the Twin Cities of Minneapolis and St. Paul, MN (Figure 4). Until recently, Farmington was largely an agricultural community, but has now become increasingly suburban in its character. As part of a wave of suburban growth sweeping the Twin Cities metropolitan area, Farmington's population has grown dramatically in recent years, with the city's total population increasing from 5,940 in 1990 to 12,365 in 2000. This growth is projected to continue with populations expected to reach 22,320 by 2010 and 32,700 by 2030. Farmington's current comprehensive plan calls for accommodating this growth through large amounts of residential construction. This will continue the dramatic suburbanization that has occurred in the city in recent years.

Figure 4. Location of the study area, Farmington, MN.



Because Farmington itself is expected to change greatly in its character in the coming decades, we felt that estimating marginal implicit prices and ecosystem service models based on 2005 data for Farmington alone would be unlikely to accurately reflect the levels of ecosystem services and amenities and the economic values of 2030 residents of the city. To address this, we used 2005 values for our target ecosystem services for all of Dakota County as well as 2005 landscape conditions to generate models of ecosystem services and amenities and used 2005 home sale price data for the entire county to estimate our hedonic pricing model. Present conditions in the county overall better approximate the variety of land-use conditions, ranging from agricultural to industrial to urban, likely to be present in Farmington in the year 2030 than do present conditions in Farmington itself. Thus, we felt that marginal implicit prices and models generated using county-wide data would better approximate the values of Farmington's 2030 residents.

Data

Many of the data used in constructing the hedonic pricing model originated in the Metropolitan Twin Cities Parcel Dataset, which consists of spatially-referenced sale price, tax, and structural data for all parcels in the Twin Cities seven-county metropolitan area and is available from the Twin Cities Metropolitan Council. We identified a total of 5,094 single-family residential properties that sold in Dakota County during the year 2005 for which full valid data were available. Excluded observations included properties for which data for one or more variables of interest were missing or that had unlikely values for one or more variables, for example, indicating that the home had been built in the year 1602 or that a 900 square foot home sold for over $2,000,000. These 5,094 properties acted as our sample in constructing our hedonic pricing model.

For each of our sample properties, we identified a series of structural, neighborhood, and environmental attributes that could be correlated with property sales price (Tables 8 and 9). Most structural attributes as well as sales price came directly from the Twin Cities Parcel Dataset. Structural attributes included finished square footage, lot size, property tax rate, and home age variables as well as dummy variables to indicate sale month. We also calculated a dummy variable to identify whether or not a home was situated in a Federal Emergency Management Agency (FEMA) floodway using a GIS dataset that delineated such floodways available from the Minnesota Department of Natural Resources.

Table 8. Definitions of variables used in the hedonic pricing model with predicted effects on home sale price.

Variable	Definition	Expected relationship to home sale price
Structural variables		
PRICE	Sale price for home	N/A
ACRES	Lot size in acres	positive
FINSQFT	Home finished square footage	positive
HOME_AGE	Age of home in years	positive/ negative*
TAX_RATE	Home's tax rate as a percentage	negative
FLOOD	Dummy variable for location in a FEMA floodway (0 if no, 1 if yes)	negative
Neighborhood variables		
IMPERVIOUS	Mean percent impervious surface within 500 m of home	negative
CBD	Euclidean distance in meters from home to closest central business district (downtown Minneapolis or St. Paul)	negative**
Sale month dummy variables (ref. month is February; 1 for sale in month, 0 otherwise)		
JAN	Dummy variable for sale in January	positive
MAR	Dummy variable for sale in February	positive
APR	Dummy variable for sale in April	positive
MAY	Dummy variable for sale in May	positive
JUNE	Dummy variable for sale in June	positive
JULY	Dummy variable for sale in July	positive
AUG	Dummy variable for sale in August	positive
SEPT	Dummy variable for sale in September	positive
OCT	Dummy variable for sale in October	positive
NOV	Dummy variable for sale in November	positive
DEC	Dummy variable for sale in December	positive
Submarket dummy variables (ref. location is Simley HSD; 1 in district, 0 otherwise)		
APPLEVALLEY	Dummy variable for location in Apple Valley High School district	positive
BURNSVILLE	Dummy variable for location in Burnsville High School district	positive
EAGAN	Dummy variable for location in Eagan High School district	positive
EASTVIEW	Dummy variable for location in Eastview High School district	positive
FARMINGTON	Dummy variable for location in Farmington High School district	positive
HASTINGS	Dummy variable for location in Hastings High School district	positive
LAKEVILLE	Dummy variable for location in Lakeville High School district	positive
ROSEMOUNT	Dummy variable for location in Rosemount High School district	positive
S_STPAUL	Dummy variable for location in South St. Paul High School district	positive
W_STPAUL	Dummy variable for location in West St. Paul High School district	positive
NFLD_RNDLPH	Dummy variable for location in Northfield or Randolph High School districts	positive
Ecosystem service and amenity variables		
Access to outdoor recreation areas		

Variable	Definition	Expected relationship to home sale price
LAKE	Euclidean distance in meters from home to closest lake	negative *
LGPKRD	Road distance in meters from home to closets 1 ha or large park	negative *
Tree cover		
TREE_PARCEL	Mean percent tree cover on the home's parcel	positive
TREE_100	Mean percent tree cover in 100 m neighborhood around parcel	positive
TREE_250	Mean percent tree cover in 100-250 m neighborhood around parcel	positive
TREE_500	Mean percent tree cover in 250-500 m neighborhood around parcel	positive
TREE_750	Mean percent tree cover in 500-750 m neighborhood around parcel	positive
TREE_1000	Mean percent tree cover in 750-1000 m neighborhood around parcel	positive
View		
VIEW_AREA	Total areal extent of a home's viewshed in ha	positive
IMP5_10	Area of 5-10% impervious land cover in home's viewshed in meters	negative
IMP11_25	Area of 11-25% impervious land cover in home's viewshed in meters	negative
IMP26_50	Area of 26-50% impervious land cover in home's viewshed in meters	negative
IMP51_75	Area of 51-76% impervious land cover in home's viewshed in meters	negative
IMP76_100	Area of 76-100% impervious land cover in home's viewshed in meters	negative
LAWN	Area of short grass (lawn) land cover in home's viewshed in meters	positive
MTD_TALLGR	Area of maintained tall grass land cover in home's viewshed in meters	positive
FOREST	Area of forest land cover in home's viewshed in meters	positive
SHRUB	Area of shrub land cover in home's viewshed in meters	positive
GRASSLND	Area of unmaintained grassland land cover in home's viewshed in meters	positive
EMER_VEG	Area of emergent vegatation land cover in home's viewshed in meters	positive
VW_H20	Area of open water land cover in home's viewshed in meters	positive
WOOD_WET	Area of woody wetland land cover in home's viewshed in meters	positive
AG	Area of agricultural land cover in a home's viewshed in meters	negative

*We expected home sale price to be negatively related to home sale price to a certain age, then positive.

**A negative relationship between distance variables and home sale price implies that home sale price decreases with increasing distance.

Table 9. Descriptive statistics for continuous variables used in the hedonic pricing model for Dakota County in 2005.

Variable	Mean	Std. Deviation	Min.	Max.
Structural variables				
PRICE ($)	319,073.79	141,121.28	100,000.00	2,870,250.00
ACRES	0.45	1.20	0.06	43.38
FINSQFT	2,215.73	812.14	614.00	11,498.82
HOME_AGE	23.50	22.54	0.00	153.00
TAX_RATE (%)	0.00	1.69	0.90	0.28
Neighborhood variables				
IMPERVIOUS (m)	28.60	18.36	0.00	100.00
CBD (m)	22,199.30	9,267,58	1,719.86	52,052.08
Ecosystem service and amenity variables				
Access to outdoor recreation areas				
LAKE (m)	898.25	824.20	0.00	9,320.77
LGPKRD (m)	555.43	1,132.93	0.00	13,095.19
Tree cover				
TREE_PARCEL (%)	13.60	22.59	0.00	93.00
TREE_100 (%)	13.40	16.84	0.00	90.00
TREE_250 (%)	14.00	17.13	0.00	88.57
TREE_500 (%)	14.57	17.26	0.00	90.00
TREE_750 (%)	15.10	17.31	0.00	88.39
TREE_1000 (%)	15.80	17.73	0.00	100.00
View				
VIEW_AREA	33.26	29.83	0.66	246.58
IMP5_10 (m2)	4,487.61	13,978.91	0.00	237,225.00
IMP11_25 (m2)	4,422.93	18,981.18	0.00	368,825.00
IMP26_50 (m2)	22,979.77	32,983.27	0.00	368,625.00
IMP51_75 (m2)	6,018.01	17,306.61	0.00	676,975.00
IMP76_100 (m2)	2,862.58	12,844.79	0.00	454,700.00
LAWN (m2)	2,583.85	11,517.40	0.00	260,225.00
MTD_TALLGR (m2)	2,731.45	14,538.67	0.00	378,000.00
FOREST (m2)	6,339.91	23,697.98	0.00	708,100.00
SHRUB (m2)	232.17	1,635.22	0.00	38,250.00
GRASSLND (m2)	4,760.88	19,999.88	0.00	665,025.00
EMER_VEG (m2)	2,313.54	14,894.02	0.00	471,600.00
VW_H20 (m2)	4,904.00	33,990.69	0.00	1,162,775.00
WOOD_WET (m2)	2,339.39	25,210.89	0.00	936,600.00
AG (m2)	19,527.16	111,402.22	0.00	1,836,450.00

We estimated neighborhood characteristics in a GIS environment using several additional datasets. We estimated mean percent impervious surface to quantify development intensity in a neighborhood. We calculated this as the mean percentage of impervious surface within 500 m of each property as identified by an impervious surface map for the region available from the University of Minnesota's Remote Sensing and Geospatial Analysis Laboratory. Additionally, because ease of access to business centers may influence home sale prices, we calculated distances to the central business districts of Minneapolis and St. Paul as identified in a GIS dataset depicting fare zones for regional transit systems available from the Twin Cities Metropolitan Council for each property. In this case, we calculated the Euclidean distance between each property and the border of its closest central business district, either Minneapolis or St. Paul. To account for the impact of the submarket in which a home is located on its sale price, we also generated a series of housing submarket dummy variables based on the high school district in which a home resides. In this way, we identified a total of twelve housing submarkets.

We estimated a series of environmental variables for each sample property, focusing on the ecosystem services and amenities of provision of access to outdoor recreation areas, scenic quality, and tree cover. To identify each sample parcel's access to areas for outdoor recreation, we identified all parks of 1 ha or more in area using two datasets available from the Twin Cities Metropolitan Council, Twin Cities Metropolitan Council Regional Recreational Open Space Features and The Lawrence Group Landmarks. Past hedonic studies have used several different measures to quantify a property's access to open space areas, including the size of the closest open space area to a home (Lutzenhiser and Netusil, 2001), dummy variables to indicate whether or not such areas are found within a given distance from a home (Lutzenhiser and Netusil, 2001; Netusil, 2005), the percentage or area of land within a given buffer distance occupied by open space (Acharya and Bennett, 2001; Geoghegan et al., 1997; Geoghegan, 2002; Irwin, 2002; Kong et al., 2007; Ready and Abdalla, 2005) , and, most commonly, the distance between a home and its closest open space area (Anderson and West, 2006; Bolitzer and Netusil, 2000; Kong et al., 2007; Lake et al., 2000a; Sander and Manson, 2007; Tajima, 2003; Troy and Grove, 2008; Wu et al., 2004). Based on previous experience and research in the study area (Anderson and West, 2006; Doss and Taff, 1996; Sander and Polasky, 2009), we chose to use the last measure, distance, to quantify each property's open space access and calculated the road distance between each sample property and its closest open space area in a GIS. Our previous research indicates that road distance best matches residents' perceptions of access to the large parks used in this study because these areas are typically accessed using roads in the study area (Sander and Polasky, 2009). As this is unlikely to be the case for properties located adjacent to or across the street from parks, we identified such properties and assigned them travel distances of zero since their owners would likely access the park directly from their property.

Lakes also serve as significant sites for outdoor recreation in the study region. As such, we calculated an additional metric to quantify access to recreational open space, distance to lakes. In this case, we identified all lakes in the study area using a dataset available from the Minnesota Department of Natural Resources. Experience and past studies conducted in the study region indicate that lakes are typically accessed at a series of points located nearly continuously along their perimeters in an as-the-crow-flies fashion rather than at discrete entry points, for instance at intersections with roads (Sander and Polasky, 2009). Thus, we calculated Euclidean distances between each sample residence and its closest lake to quantify lake access. We use this variable as well as the park proximity variable to quantify each property's access to outdoor recreation areas in our analysis.

We calculated viewsheds, computational approximations of views, in a GIS environment to identify the scenic quality of the environment around each sample home. In so doing, we used several GIS datasets: a bare-earth digital elevation model (DEM) available from the Twin Cities Metropolitan Council, a planimetric dataset that identified the footprints and locations of buildings provided by Dakota County GIS, and, to identify the land-cover composition of each property's viewshed, a land-cover map, Twin Cities Metro Hybrid Landcover (HYBLC) 2000, available from the Minnesota Department of Natural Resources, which we updated to 2005 conditions using parcel-level land-use data. To calculate viewsheds, we first modified the bare earth DEM to include buildings, then used this DEM, along with footprints for sample buildings as observer locations, to calculate the viewshed for each property using techniques established in previous studies (Sander and Manson, 2007; Sander and Polasky, 2009). Because minimal information regarding tree locations and heights is currently available in the study area, it was not possible to include trees as view obstructions in the DEM. To quantify viewshed characteristics, we next calculated the areal extent of each viewshed as well as the area of each land-cover class in each view.

To provide a further measure of the local aesthetic environment around each sample parcel as well as to provide a measure of local climate regulation, we calculated additional variables related to tree cover. To do so, we utilized the National Land Cover Database (NLCD) 2001 Tree Canopy dataset available from the Minnesota Department of Natural Resources. This datasets identifies per pixel percent tree canopy cover at a 30 m resolution based upon Landsat Thematic Mapper imagery (Homer et al., 2004; Huang et al., 2003). A temporal mismatch of four years exists between this dataset and the parcel data. However, as tree cover in the study area has not experienced much change in the short-term since most land-cover change has been from treeless agricultural land to built land covers and tree canopy cover changes little in four years, and as no other tree cover data were available, this dataset, although not ideal, was the best available dataset for our purposes. To quantify tree cover as well as to identify the sphere of influence of tree cover on home sale prices, we calculated the mean percent tree cover within a series of neighborhoods around each sample parcel (parcel level, parcel to 100 m, 100-250 m, 250-500 m, 500-750 m, and 750-1000 m). Based on the results of a previous study (Sander et al., *in revision*), we expected that tree cover in the closer neighborhoods would contribute positively to home sale prices and that tree cover at the parcel level as well as in more distant neighborhoods would not significantly impact home sale prices.

The sales, structural, neighborhood, and environmental variables were then used to construct a hedonic pricing model as described above. Based upon this model, we estimated the marginal implicit prices for significant environmental variables. We used this model in later study steps to predict the sale prices of homes in a future, 2030

Farmington landscape and to quantify the likely economic impacts of changes in each environmental variable under 2030 landscape conditions on home sale prices.

Identification of Farmington 2005/2030 Landscape Conditions

Mapping 2005 Land Use and Cover

To provide baseline land-use and cover data for the study city (Farmington, MN), we first generated a 2005 land use map for Farmington (Figure 5a). To do this, we used parcel-level data provided by the City of Farmington which identified individual parcel land use. We then used this dataset to modify two land-cover datasets, the NLCD 2001 Land Cover Dataset and the Twin Cities Metro HYBLC 2000 dataset, both available from the Minnesota Department of Natural Resources, so that land-use changes occurring between the date of each dataset's creation and 2005 were represented (Figures 6a and 6c). We used both of these land-cover maps later in the study to identify the characteristics of the 2005 landscape as well as in modeling 2030 land cover.

2005 Variable Calculation and Valuation

We identified all single-family residential properties (4,817) existing in Farmington in 2005 using the parcel-level data provided by the city. We then used the methods described above to calculate all structural, neighborhood, and environmental variables from the hedonic pricing model for these properties under 2005 conditions. In estimating viewshed characteristics, we used the modified 2005 HYBLC dataset described above. We then used variables in our hedonic pricing model for Dakota County to predict likely home sale prices for all homes in the sample in the year 2005. We also used them for comparison to the predicted values of these variables in 2030 to identify changes in each environmental amenity under 2030 landscape conditions.

Figure 5. Farmington, MN land use in 2005 (5a) and 2030 (5b).

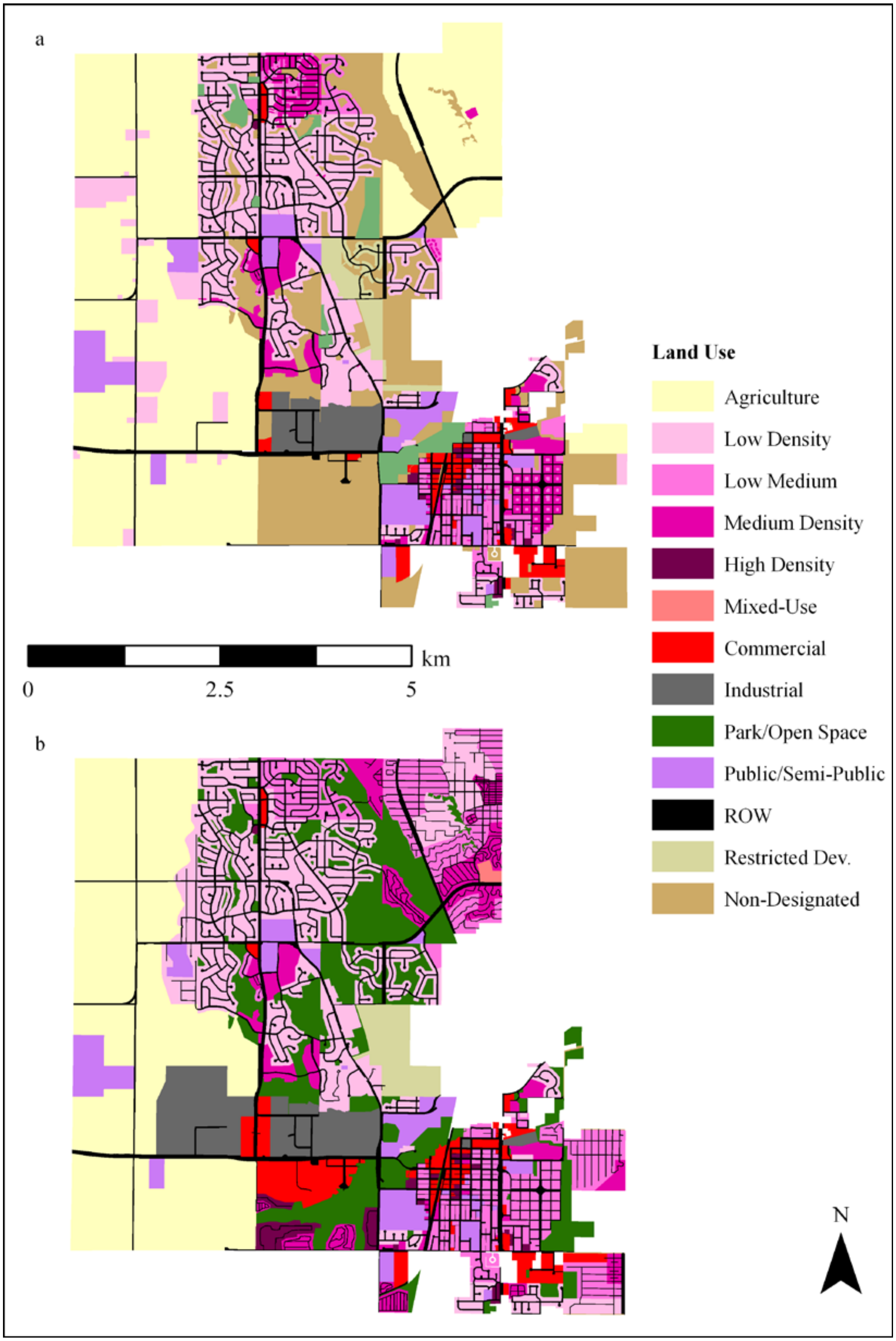
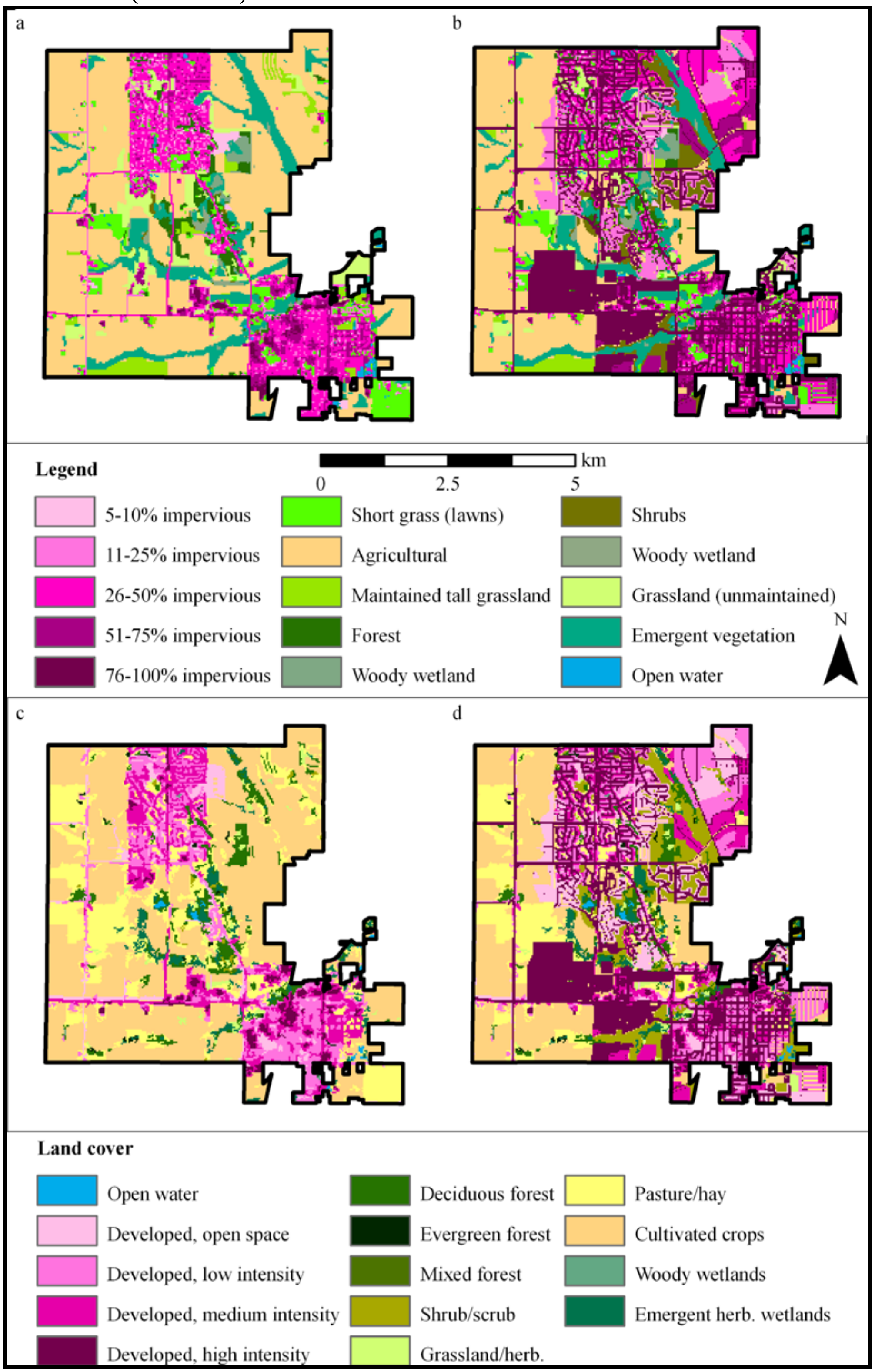


Figure 6. Farmington, MN land cover in 2005 using the NLCD (6a) and HYBLC (6c) datasets and in 2030 (6b and 6d).



Mapping 2030 Land Use and Cover

We generated a 2030 land-use map for Farmington using parcel-level data provided by the city that indicated the city's planned land use for each 2005 parcel in 2030 (Figure 5b). This dataset indicated the planned 2030 land use for each parcel as one of twelve categories, but did not subdivide existing parcels to reflect new land uses or add new roads to serve new development. To generate a 2030 land-use map from these data, we divided parcels into lots of the size indicated for each land-use type by Farmington's 2030 Comprehensive Plan, then digitized roads to serve new parcels and erased areas that became roads from the created parcels. Buildings were generated for each new built parcel by placing a point at the centroid of each new parcel, then buffering that point to the mean footprint area for buildings on parcels of corresponding land-use types in 2005 under the assumption that mean home sizes would be comparable. This may be somewhat unrealistic as the average home square footage in Farmington as indicated by the parcel dataset has generally increased over the last 50 years in the study areas from a mean of 1,846 ft^2 for homes built in the 1960s to a mean of 1,974 ft^2 for homes built in between 1995 and 2005. However, examination of the square footages of homes built from 2000 on shows this trend to be slightly decreasing, so we felt that using mean areas for homes constructed in all years would provide an adequate estimate of the square footages of future homes. These buildings were later used to generate observation points and to modify the 2005 bare earth and building DEM to include new buildings for 2030 viewshed calculation.

Using this map, we altered the NCLD 2001 Landcover Dataset and Twin Cities Metro HYBLC 2000 dataset that had previously been modified to reflect 2005 land-use conditions, to reflect 2030 conditions (Figures 6c-6d). To do this, we used a series of decision rules to identify the future land cover on each parcel. The decision rules for parcels with land uses that changed between 2005 and 2030 are summarized in Table 10. All developed parcels with land uses that did not change between 2005 and 2030 remained in their 2005 land cover in 2030. Parcels that experienced a change in land use during this time period were assigned a corresponding new land cover in 2030 based on the decision rule for each transition type.

Table 10. Decision rules used to identify 2030 land cover.

Land Use 2005	Land Use 2030	Land cover HYBLC 2030	Land cover NLCD 2030
Agricultural or vacant	Low density residential	11-25% impervious	Developed, open space
Agricultural or vacant	Low-medium density residential	26-50% impervious	Developed, low intensity
Agricultural or vacant	Medium density residential	51-75% impervious	Developed, medium intensity
Agricultural or vacant	High density residential	75-100% impervious	Developed, high intensity
Agricultural or vacant	Industrial	75-100% impervious	Developed, high intensity
Agricultural or vacant	Commercial	75-100% impervious	Developed, high intensity
Agricultural or vacant	Park/open space	Shrubs	Shrub/scrub
Agricultural or vacant	Road	75-100% impervious	Developed, high intensity
Agriculture or vacant	Restricted development	If forest in 2005, then forest in 2030; lawn or maintained grassland in 2005, then grassland in 2030; grassland in 2005, then shrub in 2030; wetland forest in 2005, then wetland forest in 2030; wetland shrub in 2005, then wetland forest in 2030.	If any forest type in 2005, then same forest type in 2030; shrub/scrub in 2005, then forest in 2030; grassland in 2005, then shrub/scrub in 2030; any wetland type in 2005, then same wetland type in 2030
Agriculture or vacant	Park/open space	If forest in 2005, then forest in 2030; lawn or maintained grassland in 2005, then grassland in 2030; grassland in 2005, then shrub in 2030; wetland forest in 2005, then wetland forest in 2030; wetland shrub in 2005, then wetland forest in 2030.	If any forest type in 2005, then same forest type in 2030; shrub/scrub in 2005, then forest in 2030; grassland in 2005, then shrub/scrub in 2030; any wetland type in 2005, then same wetland type in 2031

Park/open Space	Park/open space	If forest in 2005, then forest in 2030; lawn or maintained grassland in 2005, then same in 2030; grassland in 2005, then shrub in 2030; wetland forest in 2005, then wetland forest in 2030; wetland shrub in 2005, then wetland forest in 2030.	If any forest type in 2005, then same forest type in 2030; shrub/scrub in 2005, then forest in 2030; grassland in 2005, then shrub/scrub in 2030; any wetland type in 2005, then same wetland type in 2030

Quantifying Ecosystem Service Delivery in 2030

Based on lot size and finished square footage specifications for multi- and single-family housing listed in Farmington's Comprehensive Plan, we identified a total of 7,089 single-family properties from the 2030 parcel-level land-use map. We then calculated each variable from the Dakota County hedonic pricing model for each of these properties using the following methods. We assigned homes that existed in 2005 their 2005 lot acreage, finished square footage, flood zone status, distance to central business districts and lakes, and tax rate and calculated home age in 2030 based on the home's year of construction, assuming that these characteristics of existing homes did not change between 2005 and 2030. Both previously existing and new homes were assigned to the Farmington neighborhood submarket.

For homes that were constructed between 2005 and 2030, we calculated lot acreage for each parcel in a GIS and home square footage by multiplying home footprint area by two assuming the 2005 mean building height of two stories did not change in 2030. We assigned all single-family homes the mean 2005 tax rate of 1.35% assuming that this too did not change over time. We identified flood zone status using the same FEMA flood zones used with 2005 data and calculated distance to the central business districts of Minneapolis and St. Paul and lakes using the same definitions as used for 2005 data, again assuming that these would not change during the study time period.

Because we did not have projections for household numbers for each year in Farmington, but only at ten year increments, we used a simple regression model to identify the year in which homes would be built based on projections for the number of households in Farmington made at intervals of ten years by the city. In this model, the dependent variable was the number of households and the independent variable was the year. This model had an R^2 of 0.990 (F=396.5, $p < 0.001$) and can be summarized as follows:

$$h = 272.010y + -539{,}376.30$$

where h is the number of households and y is the year. Using this model, we calculated the total number of households in Farmington in each year between 2005 and 2030. We then rescaled the predicted values to match the predicted values for the start and end of each ten year range for which predictions were available such that the number of households at the start and end of a range was equal to predicted number in those years. We then used these predicted numbers of households to identify the number of residences constructed each year and selected the given number of properties from parcels identified as built between 2005 and 2030 at random and assigned them that building year. As a result, the number of buildings constructed each year followed a decreasing trend over time as indicated by the city's projections. We used these building years to calculate the age of all single-family residential properties in Farmington in 2030.

Using our hedonic pricing model to identify home sale prices in 2030 requires us to assume that all single-family homes in Farmington sell during the year 2030. To do this, we also need to identify a sale month for each home. To identify the likely months of sale, we first calculated the percentage of homes selling in each month in the 2005 Dakota County sample. Assuming that the distribution of home sales by month would be similar in 2030, we calculated the number of homes that would sell in Farmington in each month of 2030 using these percentages. We then randomly selected the calculated number of homes selling each month from all single-family residential properties existing in Farmington in 2030 and assigned them the corresponding sale month. We used the identified sale months to assign dummy variables for month of sale for each home.

To calculate the mean percentage of impervious surface within 500 m of each single-family residential home in 2030, we first constructed a 2030 map of impervious surface. In so doing, we assumed that all parcels for which land use did not change or that remained in undeveloped land uses retained the same level of impervious surface as it had in 2005. We assigned parcels with land uses that changed to commercial, industrial, right-of-way, or any residential type the mean impervious surface value for their land-use type in 2005 in Dakota County. These values were as follows: commercial – 48.30%, industrial – 37.68%, right-of-way – 79%, low density residential – 25.32%, low-medium density residential – 32.14%, medium-density residential – 43.66%, and high density residential – 40.91%. We then calculated the mean percentage impervious surface within a buffer area of 500 m around each single-family residential parcel from 2030 using the resulting 2030 impervious surface map.

Assuming that all areas designated as open space in Farmington's parcel data would become parks in Farmington by 2030, we calculated road distances to these parks for all existing and new single-family residential properties in 2030. In so doing, we used a new parks dataset including all areas designated as open space in 2030 with areas greater than 1 ha and a roads dataset consisting of all 2005 roads plus roads modeled as constructed between 2005 and 2030. As before, we identified properties that directly bordered or were located across roadways from parks and assigned them distances of zero as the owners of these properties would likely access parks directly without using road networks.

We calculated viewsheds for all single-family residential parcels in Farmington in 2030 using the same methods used in calculating viewsheds for 2005 data. In this case, however, we used a modified DEM that included bare earth elevations and 2005 and 2030 buildings and all 2030 single-family buildings as observer points. We then calculated the areal extents of these viewsheds and calculated the areas of each land-cover type in each viewshed using the modified 2030 HYBLC map.

To identify tree cover percentages for the 2030 Farmington landscape, we constructed a map of 2030 tree canopy cover. Because we believed that different factors impact tree cover on built parcels than on parcels without buildings, we modeled 2030 tree cover differently for these two parcel types. For built parcels, we constructed a regression model to predict tree cover at the parcel level as a function of land use using 2005 NLCD land-use and cover data and structure age data for a random sample of 2,255 built parcels in Dakota County. The dependent variable in this model was mean parcel-level percent tree cover as indicated by the NLCD tree canopy data and the independent variables included the age of the building on the parcel calculated as above; the area of a series of land-cover types within 500 m of each parcel as calculated from the modified NLCD 2001 dataset; and dummy variables to indicate the parcel's primary land use, the majority land cover on the parcel, and the market segment in which a parcel is located assigned using high school districts for the area (Tables 11-12). This model was first executed using OLS regression, but, because of significant spatial correlation in the lag term as identified using Moran's I and Lagrangian multiplier diagnostics, we calculated our final model using a SAR lag model (see description above). The final model included terms that were significant at the $p < 0.10$ level or lower. We used this model to predict 2030 percent canopy cover at the parcel level for the Farmington landscape.

To model tree cover on parcels without buildings, we constructed a second regression model using a random sample of 1,207 unbuilt Dakota County parcels. We used nearly the same variable set in constructing this model as we did to construct the model for built parcels, but omitted home age (Tables 11-12). Again, we included all variables significant at the $p < 0.10$ level or lower in our final model. In this case, Moran's I and Lagrangian multiplier diagnostics indicated that spatial autocorrelation was not significant in this model's residuals, so our OLS model was sufficient to predict tree cover on parcels that lacked buildings. We combined our resulting predictions with those of the built parcel model to generate a tree cover map for Farmington in 2030. We calculated mean tree cover values within each neighborhood area for each 2030 single-family residential parcel using the methods described previously.

Table 11. Definitions of variables used in tree cover modeling. All land-cover classes are HYBLC classes.

Variables	Definintion
(Intercept)	
HOME_AGE	Age of home in years
AG_PARCEL	Dummy variable to indicate if agriculture is designated parcel land use (1) or not (0)
COM_PARCEL	Dummy variable to indicate if commercial is designated parcel land use (1) or not (0)
LDR_PARCEL	Dummy variable to indicate if low density residential is designated parcel land use (1) or not (0)
LMR_PARCEL	Dummy variable to indicate if low-medium density residential is designated parcel land use (1) or not (0)
MDR_PARCEL	Dummy variable to indicate if medium density residential is designated parcel land use (1) or not (0)
PARK_PARCEL	Dummy variable to indicate if park/open space is designated parcel land use (1) or not (0)
DEV_LOW500	Area of developed, low intensity land cover within 500 meters in meters
DEV_MED500	Area of developed, medium intensity land cover within 500 meters in meters
DEC_FOR500	Area of deciduous forest land cover within 500 meters in meters
MIX_FOR500	Area of mixed forest land cover within 500 meters in meters
SHRUB500	Area of scrub/shrub land cover within 500 meters in meters
GRASS_HERB500	Area of grassland/herbaceous land cover within 500 meters in meters
WOODY_WET500	Area of woody wetland land cover within 500 meters in meters
HERB_WET500	Area of herbaceous wetland land cover within 500 meters in meters
CROPS500	Area of crop land cover within 500 meters in meters
BARREN_500	Area of barren land cover within 500 meters in meters
MAJ_H2O	Dummy variable to indicate if majority land cover on parcel is open water (1 if yes, 0 if no)
MAJ_DEV_OPEN	Dummy variable to indicate if majority land cover on parcel is developed, open space (1 if yes, 0 if no)
MAJ_DEV_LOW	Dummy variable to indicate if majority land cover on parcel is developed, low intensity (1 if yes, 0 if no)
MAJ_DEV_MED	Dummy variable to indicate if majority land cover on parcel is developed, medium intensity (1 if yes, 0 if no)
MAJ_DEV_HIGH	Dummy variable to indicate if majority land cover on parcel is developed, high intensity (1 if yes, 0 if no)
MAJ_DEC_FOR	Dummy variable to indicate if majority land cover on parcel is deciduous forest (1 if yes, 0 if no)
MAJ_EVER_FOR	Dummy variable to indicate if majority land cover on parcel is evergreen forest (1 if yes, 0 if no)
MAJ_MIX_FOR	Dummy variable to indicate if majority land cover on parcel is mixed forest (1 if yes, 0 if no)
MAJ_SHRUB	Dummy variable to indicate if majority land cover on parcel is scrub/shrub (1 if yes, 0 if no)
MAJ_GRASSLAND	Dummy variable to indicate if majority land cover on parcel is grassland (1 if yes, 0 if no)

Variables	Definintion
MAJ_WETLAND	Dummy variable to indicate if majority land cover on parcel is wetland (1 if yes, 0 if no)
MAJ_PASTURE	Dummy variable to indicate if majority land cover on parcel is pasture (1 if yes, 0 if no)
MAJ_CROP	Dummy variable to indicate if majority land cover on parcel isfrop (1 if yes, 0 if no)
APPLEVALLEY	Dummy variable for location in Apple Valley High School district (1 if yes, 0 if no)
BURNSVILLE	Dummy variable for location in Burnsville High School district (1 if yes, 0 if no)
EAGAN	Dummy variable for location in Eagan High School district (1 if yes, 0 if no)
EASTVIEW	Dummy variable for location in Eastview High School district (1 if yes, 0 if no)
FARMINGTON	Dummy variable for location in Farmington High School district (1 if yes, 0 if no)
HASTINGS	Dummy variable for location in Hastings High School district (1 if yes, 0 if no)
LAKEVLLE	Dummy variable for location in Lakeville High School district (1 if yes, 0 if no)
NORTHFIELD	Dummy variable for location in Northfield High School district (1 if yes, 0 if no)
ROSEMOUNT	Dummy variable for location in Rosemount High School district (1 if yes, 0 if no)
SIMLEY	Dummy variable for location in Simley High School district (1 if yes, 0 if no)
SSTPAUL	Dummy variable for location in South St. Paul High School district (1 if yes, 0 if no)
WSTPAUL	Dummy variable for location in West St. Paul High School district (1 if yes, 0 if no)
CANFALLS_RAND	Dummy variable for location in Cannon Falls or Randolph High School district (1 if yes, 0 if no)

Table 12. Descriptive statistics for continuous variables used in tree cover modeling.

	Built sample				**Unbuilt sample**			
Variable	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**
TREE_COVER	0.00	85.01	7.73	14.45	0.00	91.79	12.02	21.54
HOME_AGE	1.00	149.00	37.15	32.30	N/A	N/A	N/A	N/A
DEV_OPEN500 (m2)	0.00	574,200.00	32,532.88	50,208.40	0.00	756,000.00	46,795.53	73,798.93
DEV_LOW500 (m2)	0.00	1,112,400.00	63,265.81	94,694.27	0.00	667,800.00	52,609.36	98,469.47
DEV_MED500 (m2)	0.00	657,900.00	51,611.31	85,364.54	0.00	581,400.00	41,504.39	82,656.36
DEV_HIGH500 (m2)	0.00	582,300.00	14,270.01	41,626.58	0.00	437,400.00	18,699.42	54,756.68
DEC_FOR500 (m2)	0.00	2,124,000.00	44,057.69	104,396.33	0.00	1,441,800.00	59,911.52	124,757.46
EVER_FOR500 (m2)	0.00	207,000.00	2,533.64	2,533.64	0.00	122,400.00	3,875.15	10,573.95
MIX_FOR500 (m2)	0.00	29,700.00	312.26	1,654.79	0.00	31,500.00	527.17	2,352.93
SHRUB500 (m2)	0.00	251,100.00	2,359.01	10,502.98	0.00	202,500.00	4,153.27	14,683.40
GRASS_HERB500 (m2)	0.00	629,100.00	20,380.31	61,803.88	0.00	588,600.00	24,623.61	60,906.99
WOODY_WET500 (m2)	0.00	678,600.00	2,417.91	22,113.21	0.00	1,003,500.00	11,008.04	64,839.29
HERB_WET500 (m2)	0.00	540,900.00	4,631.64	21,810.56	0.00	1,111,500.00	13,924.28	54,797.63
PASTURE500 (m2)	0.00	1,820,700.00	33,835.45	99,514.97	0.00	1,170,900.00	56,362.97	120,904.37
CROPS500 (m2)	0.00	3,062,700.00	146,344.13	362,897.36	0.00	2,592,000.00	291,085.50	461,167.45
BARREN_500 (m2)	0.00	364,500.00	490.51	9,324.51	0.00	878,400.00	955.92	25,442.10
OPEN_WATER500 (m2)	0.00	819,000.00	6,611.64	31,854.98	0.00	1,192,500.00	21,721.54	82,538.15

2030 Ecosystem Service and Amenity Assessment and Valuation

We used the data collected above to identify the changes predicted to occur in the delivery of the target ecosystem services and amenities in Farmington under the city's 2030 land-use plan. First, to assess the economic impact of Farmington's 2030 planned land use on home sale prices overall, we used the Dakota County hedonic pricing model to predict home sale prices for all 2030 single-family residential parcels planned to exist in Farmington at that time based upon our variable estimation above. In making these predictions, we assumed that no changes would occur in the preferences of homeowners or in market conditions in the area. We made predictions in 2005 U.S. dollars so that they would be comparable to values calculated for 2005. Additionally, we calculated mean values for each ecosystem service and amenity's delivery level for all single-family residential parcels in both 2005 and 2030 so that we might compare both these levels and the likely price impacts associated with them. We discuss our findings in the following sections.

Results

Hedonic Pricing Model

The results of the hedonic pricing model for Dakota County are presented in Table 13. The adjusted R^2 value for the OLS model (0.8265) was highly significant ($p < 0.001$). However, because our Moran's I estimate was significant ($p < 0.001$) and Lagrangian multiplier tests indicated the presence of significant spatial autocorrelation in the error term (RLMerr = 743.86, $p < 0.001$; RLMlag = 0.35, $p = 0.56$), we estimated a SAR error model using 2 km weights to address spatial autocorrelation. This model represented an improvement over the OLS model as indicated by the significant value for the coefficient lambda ($\lambda = 0.7587$, $p < 0.001$), the spatial autoregression coefficient, and by its reduced Akaike's information criterion value (-5460) as compared to that of the OLS model (-5167.5). Because a Breusch-Pagan test designed for use with SAR models indicated the presence of significant heteroscedasticity, we also calculated White's standard errors (White, 1980) using a modified method for use with SAR models (*R. Bivand, personal communication*).

Table 13. Results of the SAR error hedonic pricing model for Dakota County with White's standard errors.

Variable	Coefficient	Std. Error	t-value	
(Intercept)	10.28700000	0.19082000	53.91	***
Structural variables				
LN_ACRES	0.14003000	0.00520090	26.92	***
LN_FINSQFT	0.50105000	0.00811970	61.71	***
HOME_AGE	-0.01077600	0.00029348	-36.72	***
AGE_SQ	0.00007356	0.00000264	27.82	***
TAX_RATE	-0.10109000	0.00895870	-11.28	***
FLOOD	0.08327400	0.01341900	6.21	***
Sale month dummy variables (ref. month is February; 1 for sale in month, 0 otherwise)				
JAN	0.02610700	0.01136800	2.30	*
MAR	0.01240100	0.01167400	1.06	
APR	0.02224900	0.01144000	1.94	.
MAY	0.02363600	0.01133100	2.09	*
JUNE	0.03064500	0.01088400	2.82	**
JULY	0.03810400	0.01094100	3.48	**
AUG	0.04712700	0.01105400	4.26	***
SEPT	0.04049500	0.01137400	3.56	***
OCT	0.03536400	0.01183800	2.99	**
NOV	0.03351100	0.01199200	2.79	**
DEC	0.02666800	0.01235300	2.16	*
Neighborhood variables				
IMPERVIOUS	0.00038039	0.00014732	2.58	*
LN_CBD	-0.12675000	0.01894700	-6.69	***
Submarket dummy variables (ref. location is Simley HSD; 1 in district, 0 otherwise)				
APPLEVALLEY	0.15034000	0.03353800	4.48	***
BURNSVILLE	0.09444800	0.03228000	2.93	**
EAGAN	0.13177000	0.03162900	4.17	***
EASTVIEW	0.13064000	0.03166800	4.13	***
FARMINGTON	0.11641000	0.03608700	3.23	**
HASTINGS	0.07867500	0.04358500	1.81	.
LAKEVILLE	0.18074000	0.03508900	5.15	***
ROSEMOUNT	0.10153000	0.03230800	3.14	**
S_STPAUL	0.06496300	0.02492000	2.61	*
W_STPAUL	0.06102800	0.02832800	2.15	*
NFLD_RNDLPH	0.12062000	0.05843700	2.06	*
Ecosystem service and amenity variables				
Access to outdoor recreation areas				
LN_LGPKRD	-0.00042724	0.00021280	-2.01	*
LN_LAKE	-0.00405820	0.00062261	-6.52	***
Tree cover				
MEAN_TREE	0.00012471	0.00011822	1.05	
TREE_100	0.00058086	0.00018516	3.14	**
TREE_250	0.00032274	0.00016329	1.98	*
TREE_500	0.00061027	0.00016913	3.61	***

Variable	Coefficient	Std. Error	t-value	
TREE_750	0.00034537	0.00016138	2.14	*
TREE_1000	-0.00007851	0.00014685	-0.53	
View				
VIEW_AREA	0.00056791	0.00009884	5.75	***
IMP5_10	-0.00000010	0.00000018	-0.56	
IMP11_25	-0.00000026	0.00000014	-1.81	.
IMP26_50	-0.00000026	0.00000008	-3.42	**
IMP51_75	-0.00000032	0.00000013	-2.54	*
IMP76_100	-0.00000024	0.00000017	-1.44	
LAWN	0.00000055	0.00000019	2.89	**
MTD_TALLGR	0.00000026	0.00000016	1.65	
FOREST	0.00000009	0.00000011	0.76	
SHRUB	-0.00000100	0.00000126	-0.79	
GRASSLND	-0.00000007	0.00000013	-0.57	
EMER_VEG	-0.00000007	0.00000016	-0.41	
VW_H20	0.00000025	0.00000007	3.48	**
WOOD_WET	0.00000005	0.00000010	0.52	
AG	-0.00000004	0.00000003	-1.70	.

λ = 0.75867 LR test value: 294.5 $p < 0.001$
Significance codes: ***p = 0.001, **p = 0.01, * p = 0.05, p = 0.1
Log likelihood: 2785.984 for error model
ML residual variance (sigma squared): 0.019367, (sigma: 0.13916)
Number of observations: 5094
AIC: -5460, (AIC for OLS: -5167.5)

Most coefficients for structural variables were significant and of the expected sign. The acreage of a home's lot as well as its finished square footage both were positively related to home sale prices, indicating that homes with higher acreage or finished square footage sold for more than homes with less, while tax rate was negatively related, indicating that homes with higher property tax rates sell for less than other homes. Home age was negatively related to home sale price to the age of approximately 145 years, after which it was positively related. Thus, the sale prices of homes built after about 1860 declined with age, while the prices of the few homes (66) built before this date increased with age. Surprisingly, location in a FEMA flood zone was positively related to home sale price such that homes situated within flood zones experienced higher sale prices than other homes. This is likely a function of both the desirability of living near water and a lack of awareness of flood risk on the part of the general public in the study region. Most sale month dummy variables, with the exception of March, had a significant or nearly significant and positive relationship to home sale prices as compared to February, indicating that sale prices are significantly higher in most other months than in February.

The coefficients for nearly all neighborhood variables were significant and of the expected sign. Distance to the central business districts of Minneapolis and St. Paul was negatively related to home sale price such that homes located closer to a central business district sold for more than comparable homes located further away. The mean area of impervious surface within 500 m of a home was also positively related to home sale price, indicating that homes in areas with more impervious surface and thus higher development intensities sold for more than homes with lower levels. This result is surprising and may indicate a preference for living in more developed areas which might incorporate more amenities (e.g., restaurants, shopping and fitness centers, day care providers, schools) or simply may be a function of the tendency of homes to be located in more intensively developed areas in Dakota County. This might be perceived as indicating that increasing development is valued, but, as this study did not consider very high density forms of residential development (e.g., townhomes, multi-unit apartment buildings), it is difficult to comment upon this without executing a study that includes these more densely-developed residential properties. However, as the values of these properties tend to be lower than those of single family housing, one might speculate that higher intensity development is valued only to a certain point, after which it may become a disamenity. All dummy variables for submarkets with the exception of the dummy variable for location in the Hastings High School district were significant and positive as compared to the Simley High School district indicating that homes in these submarkets experience higher home sale prices than those in the Simley submarket.

Both variables indicating a property's degree of access to outdoor recreation areas were found to significantly impact home sale prices. Road distance to parks greater than 1 ha in area had a significant and negative relationship to home sale prices, such that the marginal implicit price of a 500 m decrease in distance to such a park evaluated at the mean home sale price of $319,073 and from an initial distance of 1 km was $68. Euclidean distance to lakes also had a significant and negative relationship to home sale prices, although the impact of lakes was greater than that of parks, with a marginal implicit price for a 500 m decrease in distance calculated as above of $647. Thus, the owners of single family properties in Dakota County will pay more to live near to these outdoor recreation areas.

The results of the hedonic pricing model also indicate that some aspects of views significantly influence home sale prices in Dakota County. View area, for example, significantly and positively impacts home sale prices such that a 1 ha increase in view area from the mean view area (33.26 ha) calculated at the mean home sale price corresponds to a home sale price increase of $181 dollars. The areas of two built land-cover types in views, 26-50% impervious surface and 51-75% impervious surface, had significant and negative relationships to home sale prices, such that a 1 ha increase in each of these land-cover types from their mean values (4,423 and 22,980 m^2, respectively) resulted in a decrease in home sale price of $831 for the 26-50% impervious surface type and $1,035 for the 51-75% impervious surface type. The coefficients for other built land-cover types (i.e., 5-10% impervious, 11-25% impervious, and 76-100% impervious) were also negative, but were generally smaller and not significant. This indicates that the owners of single-family homes may prefer homes with views that include lower levels of impervious surface, below the 26% level. The failure of views with very high (76-100% impervious) levels of impervious surface to significantly impact home sale prices may indicate that the owners of homes in such highly developed areas value something else about these areas, for instance, their urban character, and that this offsets the negative value of highly developed views under other circumstances. However, the coefficient for this variable was relatively high and negative (-0.00000024) with a *p*-value of 0.15 indicating that there may be a tendency for homeowner to value it negatively in views. Additionally, taken in combination with the positive values placed on increased levels of neighborhood impervious surface described above, the negative values for many impervious land-cover types in views may indicate a preference for living in more intensely developed areas, but not actually being able to see them, for example, in situations where barriers such as slopes obstruct views of local impervious surfaces. It may also indicate that homeowners make a trade-off between the level of development in their neighborhood which may provide them with access to amenities and the level of impervious surfaces in their views.

Two other land-cover types in views, lawn and water, significantly and positively influenced home sale prices. Evaluated at the mean home sale price, a 1 ha increase in the area of lawn from the mean value (2,584 m^2) in a home's viewshed corresponded to a sale price increase of $1,742 while a similar increase of 1 ha in the area of water from its mean value (4,904 m^2) in a home's viewshed corresponded to a sale price increase of $81. This indicates a preference on the part of single-family homeowners for views of grassy areas like those found in golf courses and parks or on large lot residential housing with large areas of lawn and a lower preference for views of water. The areas of all other land-cover types in views (i.e., agriculture, maintained tall grassland, forest, shrubs, grassland, emergent vegetation, and woody wetlands) did not significantly impact home sale prices in the study area.

The mean percentage of tree cover in most neighborhood areas significantly and positively influenced home sale prices. Notably, the mean percentage of tree cover on the parcel itself did not show a significant relationship to home sale price, indicating that home owners are not concerned about the level of tree cover on their parcel itself. However, the mean tree cover percentages within the 100 m, 250 m, 500 m, and 750 m neighborhoods showed significant and positive relationships to home sale prices such that homes with more tree cover in these areas experienced higher sale prices. The marginal implicit prices for a 10% increase in tree cover within each of these four neighborhoods from their mean values (13.60, 13.40, 14.00, and 14.57, respectively) evaluated at the mean home sale price were $1,853, $1,030, $1,947, and $1,102, respectively. The level of tree cover in the 1000 m neighborhood was not significantly related to home sale price. This indicates that, while home purchasers are not particularly influenced by the level of tree cover on their own parcel, they are influenced by the level of tree cover in its surrounding neighborhood out to a distance of approximately 750 m.

2005/2030 Landscape

Comparison of the 2005 and 2030 landscapes for Farmington indicates that dramatic changes are likely to occur in the city over the 25 year time period covered by this study (Table 14, Figures 5-6). In particular, built land uses are expected to increase, while less developed land uses are expected to decrease. In terms of number of parcels, low-medium density residential land use is likely to experience the greatest total increase (3,339 parcels), followed by medium density residential (946 parcels), low density residential (373 parcels), right-of-way (218 parcels), park/open space (180 parcels), high density residential (107 parcels), commercial (18 parcels), agriculture (9 parcels), and industrial land use (8 parcels). The vacant/undesignated land-use type is predicted to experience the greatest decrease in number of parcels (347 parcels), followed by restricted development (141 parcels), and public/semi-public (2 parcels). This clearly indicates that residential land uses, particularly those of moderate intensity, will experience the greatest growth in the community between 2005 and 2030.

Table 14. Predicted changes in the areas and numbers of parcels of each land-use class in Farmington, MN between 2005 and 2030.

Land use	**# of parcels, 2005**	**# of parcels, 2030**	**change (parcels)**	**Area 2005 (ha)**	**Area 2030 (ha)**	**Change (ha)**
Vacant/undesignated	400	53	-347	750.12	4.08	-746.04
Agriculture	73	82	9	1,378.21	984.36	-393.85
Public/semi-public	63	61	-2	183.40	178.96	-4.44
Mixed Use	1	1	0	6.39	6.39	0.00
Restricted development	151	10	-141	63.30	79.69	16.39
High density residential	114	221	107	11.44	42.99	31.55
Low density residential	3,850	4,223	373	574.30	622.50	48.20
Medium density residential	1,636	2,582	946	129.84	195.54	65.70
Commercial	224	242	18	76.68	156.29	79.61
Right-of-way	376	594	218	379.73	474.95	95.22
Industrial	40	48	8	93.89	214.13	120.24
Low-medium density residential	1,054	4,393	3,339	120.25	366.14	245.89
Park/open space	9	189	180	76.04	517.57	441.53

Because lots vary greatly in size, change in terms of number of parcels, can be misleading in examining overall land-use change. For example, the number of agricultural parcels is expected to increase as stated above. However, this land use is also predicted to experience a large decrease in total area of nearly 400 ha. In actuality, the change in number of agricultural parcels is due largely to the fragmentation of 2005 agricultural parcels by residential development. Looking at change in terms of area for other land uses shows a trend similar, but not identical, to that of parcel change. The park/open space land use is expected to experience the greatest increase in area (441.53 ha), much of which was in the vacant/undesignated land use in 2005, accounting for a large portion of the 746 ha decrease in this land use, the highest decrease for any land-use type. The low-medium density residential land-use type places second in terms of overall area increase (246 ha), followed by industrial (120 ha), right-of-way (95 ha), commercial (80 ha), medium density residential (66 ha), low density residential (48 ha), high density residential (32 ha), and restricted development (16 ha). The public/semi-public land-use type is projected to experience a small decrease of approximately 4 ha while the mixed use land use is not projected to change in terms of either total area or number of parcels. Thus, a picture emerges of a 2030 Farmington landscape in which agricultural and vacant lands are largely replaced by residential and other built land uses and much vacant land is protected as park or open space.

The land-use changes projected to occur in Farmington between 2005 and 2030 will result in great changes in Farmington's land cover (Table 15). As with land use, built land covers are projected to increase dramatically (by 1,067 ha on the HYBLC map and 1, 061 ha on the NLCD map) while vegetated land covers should decrease (by 1,159 ha on the HYBLC map and 1,069 ha on the NLCD map). According to both 2030 land-cover maps, heavily-built land covers will experience some of the greatest increases. Of the HYBLC built classes, the 76-100% impervious class is predicted to have the greatest increase (962 ha) followed by 11-25% impervious (191 ha), and 51-75% impervious (27 ha). Two lower intensity built HYBLC classes, 5-10% impervious and 26%-50% impervious, are expected to decline, most likely as a result of intensification of development in such areas. The 2030 NLCD map shows increases in built land cover occurring in the developed, high intensity class (934 ha) and in the developed, open space land-cover class (227 ha) and decreases in the developed, low intensity and developed, medium intensity land-cover classes of 8 ha and 92 ha, respectively. This, combined with the area predictions from the 2030 HYBLC map, suggests that Farmington will experience an increase in moderate to high intensity developed land covers with some decrease in lower intensity land covers. It also suggests that an increase may occur in large lot residential development, as exemplified by the increases in the NLCD developed, open space, and HYBLC 11-25% impervious land-cover classes.

Table 15. Predicted changes in the areas of each land-use class in Farmington, MN between 2005 and 2030.

	Area (ha)		
Land cover	**2005**	**2030**	**change**
HYBLC			
76-100% impervious	32.85	994.68	961.83
11-25% impervious	168.66	359.64	190.98
Shrubs	9.27	143.55	134.28
51-75% impervious	189.09	216.09	27
Open water	14.31	12.33	-1.98
Woody wetland	61.92	50.85	-11.07
5-10% impervious	41.22	20.7	-20.52
Forest	107.73	67.68	-40.05
Maintained tall grassland	105.57	63.63	-41.94
Emergent vegetation	355.77	306	-49.77
Short grass (lawns)	211.05	145.62	-65.43
26-50% impervious	520.02	427.86	-92.16
Grassland (unmaintained)	171.81	79.38	-92.43
Agricultural	1843.56	944.82	-898.74
NLCD			
Developed, high intensity	78.75	1012.41	933.66
Shrub/scrub	10.98	285.12	274.14
Developed, open space	138.24	365.67	227.43
Mixed forest	2.07	1.98	-0.09
Woody wetlands	2.25	1.89	-0.36
Evergreen forest	15.21	13.68	-1.53
Open water	11.79	9.81	-1.98
Grassland/herbaceous	35.01	28.08	-6.93
Developed, low intensity	422.46	414.09	-8.37
Emergent herbaceous wetlands	95.22	76.77	-18.45
Deciduous forest	172.62	122.13	-50.49
Developed, medium intensity	368.82	276.93	-91.89
Pasture/hay	657.27	384.03	-273.24
Cultivated Crops	1822.14	840.24	-981.9

Nearly all vegetated land-cover classes experience declines in total area in both 2030 land-cover maps. Both maps predicted the greatest declines in agricultural land-cover types (i.e., agricultural in HYBLC, pasture/hay and cultivated crops in NLCD) with declines of 899 ha in the HYBLC map and 1,255 ha in the NLCD map. The HYBLC map also predicts declines in unmaintained grassland (92 ha), short grass (65 ha), emergent vegetation (50 ha), maintained tall grassland (42 ha), forest (40 ha), and woody wetland (11 ha) classes. Similarly, the NLCD map indicates declines in deciduous forest, emergent herbaceous wetland, and grassland/herbaceous land covers of 51, 18, and 7 ha respectively. Slight decreases should also occur in the evergreen forest, woody wetland, and mixed forest land-cover types of 2, 0.36, and 0.09 ha, respectively. These declines are predominantly due to transformation to built land covers. Both maps indicate minimal reductions in the area of open water in 2030 of approximately 2 ha. This is likely caused by inaccuracies in mapping the extents of water bodies, fluctuations in their extents with season, and to issues of raster resolution. In actuality, changes in the area of open water as a result of land-use change in Farmington are likely to be zero. Shrub land is the only vegetated land-cover type to experience an increase in total area (134 ha in HYBLC, 274 ha in NLCD). This is the result of regrowth on formerly grassy or agricultural lands that became park/open space or restricted development in 2030. Thus, the picture of a Farmington in which 2005 vegetated land covers are largely replaced by built land covers, particularly moderate intensity ones, in 2030 becomes clearer.

2005/2030 Tree Cover

Both of our tree cover models predict an overall increase in mean tree cover in 2030 (Figure 7). The adjusted R^2 value for the OLS model of tree cover on built parcels (0.51) was highly significant ($p < 0.001$), but our Moran's I estimate for this model was also significant ($p < 0.001$) and Lagrangian multiplier tests indicated the presence of significant spatial autocorrelation in the lag term (RLMerr = 3.75, $p > 0.05$; RLMlag = 1.12, $p < 0.001$), so we estimated a SAR lag model using ten nearest neighbor weights to address spatial autocorrelation. This model was an improvement over the OLS model as seen in the significant value for the coefficient rho ($\rho = 0.20538$, $p < 0.001$), the autoregression coefficient; by the model's reduced Akaike's information criterion value (35,104) as compared to that of the OLS model (35,291); and by the absence of significant residual spatial autocorrelation (p = 0.1225). A Breusch-Pagan test designed for use with SAR models indicated the presence of significant heteroscedasticity ($p <$ 0.001), so we calculated White's standard errors (White, 1980) using a modified method for use with SAR models (*R. Bivand, personal communication*). These results are presented in Table 16. Home age; agricultural, low density residential, low-medium density residential, and medium density land uses at the parcel level; the areas of developed low intensity and deciduous forest land uses within 500 m; a parcel's majority land-cover class as compared to parcels with most of their land cover in the high-intensity developed class; and parcel location in all included submarkets positively influenced tree cover such that tree cover was higher on these parcels. The area of developed medium intensity, barren, grassland/herbaceous, and crop land cover within 500 m of a parcel negatively impacted the percentage of tree cover on parcels such that parcels with more of these land covers in their neighborhoods had lower levels of tree cover. This indicates that parcel level tree cover on built parcels typically increases with the time since construction on a parcel, that parcels with forested or lower intensity development tend to have more tree cover than others; that parcels with land-cover types other than developed, high intensity have higher tree cover levels than parcels with high intensity developed land covers; and that parcels with high areas of barren, grassland, moderate-intensity residential, and crop land covers have lower levels of tree cover than others.

We further assessed model accuracy by running our model with a randomly-selected independent sample dataset of 2,255 built parcels. Our results indicated that our model predicted percent tree cover on these parcels with reasonable accuracy such that the mean difference between predicted and actual tree cover percentage values was low (0.4316) and 77% of parcels had tree cover percentage predictions within 10 percentage points of their value. The predicted value for only 6% of parcels exceeded actual values by over 20 percentage points. Examination of those parcels with predicted tree cover percentages that were more than 20 percentage points away from their actual values showed little pattern in any of their characteristics, coming from all land-use types and locations and a variety of structure ages and land-cover types. Based on this evidence, we concluded that, on built parcels, some other factor or combination of factors is operating that determines parcel level tree cover. We believe the most likely explanation for these differences to be the preferences of individual land owners which lead some to plant more trees than predicted and others to keep tree numbers on their property low. This factor would be difficult to include in a model such as this one.

Figure 7. Percent canopy cover in Farmington, MN in 2005 and 2030.

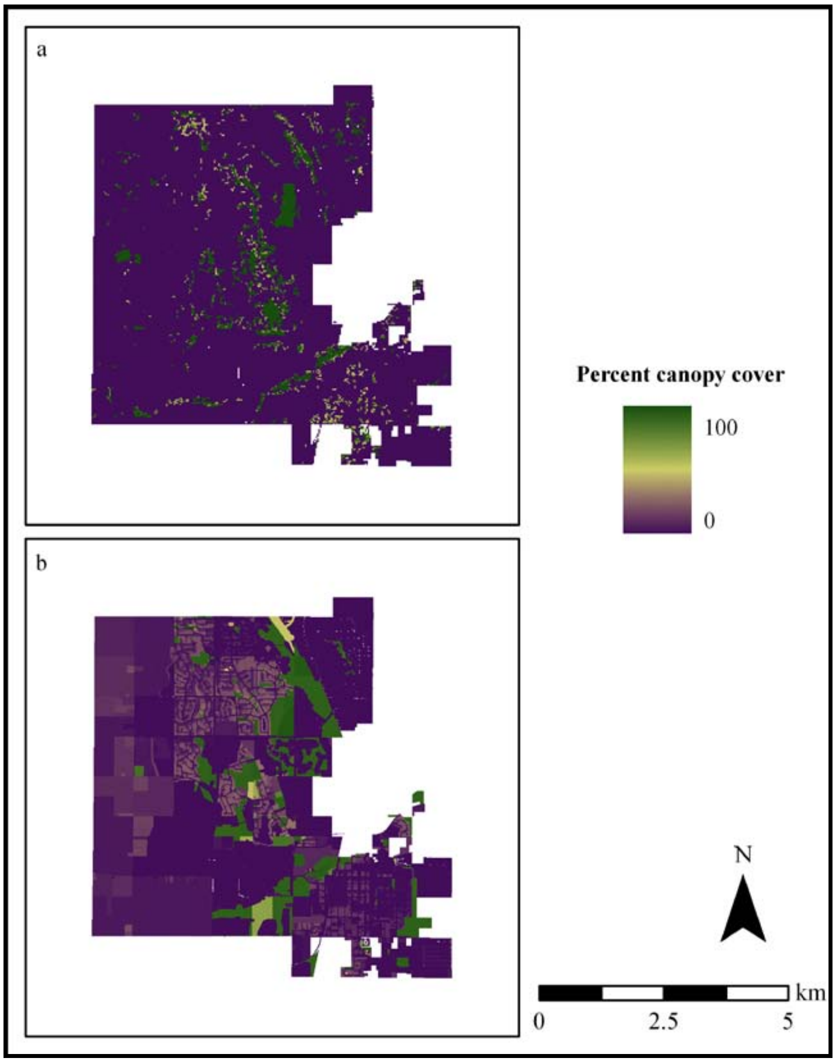


Table 16. Results of the SAR error model for tree cover on built parcels with White's standard errors.

Variable	Estimate	Std.Error	
(Intercept)	-4.817900	0.779660	***
HOME_AGE	0.025331	0.007656	***
AG_PARCEL	1.879000	1.064400	.
LDR_PARCEL	5.177700	0.731780	***
LMR_PARCEL	0.795500	0.724540	.
MDR_PARCEL	0.794330	0.804680	.
DEV_LOW500	0.000005	0.000004	.
DEV_MED500	-0.000011	0.000005	*
BARREN_500	-0.000072	0.000034	*
DEC_FOR500	0.000017	0.000003	***
GRASS_HERB500	-0.000011	0.000005	*
CROPS500	-0.000001	0.000001	.
MAJ_WETLAND	25.111000	3.702400	***
MAJ_H2O	12.524000	3.457000	***
MAJ_DEV_OPEN	8.612600	1.034600	***
MAJ_DEV_LOW	7.409600	0.842980	***
MAJ_DEV_MED	2.139000	0.752550	**
MAJ_DEC_FOR	47.957000	1.236000	***
MAJ_EVER_FOR	54.201000	3.559200	***
MAJ_MIX_FOR	56.035000	13.473000	***
MAJ_SHRUB	49.070000	5.166000	***
MAJ_GRASSLAND	12.010000	1.839800	***
MAJ_PASTURE	5.732100	1.215900	***
MAJ_CROP	4.061800	1.214400	***
APPLEVALLEY	4.692000	0.958340	***
BURNSVILLE	5.572800	0.802770	***
EAGAN	4.598000	1.012200	***
EASTVIEW	1.718200	0.965770	.
LAKEVLLE	1.588600	0.789220	*
SIMLEY	3.818800	1.010200	***
SSTPAUL	3.466200	1.000700	***
WSTPAUL	5.166300	0.769700	***

$\rho = 0.309$ LR test value: 198.03 $p < 0.001$

Significance codes: ***$p = 0.001$, **$p = 0.01$, * $p = 0.05$, $p = 0.1$

Asymptotic standard error: 0.021736, z-value: 14.216, $p < 0.001$

Wald statistic: 202.1, $p < 2.22\text{e-}16$

Log likelihood: -17507.36 for lag model

ML residual variance (sigma squared): 180.04, (sigma: 13.418)

Number of observations: 4355

AIC: 35083, (AIC for lm: 35279)

LM test for residual autocorrelation: 2.0803, $p = 0.14921$

The adjusted R^2 for the unbuilt model was 0.7092 and was significant at the 0.001 level. Because our Moran's I estimate for this model was not significant ($p > 0.05$), we did not need to execute further treatments to address spatial autocorrelation. A Breusch-Pagan test, however, did indicate the presence of significant heteroscedasticity ($p < 0.01$), so we calculated heteroscedasticity-consistent standard errors following White's method (White, 1980). This model is presented in Table 17. Results differed from those of the built model, indicating that different factors impact tree cover on unbuilt parcels. Agricultural, commercial, and park/open space land uses at the parcel level positively impacted tree cover as did the area of deciduous forest, mixed forest, and woody wetland land covers within 500 m of parcels. All included submarket variables also positively impacted tree cover percentages. The relationship between percent canopy cover on a parcel was negatively related to the variables for the majority parcel land covers of water, all developed categories, pasture, cropland, wetland, and grassland such that parcels with majority NLCD land covers in these classes experienced lower levels of tree cover. Due to the relative rarity of unbuilt parcels, we validated this model using a small independent dataset of 685 unbuilt parcels. Our results indicated that this model was highly accurate with a mean difference between predicted and actual values of 0.0235 and with mean tree canopy cover percentages predicted within 10 percentage points of their actual values for 91% of parcels. No parcel exceeded a difference of over 15 percentage points from its actual value. Thus, it appears that on unbuilt parcels variables, the choices of individual property owners for which we could not account in the built parcel model may have less of an impact on tree cover overall. Thus, tree cover percentages are somewhat easier to predict on parcels that lack buildings using a regression model.

Table 17. Results of the OLS model for tree cover on parcels that lack buildings with White's standard errors.

Variables	**Estimate**	**Std.Error**	**t-value**	
(Intercept)	48.810000	2.173000	22.464	***
AG_PARCEL	2.906000	1.712000	1.697	.
COM_PARCEL	4.337000	1.561000	2.778	**
PARK_PARCEL	8.024000	1.605000	4.999	***
BARREN500	-0.000050	0.000013	-3.712	***
DEC_FOR500	0.000028	0.000003	8.152	***
MIX_FOR500	0.000243	0.000150	1.621	
SHRUB500	-0.000086	0.000029	-2.992	**
WOODY_WET500	0.000022	0.000007	3.363	***
HERB_WET500	-0.000036	0.000007	-4.876	***
MAJ_H2O	-48.740000	3.282000	-14.851	***
MAJ_DEV_OPEN	-45.380000	1.538000	-29.505	***
MAJ_DEV_LOW	-51.640000	1.823000	-28.331	***
MAJ_DEV_MED	-53.940000	1.972000	-27.349	***
MAJ_DEV_HIGH	-55.060000	2.217000	-24.838	***
MAJ_ PASTURE	-46.410000	1.772000	-26.189	***
MAJ_CROP	-50.280000	1.491000	-33.728	***
MAJ_WETLAND	-18.580000	2.413000	-7.701	***
MAJ_GRASSLAND	-41.800000	3.508000	-11.915	***
APPLEVALLEY	3.211000	2.536000	1.266	
BURNSVILLE	1.811000	2.061000	0.879	
EAGAN	4.662000	2.567000	1.816	.
EASTVIEW	5.913000	2.325000	2.543	*
FARMINGTON	0.276800	1.274000	0.217	
HASTINGS	0.919500	1.239000	0.742	
NORTHFIELD	1.960000	1.666000	1.176	
ROSEMNT	1.292000	1.838000	0.703	
SIMLEY	7.259000	1.962000	3.7	***
SSTPAUL	6.559000	2.197000	2.985	**
WSTPAUL	4.147000	1.781000	2.329	*
CANFALLS_RAND	0.150900	1.510000	0.1	

Significance codes: ****p* = 0.001, ***p* = 0.01, * *p* = 0.05, *p* = 0.1
Dependent variable = percent canopy cover
Adjusted R^2 = 0.7092
F = 99.04 (df = 1,176), $p < 0.001$

By running these two models for Farmington parcels with 2030 structural and land-use and land-cover data generated as described above and combining their results, we produced a map of Farmington tree cover in 2030 (Figure 7). Overall, this map shows that tree cover in Farmington is likely to increase with mean percent canopy cover increasing from 5.80% in 2005 to 8.07% in 2030. The maximum percent canopy cover in Farmington, however, is predicted to decrease from 100% in 2005 to 73% in 2030, largely due to construction in areas that previously had very high tree cover levels. Areas predicted to have the greatest tree cover increase appear to be in regions of the city developed prior to 2005 or in protected areas. These results suggests that, in general, tree cover in Farmington will increase during this time period as a result of planting and regrowth on aging built parcels as home age is positively related to tree cover, although tree cutting on undeveloped parcels built during this time period is likely to reduce the maximum tree cover in the area somewhat. Some mismatch is likely to occur between the two maps as the 2005 map maps canopy cover is predicted at the pixel level and 2030 tree cover is predicted at the parcel level. However, overall prediction accuracy should be sufficient for the purposes of this study.

2005/2030 Ecosystem Service Delivery

The changes occurring in the Farmington landscape between 2005 and 2030 are likely to impact the delivery of the ecosystem services and environmental amenities examined in this study. Our results indicate that some services will be negatively impacted by planned land-use changes while others will be positively impacted (Table 18). The mean distances between single-family residences and both outdoor recreation areas (parks and lakes) investigated in this study are predicted to decrease. Due to the increase in the number and area of parks in the city, mean road distance to parks is expected to decrease from 691 m in 2005 to 175 m in 2030. This large change in mean distance to parks is explained by several factors. First, the creation of a large number of new parks throughout Farmington between 2005 and 2030 means that homes that were previously located at some distance from parks will be closer to them. Second, in 2005, some rural homes were located at a great distance from parks. As the city grows, parks will spread throughout the entire area, reducing the distances between currently rural homes and parks. Lastly, many new homes are projected to be built in areas that are also expected to contain additional parks in 2030, thus making the mean distance between new homes and parks lower than the 2005 mean distance. Mean Euclidean distance to lakes is expected to decrease by 129 m, moving from 880 m in 2005 to 751 m in 2030, a result of increased construction along and near lakeshores. Thus, access to areas for outdoor recreation is likely to be increased in Farmington in 2030.

Changes are also predicted to occur in the percentage of tree cover in Farmington between 2030 and 2005. Overall, the city of Farmington had a mean tree cover percentage of 5.80% in 2005. In 2030, this is predicted to increase to 8.81%. As a result, single-family properties are predicted to experience increases in their mean percentages of tree cover in most of the neighborhoods examined in the study, although mean parcel level tree cover is predicted to decrease from 6.5% in 2005 to 5.6% in 2030. Mean tree cover percentages are predicted to increase in the 100 m, 250 m, 500 m, 750 m, and 1000 m neighborhoods by 2.32%, 4.18%, 5.93%, 6.62%, and 5.98% respectively. This, as well as the increased mean values for tree cover for the city as a whole, indicates that tree cover levels in Farmington are likely to increase by 2030. As stated above, this is most likely due to a combination of regrowth and planting on parcels with previously existing homes and on open space areas with a smaller amount of tree cover loss on newly built parcels.

Table 18. Estimates of ecosystem service and amenity delivery in 2005 and 2030 in Farmington, MN.

	2005				2030				
variable	**mean**	**std dev**	**min**	**max**	**mean**	**std dev**	**min**	**max**	**change (mean)**
Structural variables									
SALE_PRICE ($)	258,259.46	60,341.03	89,845.79	528,136.47	216,699.46	48,378.31	79,871.95	625,946.39	-41,560.00
ACRES	0.29	0.39	0.07	18.14	0.27	0.33	0.08	18.17	-0.02
FINSQFT	1,971.74	570.68	456.00	4,546.00	2061.81	510.59	626.41	4546	90.07
HOME_AGE	18.16	22.75	0.00	149.00	34.62	22.14	0.00	174.00	16.46
TAX_RATE (%)	1.35	0.13	0.85	2.61	1.35	0.10	0.85	2.61	0.00
Neighborhood variables									
IMPERVIOUS	25.72	21.78	0.00	100.00	25.53	21.28	0.00	100.00	-0.19
CBD (m)	31,176.72	1,953.00	28,356.74	35,192.33	30,600.99	1,797.06	28,282.54	35,242.22	-575.73
Ecosystem service and amenity variables									
LAKE (m)	879.83	583.28	0.00	2,348.66	750.52	512.35	0.00	2,344.91	-129.31
LGPKRD (m)	690.78	471.56	0.00	1,964.96	174.50	232.97	0.00	1,394.09	-516.28
TREE_PARCEL(%)	6.45	16.84	0.00	100.00	5.60	8.73	0.00	72.00	-0.85
TREE_100 (%)	6.74	15.07	0.00	90.00	9.06	14.15	0.00	68.00	2.32
TREE_250 (%)	6.73	14.58	0.00	93.50	10.91	16.57	0.00	63.00	4.18
TREE_500 (%)	6.40	13.87	0.00	92.00	12.33	17.28	0.00	65.00	5.93
TREE_750 (%)	6.03	12.25	0.00	88.17	12.65	16.71	0.00	61.00	6.62
TREE_1000 (%)	5.67	11.74	0.00	91.00	11.65	15.62	0.00	66.00	5.98
VIEW_AREA (ha)	32.96	30.70	1.00	214.43	88.11	49.56	1.86	268.30	55.15
IMP5_10 (m2)	5,140.76	7,719.06	0.00	75,600.02	9,768.03	9,753.52	0.00	50,259.25	4,627.27
IMP11_25 (m2)	17,614.37	13,681.35	0.00	102,600.30	83,513.07	63,364.40	0.00	379,292.44	65,898.70
IMP26_50 (m2)	58,445.97	42,984.28	0.00	302,800.21	136,627.30	118,902.38	0.00	609,605.69	78,181.33
IMP51_75 (m2)	17,889.12	19,430.84	0.00	155,600.09	45,835.76	53,442.52	0.00	298,457.99	27,946.64
IMP76_100 (m2)	1,633.24	3,779.64	0.00	45,875.00	270,120.42	229,471.83	0.00	1,083,021.81	268,487.18
LAWN (m2)	19,014.69	30,060.73	0.00	241,100.05	38,914.11	45,846.95	0.00	287,566.82	19,899.42
AG (m2)	131,539.78	191,931.22	0.00	1,474,900.03	156,841.15	192,750.83	0.00	1,489,791.98	25,301.37
MTDTALLGR (m2)	3,507.08	9,192.13	0.00	127,600.10	5,936.49	12,943.55	0.00	139,786.65	2,429.41

	2005				2030				
variable	**mean**	**std dev**	**min**	**max**	**mean**	**std dev**	**min**	**max**	**change (mean)**
FOREST (m2)	14,801.47	22,745.75	0.00	172,200.04	18,541.87	20,689.87	0.00	138,187.95	3,740.40
SHRUB (m2)	1,231.24	3,814.32	0.00	38,600.04	28,108.68	40,660.00	0.00	245,900.61	26,877.44
WOOD_WET (m2)	9,843.04	29,349.72	0.00	251,400.21	12,902.03	31,770.09	0.00	319,249.24	3,058.99
GRASSLND (m2)	17,121.03	32,258.14	0.00	477,900.08	20,326.51	292,415.63	0.00	409,967.57	3,205.48
EMER_VEG (m2)	30,036.08	60,984.84	0.00	460,200.00	46,826.94	62,040.89	0.00	427,952.99	16,790.86
VW_H20 (m2)	1,789.31	6,610.42	0.00	74,325.44	6,300.41	12,733.61	0.00	62,049.69	4,511.10

Not surprisingly, the characteristics of views from single-family residences in Farmington are also predicted to change as a result of changes in the landscape between 2005 and 2030. The mean overall view areal extent for parcels is predicted to increase substantially from 32.96 ha in 2005 to 88.11 ha in 2030. This results largely from increased construction in areas bordering parks, lakes, shrubland, and agricultural fields where little exists to block views. The areas of all land-cover types in the views of single-family residences are generally predicted to increase. Our results indicate that the mean areas of the four most intensively developed built land-cover types present in views will experience the greatest increases with the 76-100% impervious land cover experiencing the largest increase (268,487 m^2) followed by views of 26-50% impervious, 11-25% impervious, and 51-75% impervious with increases of 78,181 m^2, 65,899 m^2, and 27,946 m^2, respectively. Views of 5-10% impervious land covers are also expected to increase, but by much less, only 4,627 m^2, probably due to the overall rarity in this land cover in the landscape in 2030 caused by urban intensification. The overall high increases in developed land-cover types in views is undoubtedly due to the increases occurring in corresponding land-use types during the 2005-2030 study time period as well as the tendency for residential parcels, like those that are the foci of this study, to be located in areas with moderate to high levels of impervious surface.

The areas of vegetated surfaces as well as of low-intensity (5-10% impervious) developed land covers present in views are also projected to increase between 2005 and 2030. Mean areas of shrub land are predicted to increase by the greatest amount, 26,877 m^2, probably as a result of increases in this land-cover type overall in Farmington as well as increases in the number of homes bordering such areas. This is largely a result of the decision rules used to model land-cover change which resulted in the transformation of grassland in vacant and park land uses as well as abandoned agricultural lands that were not built to shrubland following basic successional principles. In reality, it is likely that some land management would occur on these lands that might prevent this from occurring, and that some of these lands might actually be grassland or early-successional forest in 2030. Land management practices, however, are difficult to predict and thus were not considered in this study. Increases in shrubland were followed closely by increases in the mean area of agriculture in views which is projected to increase by 25,301 m^2. This was caused by increases in the number of homes located near or adjacent to agricultural lands in 2030, particularly as lands in the city's bordering Farmington were assumed to remain in their 2005 land covers which, along the northeastern border of Farmington where a great deal of residential construction is expected to occur, were dominated by agriculture. In the future, this might be improved by modeling change within the areas of other jurisdictions likely to be a part of a study area's viewshed. Both the mean areas of lawn and emergent vegetation land covers present in views will increase by somewhat less, 19,899 m^2 and 16,791 m^2, respectively, also due to the simple presence of more homes near such land covers. In the case of lawns, this is also likely the result of this land-cover type's tendency to be associated with residential development, a large amount of which is planned to occur in the city between 2005 and 2030. The mean areas of other land-cover classes in views are expected to experience smaller increases between 2005 and 2030. These include water, forest, grassland, woody wetland, and maintained tall grasslands with increase of 4,511 m^2, 3,740 m^2, 3,205 m^2, 3,059 m^2, and 2,429 m^2. Thus, as a result of the high amount of development expected to occur in the city by 2030, the mean areas of developed land-cover types visible from single-family residences is likely to increase greatly while, due to the construction of large numbers of homes bordering other land-cover types, the mean areas of undeveloped land-cover types are also expected to increase in views, but by a lower amount.

2005/2030 Values

We used the hedonic pricing model estimated for Dakota County and the variable values estimated for 2030 single-family residential parcels in Farmington to predict Farmington's home sale prices for all single-family residential properties in Farmington in 2005 and 2030. Our results predict a mean home sale price for all homes in Farmington in 2005 of $258,259. This is very close to the actual mean sale price for the 567 homes that actually sold in Farmington during that year ($258,401).

Using the 2030 land-use plan data, mean home sale price in the city are predicted to be nearly \$42,000 lower, about \$216,700. Based on our predictions, the sum of the sale values of all single-family homes, which indicates the size of the city's tax base, in Farmington in 2005 was \$1,244,035,838. This is predicted to increase by about \$292,146,667 to \$1,536,182,505 in 2030 with the addition of new homes. Thus, although the mean value of residential single-family homes in Farmington in 2030 is likely to be lower than in 2005, the great increase in the number of these homes should increase the city's tax base substantially. Whether this increase is sufficient to meet the needs of the more populous 2030 city is uncertain. Certainly the costs of road construction as well as of constructing and maintaining services for new residents are likely to be high.

The predicted decline in Farmington's mean home sales price of approximately \$42,000 in Farmington between 2005 and 2030 is caused by changes in a number of variables (Table 19). First, it is partially due to changes in structural and neighborhood variables, for example, reductions in lot acreage and increases in home age and mean neighborhood impervious surface percentages which collectively reduced Farmington's mean home sale price by \$53,833, but also to changes in the delivery of some of the ecological services and amenities assessed here. For example, increases in the areas of 26-50% and 51-75% impervious surface land-cover classes present in views reduced the mean home sale price by \$9,394 and increases in the area of the 76-100% impervious surface class decreased the mean home sale price by \$20,856, although this variable was not significant at the $p = 0.05$ level. It is also worthy of note that the overall values of Farmington's single-family homes would have been predicted to decrease by much more had the levels of some ecosystem services that increased in delivery and had positive marginal implicit prices not increased between 2005 and 2030. These include distances to lakes and larger area parks, tree cover in the 100, 250, 500, and 750 m neighborhoods, view area, and the area of open water and lawn in views which together added \$16,806 to the mean home sale price of Farmington's single-family homes in 2030. This suggests that, if cities like Farmington considered the environmental impacts of land-use change and their economic values in planning future land use, they might be able manage land use so that the negative impacts of development could be offset by increases in ecosystem service delivery.

Table 19. Impact of changes in continuous variables on mean home sale prices.

Variable	Change	Impact on mean home sale price		Net impact (mean*number of homes)
Structural variables				
ACRES	-0.02	-$3,574	***	-$25,338,866
FINSQFT	90.07	$14,399	***	$102,079,218
HOME_AGE	16.46	-$50,235	***	-$356,121,839
TAX_RATE (%)	0.00	$0	***	$0
Neighborhood variables				
IMPERVIOUS	-0.19	-$23	***	-$163,477
CBD (m)	-575.73	$23,284	*	$165,060,416
Ecosystem service and amenity variables				
Recreational access variables				
LAKE (m)	-129.31	$167	***	$1,186,975
LGPKRD (m)	-516.28	$70	***	$498,922
Tree cover variables				
TREE_PARCEL(%)	-0.85	-$33		-$239,770
TREE_100 (%)	2.32	$429	**	$3,048,144
TREE_250 (%)	4.18	$430	*	$3,051,442
TREE_500 (%)	5.93	$1,154	***	$8,185,643
TREE_750 (%)	6.62	$729	*	$5,171,525
TREE_1000 (%)	5.98	-$149		-$1,061,877
View variables				
VIEW_AREA (ha)	55.15	$9,993	***	$70,843,684
IMP5_10 (m2)	4,627.27	-$149		-$1,061,301
IMP11_25 (m2)	65,898.70	-$5,416	.	-$38,395,643
IMP26_50 (m2)	78,181.33	-$6,498	**	-$46,070,214
IMP51_75 (m2)	27,946.64	-$2,895	*	-$20,523,331
IMP76_100 (m2)	268,487.18	-$20,855		-$147,845,952
LAWN (m2)	19,899.42	$3,466	**	$24,570,933
AG (m2)	25,301.37	-$345	.	-$2,447,191
MTD_TALLGR (m2)	2,429.41	$200		$1,420,487
FOREST (m2)	3,740.40	$104		$738,065
SHRUB (m2)	26,877.44	-$8,547		-$60,593,838
WOOD_WET (m2)	3,058.99	$48		$347,307
GRASSLND (m2)	3,205.48	-$75		-$535,581
EMER_VEG (m2)	16,790.86	-$360		-$2,556,057
VW_H20 (m2)	4,511.10	$364	**	$2,583,480

Significance codes: ***p = 0.001, **p = 0.01, * p = 0.05, p = 0.1

The changes in the ecosystem services and environmental amenities described above are predicted to have an economic impact on the city as evidenced by the values calculated for many of these services (Tables 18 and19). Not all of these, however, were significant in our hedonic pricing model. Our results indicate that some of the changes in services and amenities that were found to have a significant relationship to home sale price in our hedonic pricing model are likely to have positive economic impacts, while others are likely to have negative economic impacts. Changes in distances to both lakes and parks greater than 1 ha, both of which are predicted to decrease, should have a positive economic impact. Calculated at the mean home sale price for Dakota County of $319,074, the marginal implicit price of a 1 meter decrease in distance to these features was $1.29 for lakes and $0.14 for parks. Thus, the 129.31 m mean decrease in distance from single family residential parcels to lakes corresponds to an increase in mean home sale price of $167. For the 7,089 single-family residential properties expected to exist in Farmington in 2030, this would correspond to a collective increase of $1,186,975. The decrease in mean distance to parks of 516 m should have a lower impact of $498,923 total or a $70 increase in the sale price of the mean home. Thus, the creation of a large number of new parks in Farmington between 2005 and 2030 which results in a decrease in the mean home distance to parks as well as the decreased distance to lakes from the average home due to more residential construction near lakes are likely to impact the City of Farmington positively.

Mean tree cover in the 100 m, 250 m, 500 m, and 750 m areas surrounding homes was found to significantly impact home sales prices in our hedonic pricing model. Thus, projected increases in mean tree cover in these neighborhoods are predicted to positively impact Farmington economically. In the 100 m neighborhood, the marginal implicit price of a 1 percentage point increase in tree cover was $185.34. As mean tree cover in this neighborhood is predicted to increase by about 2.32 percentage points, this corresponds to a mean home sales price increase of $430. When extrapolated to all single family homes in the area, this corresponds to a net home sale price increase for all homes of $3,051,442. Similarly, mean tree cover increases of 5.93, 6.62, and 5.98 percentage points in the 250 m, 500 m, and 750 m neighborhoods are expected to results in mean sales prices increases of $430, $1,155, and $730 per home, respectively, or home sale value increases of $3,051,443, $8,185,643, and $5,171,526 for all 2030 single family residential homes in Farmington. Thus, changes in tree cover in Farmington are likely to have high and positive impacts on the city's tax base, collectively increasing the value of the average home by $2,745 and of the city's tax base by $19,460,054.

Several aspects of views also were found to have a significant relationship to home sale prices in our hedonic pricing model. Among these is view area, the mean value of which is projected to increase by 55 ha, which using the calculated marginal implicit price for a 1 ha increase in view area of $181.21, corresponds to a $9,993 increase in the mean home sale price or a $70,843,684 increase in the total sale values for all single-family homes in 2030. Thus, increases in the view area for the average home will have a positive impact on Farmington's tax base in 2030.

Changes in the areas of specific land-cover types in views will also impact home sale prices in 2030. These include the areas of 26-50% impervious and 51-75% impervious land covers, both of which were negatively and significantly related to home sale prices. The mean areas of both of these land-cover types are projected to increase in views by 78,181 m and 27,947 m respectively. This corresponds to large mean home sale price decreases of $6,499 and $2,895 or to decreases in the total sale price for all 2030 Farmington single-family residential properties of $46,070,214 and $20,523,332. Additionally, the mean areas of two land-cover types, 76-100% impervious and 11-25% impervious, that negatively, but not significantly (p = 0.1562, p = 0.0754) impacted home sale prices, are expected to increase substantially during the study time period (by 268,487 m^2 and 65,899 m^2, respectively). The marginal implicit prices for increases of one percentage point in both of these land covers, estimated at their mean values and the mean home sale price, would be -$0.08. Increases in the mean area of 11-25% impervious land covers in views would thus reduce the mean home sale price by $5,146 and total home sale prices by $38,395,644. Increasing the mean area of the 76-100% impervious class in views would have the greatest impact of any ecosystem service or amenity examined here, reducing the mean home sale price by $20,856 and the sum of the home sale prices for all homes by $147,845,953. Thus, increases in the areas of these built land-cover types in Farmington views are likely to decrease the mean home sale price in the city in 2030 substantially and to negatively impact the city's tax base.

The mean areas of lawn and water in views, which were found to significantly and positively impact home sale prices in the Dakota County hedonic pricing model, are predicted to increase in the study area between 2005 and 2030. The area of lawn in the view from the average home is expected to increase by 19,899 m^2, which, as the marginal implicit price for a 1 percentage point increase in this land-cover type in views was estimated at $0.17, should result in a corresponding mean home sale price increase of $3,466 in 2030, or a combined sale price increase of $24,570,934 for all homes. The marginal implicit price of a 1 percentage point increase in the area of open water present in views as estimated from the hedonic pricing model was $0.08 for the mean home. The mean area of this land-cover type in views in predicted to grow by 4,511 m^2. This should thus correspond to a mean home sale price increase of $364 or a total home sale price increase of $2,583,480 in Farmington in 2030. As such, increases in these two land-cover types in views are likely to have a positive impact on Farmington's tax base.

Shrub (26,877 m^2) land cover, had a negative, but not significant ($p = 0.4338$) relationship to home sale price. The marginal implicit price for an increase of one percentage point in this land cover, estimated at its mean value and the mean home sale price, is -$0.32 per home. When the size of the mean increases in this land cover in views is considered, its economic impact is considerable, with increases in the mean area of shrub land in views resulting in decreases mean home sale prices of nearly $8,550 per home or $60,593,839 for all homes. However, the large increase in shrub land was largely due to the use of decision rules in identifying future land cover that favored the generation of shrub land on parcels in vacant and park land uses. If these rules were inaccurate, for example, due to the enactment of land management practices that favored other land cover types, this effect would likely be reduced.

Discussion and conclusions

Our results clearly indicate that increasing suburbanization will cause the Farmington landscape to change dramatically between 2005 and 2030. This change will impact the levels of delivery of the ecosystem services examined in this study and this, in turn, will impact the community economically. As such, one may consider these environmental and economic changes to identify the overall and environmental impacts of Farmington's planned 2030 land use and its potential benefits and drawbacks.

Each of the ecosystem services and amenities examined in this study will experience changes in their delivery. The average Farmington resident in 2030 will have greater access to areas for outdoor recreation, have higher percentages of tree cover in the areas surrounding their homes, and will be able to see larger areas of vegetated land covers from their homes. They will also, however, have greater areas of built land-cover types present in the views from their homes and these will far exceed the areas of most vegetated land covers, such that, for most homes, these built land-cover types will dominate views. These changes in views are likely to be huge, indicating a large change in the aesthetic environment of the city of Farmington.

Changes in the focal ecosystem services and amenities are likely to have economic impacts on Farmington in 2030. Some of these impacts can be seen in changes in home sale prices, which capture a portion of these economic impacts. Notably, increased access to parks and lakes as well as increases in tree cover in the 100-750 m neighborhoods examined added substantially to, and the areas of impervious surfaces in views detracted substantially from, the mean home sale price for the city in 2030. Tree cover increases alone were predicted to add $2,745 to the mean home sale price, or $19,460,054 to the sum of all home sale prices in 2030. This would result in a substantial increase in the city's tax base. Conversely, increases in other services, particularly the areas of land covers with 25-50% impervious and 51-75% impervious surfaces in views would substantially decrease property values, reducing the mean home sale price by over $9,000 and the sum of home sale prices by $66,593,546. Thus, although changes in some services caused by land-use change may add to the community's tax base, changes in others may detract from it. This suggests that land-use plans and policies might be set so as to increase the delivery of high value services and thus to offset the negative impacts of development.

Notably, our model predicts that the mean home sale price will decline by approximately $42,000 in Farmington between 2005 and 2030, although the overall size of the tax base as a function of the sum of all home sale prices should increase due to the construction of a large number of single-family homes. This reduction in mean home sale price is in part due to decreases in lot size and increases in homes age, but is also caused by increases in the areas of impervious surfaces and shrub land in views. Additionally, the decrease in mean home sale price would have been much larger had desirable services such as tree canopy cover and access to parks and lake not improved, increasing mean home sale prices. This suggests that Farmington could seek to mitigate negative price impacts associated with development by consciously planning to increase the delivery of desirable ecosystem services in its development. For instance, the city could seek to offset the negative impacts of smaller lot sizes on home sale prices by setting policies that would increase tree cover or by providing greater access to parks.

Overall, these findings imply that, although Farmington is likely to have a higher tax base as evidenced by higher net sale values for all single-family residential homes in the city in 2030 as compared with 2005, this gain will come at a cost. Some valuable services will decline as will the mean home sale price in the city in 2030 under the present land-use plan. It is necessary to note here that the values calculated in this study represent only partial values for the services and amenities examined in this study, the values that accrue to single-family homeowners. Total values that include, for example, the values of park and lake access to residents of rental units or from outside the local area for which fees might be collected, are likely to be much higher. Additionally, this study considered only a few ecosystem services and amenities of interest in the local area. Inclusion of other services, such as the provision of water quality for drinking or recreation, of carbon storage for climate change mitigation, and of habitat for wildlife, would add to the completeness of our understanding of the environmental and economic impacts associated with land-use change in this and other areas and would serve to better inform development decisions. Thus, this method's utility in land-use planning and policy-making could be increased by the inclusion of values accrued to groups other than single-family homeowners and of additional ecosystem services and amenities.

As noted above, the methods employed in this study could also be used to plan future land use to offset the negative consequences of development. For example, the negative impacts of increases in home age and in the levels of impervious surfaces in neighborhoods and views and could be counterbalanced by increasing tree cover and access to outdoor recreation areas. Expanding the method employed here in this way could improve decisions made by planners and policy-makers, enabling communities to intensify their development while maintaining or increasing their tax bases and local environmental conditions. This deserves further attention in later studies.

A number of sources of error and uncertainty exist in the models used in this study that could impact the results. The main factor behind most of these lies in the possibility that Farmington's comprehensive plan may not accurately depict its future land use, for example, if variances were granted that allowed land uses not indicated by the plan to occur in an area, if zoning or other policies did not reflect the comprehensive plans' intentions, or if other factors, such as changes in climate, individual behavior, or prices or demand for different housing or land use types, occurred during the study's time period. This would reduce the accuracy of our identification of park locations in 2030 and the distance estimates dependent upon them, of our 2030 impervious surface map and 2030 neighborhood impervious surface estimates, and of our 2030 land cover maps as and the viewshed metrics and tree cover predictions made using them. Tree cover on built and unbuilt parcels in Farmington might also be impacted directly by climate conditions (as, indeed, might many of the variables examined in this study such as lake levels), or exotic pests or diseases. Distances to lakes might be inaccurate if Farmington deviates significantly from their planned land use and builds homes in different locations. The accuracy of viewshed calculation, which is highly dependent on the location of observer points and the heights and locations of buildings in the landscape, could also be negatively impacted if building locations and heights differed significantly from those specified in our analysis which would, in turn, impact the areas of different land-use and land-cover types in viewsheds. Additionally, inaccuracies in the estimates of building year, tax rate, sales by month, and mean impervious surface used in this analysis would also impact results as would changes in the delineations of FEMA flood zones. Thus, as all or a few of these factors are likely to impact the accuracy of ecosystem service and amenity estimates as well as associated economic values calculated in this study, this study's results should be seen as representative of a possible Farmington future, one that closely mirrors the specifications of the city's 2030 land-use plan. Future studies might benefit from the use of multiple models of landscape structure in target years to provide estimates of the ranges of value and delivery possible under a given land-use plan.

This study's results could also be inaccurate if the assumptions on which it is based are violated. These include assumptions that the market is in equilibrium and that demand for the variables examined here remains constant. It seems highly likely that demand, in particular, for some variables will change over the time period covered by this study and that this would change the marginal implicit prices of these variables. Thus, the values provided in this study should be understood to be 2005 values applied to a 2030 housing market that is comparable to the 2005 housing market. They could be altered significantly by changes in this market.

Our results highlight some clear benefits of using the approach detailed in this study to generate information to inform land-use decision making. First, the methods employed here provide both predictions of changes in the delivery of ecosystem services and amenities occurring as a result of land-use change and of their associated economic values. This information, if incorporated in local level land-use decision making, could help communities to ensure that the outcomes of their plans are acceptable to them in both economic and environmental terms. This, in turn, could help them to make land-use decisions that are more sound both economically and environmentally. Communities using these techniques could tailor them to include key services and amenities of concern to insure that planned land use does not negatively impact community or regional interests. This method might also be applied in a regional context for use in regional land-use planning and policy-making.

Our results also illustrate some drawbacks of using such methods like those used in this study and suggest room for improvement. From our results, it would appear that a mismatch exists between human perceptions of the environment and actual environmental quality that impacts environmental values. For example, in this study, homeowners were found to prefer views with high areas of water and as well as proximity to lakes. However, maximizing these values would mean a large amount of construction near water bodies that would almost certainly degrade their water quality. Humans also were found to positively value living in homes in FEMA floodways which indicates a lack of awareness of both the risks of living in such areas as well as of the potential negative impacts building in such areas might have on environmental quality. Thus, for some services, human values may not coincide with measures of environmental health. However, it is likely that humans do value these aspects of environmental quality, but that these values were not reflected in this study because these and related services were omitted from the analysis. This issue requires particular attention in future studies that use environmental values in planning and policy making. Careful selection of services and of the means by which they are quantified may help to alleviate this problem in additional studies.

Additionally, several factors may impact the accuracy of the values calculated here as applied to 2030 amenities. First, because the prices estimated here are marginal prices and are those that accrue only to the owners of single-family homes, the values estimated are likely to underestimate the full values of these services. We also assume constant marginal implicit prices between 2005 and 2030. This would be inaccurate if the values for changes in some of these services changed during this time period, for example, as the services became more or less scarce. Notably, the supply of and demand for these services is likely to change between 2005 and 2030, causing marginal implicit prices to differ from those calculated here. In the case of tree cover, view areal extents, the areas of lawn in views, and park and lake access, all of which are projected to increase during the study time period, this increase in supply would likely lead to a decrease in demand, thus lowering the marginal implicit prices for these services. Similarly, increases in the areas of views of impervious surfaces and shrub land in views, both of which had negative marginal implicit prices, may cause increased demand for views that do not include these land cover types, increasing their marginal prices and further decreasing the marginal implicit prices of views of impervious land covers. Thus, the actual values for changes in service delivery between 2005 and 2030 are likely to differ from those calculated here. However, the values estimated in this study do provide an indicator of the economic impacts that may be associated with changes in ecosystem service delivery that is useful in identifying the potential economic impacts of land use change.

The results of this study clearly illustrate that ecosystem services and amenities can be highly valued by humans. They also show that changes in land use can have significant impacts on these services and amenities. The use of combined spatial, environmental, and economic modeling as employed here can be used to identify these changes as well as the values associated with them so that they may be used to inform land-use planning and policy. The provision of both economic values as well as estimates of actual changes in service delivery could be used, for example, to evaluate alternative land-use plans or to identify land-use plans that have particularly high or unexpected costs or benefits, either economically or environmentally. Future studies should take special care in selecting, modeling, and valuing services so that results are accurate and mismatches between human values and environmental health are minimized and might make use of multiple models of the same future landscape to generate possible ranges for the conditions and values estimated. However, the benefits of providing predictions of both the environmental and economic impacts of proposed land-use change are likely to greatly improve the land-use decision making process at the local level. Thus, this method could substantially improve the consideration of ecosystem services and amenities in local land-use decision-making and could, as a result, improve the environmental and economic sustainability of future landscapes.

CHAPTER 5 – SUMMARY AND CONCLUSIONS

Local communities gain valuable benefits from their environments in the form of ecosystem services and environmental amenities. These services and amenities may be negatively impacted by land-use change as these communities develop. Unfortunately, as local planners and policy makers are rarely aware of the likely environmental impacts of land-use change and lack economic values for changes in environmental amenities, these generally are not considered in market-driven, local land-use decision and policy making. As a result, ecosystem services and amenities are often sacrificed as communities develop. The studies encompassed in this dissertation, by identifying the economic values of select ecosystem services and amenities and by illustrating a method by which changes in their delivery under proposed future land-use conditions may be estimated and valued, will help to rectify this problem by advancing ecosystem service valuation and modeling at scales useful to local land-use decision making.

Chapter 2 examined how ecosystem services and amenities, particularly views and open space access, impact residential home sales prices in Ramsey County, Minnesota using a hedonic pricing model. Home sale prices were found to increase with closer proximity to parks, trails, lakes, and streams. Proximity to lakes produced the greatest impact on home sale value of these distance variables, followed by parks, trails, and streams. Increasing view areal extents as well as increasing the amount of water and grassy land covers in views also resulted in increased sale prices. Increased view richness in terms of the number of different land-cover types in a view reduced home sale prices. These results illustrate the importance of these environmental amenities to single family homeowners and can be used to inform land-use planning and policy decisions aimed at their preservation. For example, the values estimated in this study might be used by communities in the region to identify the potential economic costs of proposed development. As such, these communities would be able to consider these costs in planning so that they might avoid some of the heretofore unforeseen costs of development.

Chapter 3 details a study in which a hedonic property price model was used to estimate the value of urban tree cover in Dakota and Ramsey Counties, MN, USA. This study related percent tree cover measured as the percent tree cover at the parcel level and within various neighborhoods around the parcel, to home sale price using a SAR error model. Two hedonic pricing models were estimated, model one that included the raw tree cover values and model two that included these variables plus their squares. Both models show that tree cover significantly influences home sales prices. Model one indicates that increased levels of tree cover within the closest neighborhoods (100 m and 250 m) increase home sale prices significantly and that parcel level tree cover does not contribute significantly to home sale price. Model two shows that the effect of tree cover varies with increasing tree cover at the parcel level decreasing home sale price to approximately 48% tree cover above which it increases home sale price. The opposite relationship exists between tree cover at the 100 m level and home sale price such that increasing tree cover within this neighborhood increases home sale price to nearly 87% tree cover, above which it decreases home sale price. Model two also indicates that increases in tree cover within the 250 m neighborhood increases home sale prices at all levels of tree cover. Tree cover in more distant neighborhoods did not contribute significantly to home sale prices in either model. These results suggest there are significant positive effects of tree cover at a local neighborhood level, for instance, resulting from the shading and aesthetic quality of tree-lined streets, but that values for tree cover on a parcel itself may minimal or negative. The fact that neighborhood level tree cover increases property values so much more than tree cover on the property itself, which may actually negatively impact home sale prices, indicates that tree cover provides neighborhood externalities such that home owners benefit if their neighbors plant trees, but no individual property owner has an incentive to do so. Municipal governments may thus play a positive role by promoting tree planting as a way to overcome the externalities that may prevent optimal tree cover. Local jurisdictions, could, for example, use the values generated in this study to evaluate the partial economic costs and benefits of tree planting incentives or policies or might use these values to predict some of the benefits likely to be accrued to the community by tree cutting restrictions.

The study described in Chapter 4 combined spatial, environmental models and economic valuation techniques to identify the likely environmental and economic impacts of planned land use in a developing community. Using a hedonic pricing model to identify the marginal implicit prices of three groups of ecosystem services and amenities (access to outdoor recreation areas, tree cover, scenic quality) as well as spatial models of these services and amenities, this study quantified the changes that are likely to occur in their delivery between 2005 and 2030 as a result of land-use change as well as the economic impacts of these changes. Its results indicate that large changes are likely to occur in the delivery of the target services as a result of planned land-use change. Some of these will impact the community's tax base positively, offsetting the results of many of the negative economic impacts of development, while others will impact it negatively. This study contributes methods and generates insights into the values of ecosystem services and amenities and identifies the relationships between these services and human use of the landscape in such a way that the impacts of future land-use change on these services and delivery can be predicted. Future use of the methods described in this chapter, with some modifications, could provide valuable information to local planners and policy makers that could improve the environmental and ecological sustainability of their land-use decisions.

These studies do not agree perfectly in their identification of ecosystem services and amenities that contribute significantly to home sale prices nor do they agree as to the magnitude of their contributions. All three studies found that decreasing the distance to lakes significantly impacted home sale prices, but disagreed as to the magnitude of this impact. The study in Chapter 2 estimated the marginal implicit price for a 100 m decrease in the distance between a home a lake from a starting distance of 1 km to be $216, while the study in Chapter 3 estimated this marginal implicit price to be $134 and the study in Chapter 4 estimates this value to be $181. This difference is much greater for the values of proximity to parks. Here, Chapter 2 estimated the marginal implicit price for a 100 m decrease in distance starting from a distance of 1 km to be $136 while chapter 4 estimated this value to be only $14 and Chapter 2 did not find a significant relationship between home sale prices and proximity to parks. This result may be caused by differences in the two counties and in the variables included in their hedonic pricing models. For example, the estimates of the marginal implicit price of a 100 m decrease in distance to lakes from Chapter 3, which included both Dakota and Ramsey Counties, and from Chapter 4, which included only Dakota County, are within $5 of each other while the estimate from Chapter 2, which included only Ramsey County differs from these two by between $82 and $87. This suggests that, in Ramsey County, lake access is more valuable than it is in Dakota County especially since, in the study that included both, the estimated value is between the values for each county alone. The reasons for the differences in the relationship between park access and home sale price among studies are less clear. It is clear, however, that values for park access are quite a bit lower in Dakota County than in Ramsey County and this accounts for some of this difference. In addition, the study detailed in Chapter 4 did not include trail distances while the other two studies did. Thus, it seems possible that controlling for trail distances reduces the significance of access to parks to the point that this variable is not significantly related to home sale price in Dakota County when it is included. The inclusion of a wide number of view composition metrics may have a similar impact, perhaps by eliciting values that are associated with parks, for instance, high levels of grassy cover and low levels of impervious cover.

All three studies found that the area of the view from a home significantly impacted home sale prices with 1 ha increases in view area, starting at the mean view area, corresponding to $241, $213, and $181 sale price increases from the studies in Chapters 2, 3, and 4. These values imply that view area is more valued in more urban Ramsey County than it is in more rural and suburban Dakota County. View composition metrics were examined only in Chapters 2, 3, and 4 and different land-cover maps were used in these chapters, so values are not readily comparable. However, they do agree that increased areas of water and grassy land covers in views positively impact home sale prices. The study detailed in Chapter 4 used a much more detailed land-cover map, however, and was able to more specifically identify lawn land covers as having a positive impact while other grassy land covers, for instance, grassland and maintained tall grassland, did not have a significant relationship with home sale prices. Thus, from the results of these studies, one can conclude that larger views and views that include water and grassy land covers like lawns are more valuable to property owners in the Twin Cities metropolitan area than smaller views that include more impervious surfaces.

The studies reported in Chapters 3 and 4 both examined the impact of tree cover on home sale prices. Model 1 in Chapter 3 and the hedonic pricing model generated in Chapter 4, which used the same tree cover variables, agree that tree cover within the 100 and 250 m buffers positively impact home sale prices, but disagree as to the magnitude of this impact with Chapter 3 estimating a $1,371 increase in home sale price with a 10 percentage point increase in tree cover in the 100 m buffer and Chapter 4 estimating this increase to be higher, $1,853. Chapter 4 also estimates a higher price increase for the same increase in tree cover in the 250 m buffer, $1,030 as opposed to $836. Neither of these two models found a significant relationship between tree cover at the parcel level or home sale price, but the model from Chapter 4 determined that tree cover in the 500 m and 750 m buffers had a significant relationship to home sale price while model 2 in Chapter 3 did not. The marginal implicit prices for 10 percentage point increases in tree cover in these areas was also quite high, $1,853 and $1,030, respectively. These differences may, again, be caused by a number of factors. First, much of the difference is likely to be accounted for by differences in how residents of the two counties value tree cover. It appears, from these results, that residents of Dakota County may place a higher value on tree cover than Ramsey County residents. This makes sense as residential areas in Ramsey County have higher mean levels of tree cover than residential areas in Dakota County, that is, tree cover is less scarce in Ramsey County. Thus, scarcity may account for the difference in values between the two counties. The high and significant values calculated for tree cover in the 500 m and 750 m neighborhood areas in Chapter 4 may also result from this difference, such that residents of Dakota County, where tree cover is generally more scarce, may value it at greater distances from their homes than in Ramsey County. This effect could have been obscured by the inclusion of Ramsey County in Chapter 2. Thus, it appears that tree cover is valued more in Dakota County where it is more sparse and less in Ramsey County, where levels of tree cover tend to be higher. Additionally, the differences in tree cover values and significance might also be accounted for by the inclusion of different variables in the two models, most notably by the inclusion of view composition metrics in Chapter 4 which could reduce the significance of the impact of tree cover on property values.

All three of these studies serve to achieve goal one of this dissertation, to identify the economic values associated with changes in the delivery of ecosystem services and amenities by estimating the marginal implicit prices of a selection of ecosystem services and amenities in the study area region. As such, they are illustrative of the great impact that changes in ecosystem service delivery may have economically. Use of these values in future land-use planning and policy making would thus be helpful in assessing the tradeoffs inherent in selecting land-use plans and policies and in avoiding or minimizing negative economic and environmental consequences.

Chapter 4 addresses all three dissertation goals, including goal two, to predict the environmental impacts of land-use change using spatial models of ecosystem services and amenities, and goal 3, to provide a novel general environmental modeling and economic valuation framework centered on land-use that can be used to evaluate local level land-use plans and policies. This chapter's findings have great potential to improve land-use planning and policy making and its methods provide an example that communities and researchers could follow to better incorporate ecosystem services and amenities in decision making. Future studies could follow this example to evaluate additional land-use plans or could use service delivery models in combination with economic valuation techniques to ensure that the delivery of highly valued services is maintained or increased under future land-use plans. This would enable communities to make more informed land-use decisions and to offset some of the negative impacts of urbanization, for instance, by ensuring that levels of tree cover are increased to offsets negative impacts associated with smaller lot development.

The methods detailed in Chapter 4 require some modification to increase their usefulness to land-use policy making. Notably, many of the values individuals were found to place on ecosystem services did not correspond well with ecosystem health. For example, individuals valued proximity to and views of lakes, but construction in these areas can have very negative impacts on water quality, flood and erosion control, and on species dependent on aquatic habitats. It is unlikely that individuals fail to value these services, rather, their values are not available because they were not considered in this study, rendering them “invisible” in this analysis. This indicates a need carefully consider the services included in an analysis and, particularly, to include more non-cultural ecosystem services in future studies. For example, Chapter 4’s study could be augmented by including services such as the provision of water quality for recreation or drinking. This would enable policy makers to assess the ecological and economic tradeoffs between developing areas near water bodies to provide easy access to recreation and impacts on water quality. This would increase the ability of those using the methods detailed in this chapter to identify the tradeoffs between different services and land-use plans. Thus, future applications of the techniques applied in this chapter would benefit from the consideration of a wider and better-rounded suite of ecosystem services and amenities. The use of these and similar methods with these modifications in a large number of communities would serve to increase the visibility of ecosystem services and amenities in land-use decision-making and would improve the sustainability of these decisions.

Urbanization will undoubtedly continue to transform the American and, indeed, the global landscape in the foreseeable future. The impacts this urbanization has on local, regional, and global environmental quality will depend largely on how well we consider environmental consequences as we plan our future development. If we continue to use planning and policy evaluation techniques that fail to consider the impacts of land-use change on ecosystem services and amenities, the prospects for future environmental quality are bleak. However, if we make strides in our incorporation of these services and amenities in the planning and policy making process, we may be able to avoid many of the negative environmental outcomes associated with urbanization. Collectively, the studies encompassed in this dissertation increase our understanding of how we as humans value environmental amenities, how these amenities are impacted by land-use change, and of how we might better use these amenities and their values to inform land-use decision making at the local level. As such, they have great potential to inform the land-use decision making process, helping to improve the visibility of ecosystem services and amenities in this process. Further use and improvement of the techniques used in this dissertation thus has great potential to improve future environmental quality.

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