Integrating Property Value and Local Recreation Models to Value Ecosystem Services in Urban Watersheds

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ABSTRACT. *This paper outlines a new revealed preference method to estimate the effects of changes in land use associated with residential development on water quality and the implied ecosystem services at the watershed level. The analysis integrates data describing several types of behavior and uses hedonic property value and random utility models for local recreation to consider the multiple impacts of ecosystem services on household well-being. Several policy examples drawn from changes in Wake County, North Carolina, are used to demonstrate how spatial differences in residential development are reflected in the model's estimates of the economic costs of deterioration in watershed quality.* (JEL Q51, Q57)

I. INTRODUCTION

One of the more important challenges facing environmental policy analysts today is the need to measure the gains or losses resulting from changes in ecosystem services.[1] Land use changes are significant factors in influencing the amount and quality of the services provided by watershed-based ecosystems. Recently Hascic and Wu (2006) have undertaken a comprehensive analysis of the effects of land use as well as other proxy measures for human activities on the watersheds in the lower 48 states of the United States. They consider 2,100 watersheds defined based on the USGS's eight-digit hydraulic units. Based on a count of the water samples in each watershed with concentrations for one or more of four water quality measures (phosphorus, ammonia, dissolved oxygen, and PH) exceeding national reference points, they found that transforming forests to urban land uses consistently increases this index of deterioration in water quality. Moreover, reductions in water quality increase the number of species at risk using the same watershed framework. Their research provides a key motivation for integrating the ecological impacts of alternative land uses into any evaluation of the private benefits and net social costs of transforming the landscape.

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[1] There are a number of activities supporting this. The U.S. Environmental Protection Agency has established a committee of the Science Advisory Board to consider methods for valuing the protection of ecological systems and services. Related to this activity the Agency has also drafted an *Ecological Benefits Assessment Strategic Plans*. A recent National Academy of Sciences volume on valuing ecosystem services (see Heal and committee 2005) observed that: "The fundamental challenge of valuing ecosystem services lies in providing an explicit description and adequate assessment of the links between the structures and functions of natural systems, the benefits (i.e., goods and services) derived by humanity, and their subsequent values" (p. 2).

Unfortunately, the literature has been unable to establish convincing linkages between private locational choices and the amenities provided by healthy watersheds. This information is important because policy analyses often need to consider whether and how these non-market losses will count in relation to the tangible private benefits from increased development. Inevitably, this type of assessment defines an implicit tradeoff between urban development and ecosystem services. While the final policy choices are based on many considerations, it is important from the perspective of efficient land use that one of these factors be the public cost of the development-related changes in land cover.

This paper develops a new revealed-preference method to address these needs. Our model integrates data describing several different types of behavior to allow the multiple impacts of ecosystem services to be considered simultaneously. Most benefit estimation methods focus on a single-choice margin. They might consider the factors relevant to the selection of a house and neighborhood or the reasons for choosing a recreation site for a one-day trip, but not both. In these contexts, ecosystem services become the attributes of each potential choice alternative. By contrast, policies often affect the quality of local neighborhoods and local recreation sites simultaneously.

We use the concept of short-run and long-run decisions to adapt a static model and allow residential and recreational choices to be combined. In making a decision about a home, we hypothesize that an individual considers, along with conventional housing characteristics, the availability and quality of local recreation sites for short outings. The water quality of these sites offers a way to describe how one aspect of ecosystem services contributes to the quality of recreation sites available to homeowners. A quality-adjusted measure of the available recreation choices in a neighborhood is treated as an attribute of that neighborhood. Implementing this logic requires data that connect homeowners' recreation behavior to their housing choices. Moreover, to link each of these decisions to land use/ecosystems service outcomes requires a consistent geo-coded mapping of the economic and environmental data. Comprehensive data of this type are not generally available. They were assembled for our analysis from a special purpose survey of home buyers in Wake County, North Carolina, together with detailed records of their home sales and a wide array of public data and special reports on the watersheds in this county. This type of spatial integration was one of the recommendations of the Hascic and Wu analysis.

To illustrate the payoff, we selected two types of current policy questions associated with local land use decisions. For our first examples, we construct estimates from recent reports of the differences in population growth for selected communities in Wake County. Our estimates suggest these costs are not confined to the communities experiencing rapid expansion and their immediate spatial neighbors. The costs spread and the pattern depends on the scale of the growth impulse, the pre-existing density of residential development, and the nature of the integration of hydrological units within the watershed. The second example compares two types of benefits of an urban lake: the proximity amenities of living close to a lake and the local recreation benefits provided to the general population in the area.

By integrating a spatially delineated description of ecosystem services with a consistently matched description of household choices, it was possible to identify the separate ways these services contribute to well being. A recreation site such as a lake contributes amenity services to the houses near it. With public access, the lake also contributes to recreation use and this role is reflected in our index of accessible recreation. Changes in its water quality affect the value of recreation access and, ultimately, the amenity value of proximity as well.[2] Our

[2] Our model does not at this point include the water-quality effects on the amenity services provided by lakes to nearby homes. Our logic could with adequate data be expanded to reflect this effect as well.

model exploiting the information conveyed by considering multiple choice margins allows us to distinguish these separate influences.

The remainder of the paper is organized as follows. Section 2 provides a description of Wake County, N.C. Section 3 reviews literature related to the role of water resources for property value models. Section 4 describes the conceptual basis for our approach, and Section 5 summarizes the data. Section 6 outlines our estimation methods and results, Section 7 details our checks for the sensitivity of our estimates to implementation decisions, and Section 8 reviews the policy scenarios. The last section discusses the more general implications of our findings.

II. STUDY AREA

Over the past decade, North Carolina's landscape has changed rapidly. It was ranked fifth in land area developed during the middle 1990s according to statistics from the Center on Urban and Metropolitan Growth, and that pattern seems to have accelerated in the area around Research Triangle Park. For example our study area, Wake County (shown in Figure 1a), currently has the second largest population in the state. Population grew by 48% between 1990 and 2000 and added another 15% between 2000 and 2004. This growth generates new housing units (4,208 building permits were issued in 1990 compared with 13,779 in 2000) and an increased proportion of land in impervious surface. There are 12 political jurisdictions in the county. Figure 1b shows their land area and location in relation to major water bodies in the region.

A key consideration in developing an economic description of the role of the services provided by watershed-based ecosystems for household location choices concerns the relationship between the spatial unit of measurement for watershed characteristics and that for economic analysis. In our case, the two decisions relevant to the analysis involve the selection of a home and the local recreation outings made after a home is chosen. For the former, neighborhood attributes must be integrated into the description of household choices. Distances to employment centers, shopping, schools, and so on are obvious parts of this characterization. It is more difficult, however, to measure directly neighborhood attributes that are not reflected by distance measures. Often submarkets arise based on these differences. The submarkets may reflect different ethnic or demographic groups present in areas, heterogeneity in housing prices or characteristics (e.g., mature older neighborhoods versus new subdivisions), or density of development. To capture the influence of these factors we used the Board of Realtors' Multiple Listing Service (MLS) definitions for submarkets. These 18 sub-areas are shown in Figure 1c. The MLS definitions were used in the design of our sampling plan and in the definition of our quality adjusted index of recreation accessibility described below.

An important issue in implementing our model arises in establishing a concordance between the political and economic definitions for spatial units and the hydrological layout of the county. This task would not be difficult if there were one accepted definition for each perspective—the economic and hydrological models. There is not, and a number of alternatives are possible for each type of analysis. For example Wake County commissioned a comprehensive watershed management plan in 2000, responding to the rapid growth. The environmental engineering firm preparing the report (CH2MHILL) refined its watershed definition, disaggregating the USGS hydrological units and identifying 80 hydrologic zones for the county. One might also use the water bodies (lakes and rivers) in the county and their surrounding areas as a framework that might be more recognizable to households. Similarly for the economic definition there are alternative ways to define the submarkets.[3] The final decisions about how to

[3] The county has a unified school district so this distinction is not as relevant as it might be expected to be in other locations.

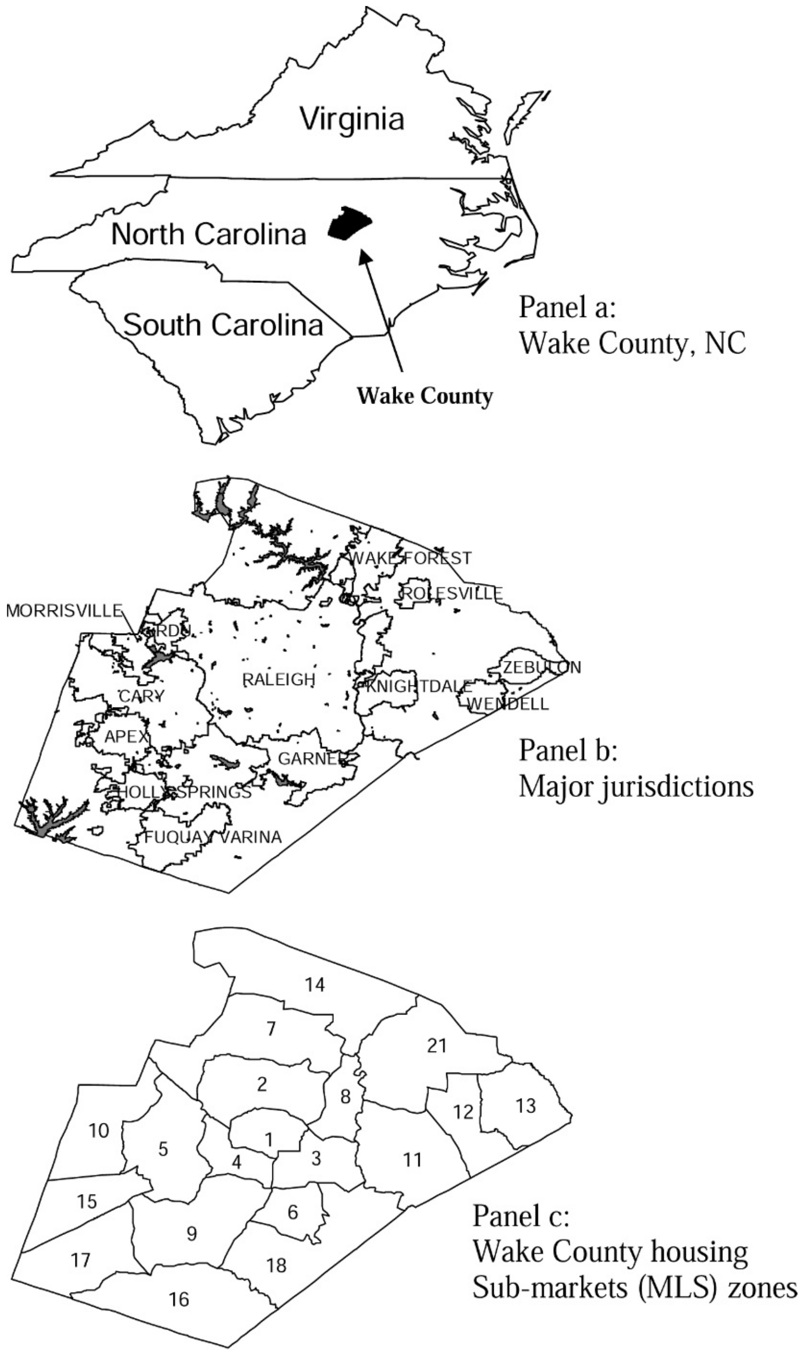

FIGURE 1
Economic, Hydrological, and Jurisdictional Divisions of Wake County, North Carolina

define the relationships linking economic and hydrologic areas require compromises that may influence conclusions. As a result, we evaluated the sensitivity of our findings to some of these choices and discuss our evaluations below.

III. RELATED LITERATURE

Property value models have been applied to a large set of environmental problems. However, there have been fewer hedonic studies of water pollution and its effects on watershed services. This is probably because water and water quality affect properties in a variety of ways and it is not clear whether these effects are fully reflected in the standard hedonic framework. Water quality can have a direct amenity effect on properties, but only for properties that are adjacent or very close to the water body. This can enhance the services that would be considered as delivered by watershed ecosystems (see Boyd and Banzhaf 2007). It is often difficult to find a sufficient number of waterfront properties and enough variation in water quality to conduct such a study.[4] It is also reasonable to expect that nearby water bodies will affect properties that are not immediately adjacent to them. They provide areas for uses such as swimming, fishing, and taking walks. Water quality can affect these local recreation opportunities and this in turn can influence property values.

The study of local recreation trips for short outings is also a neglected area of research; so it is not surprising that this connection seems to have been overlooked. Nonetheless, there is some existing literature relevant to our analysis. There are a handful of studies on the effect of water quality on waterfront property values.[5] The earliest of these was done by Elizabeth David (1968) for waterfront properties in Wisconsin. David used three categories of water quality based on the opinions of government officials. For their study of Pennsylvania streams, Epp and Al-Ani (1979) used an objective measure, a dummy variable for pH below 5.5, and a subjective measure, a dummy variable for the perceived water quality problems. More recently Leggett and Bockstael (2000) used a measure of fecal coliform in their carefully designed study of the coastal properties on the Chesapeake Bay. Finally, waterfront properties on Maine lakes were studied in Michael, Boyle, and Bouchard (2000) and Poor et al. (2001). The latter study used an objective measure, clarity measured by Secchi disk, and a subjective measure, perceived clarity from a survey.

A second set of related research concerns the potential for double counting measures of site specific amenities in travel cost recreation site demand and hedonic property value models. McConnell (1990) first raised these questions within a conceptual model for a lake that is used for recreation and also contributes to the amenities enjoyed by homeowners in the vicinity of the lake. Considering the theoretical implementation of both a two-stage hedonic model and a travel cost model, he concludes that if the lake only has value for recreation, the two models yield identical results. However if the lake also has amenity value for the properties separate from the on site recreation use, then the hedonic model captures all benefits and the travel cost model captures only part. Adding pollution to his model as a gauge of reductions in lake quality (or its amenities) yields similar results.

Parsons (1991) also raised the issue that recreation and residential location decisions

[4] Some studies, such as Michael, Boyle, and Bouchard (2000), have selected lakes and the homes around them as the unit of analysis. This strategy inevitably confronts the questions of whether homes around different lakes are part of the same market (and hence have the same hedonic price function) and whether the homes near lakes are a separate market from other homes selling in the same areas.

[5] We restrict our review to studies that were published in refereed journals and used market sales prices. There are some other studies in government reports and filings in litigation. Many of these are discussed in Palmquist and Smith (2002). Other unpublished studies are cited in the papers discussed here.

may be intertwined. If residential decisions are partially based on recreation opportunities, then the price variable in a travel cost model will be endogenous. Parsons proposes several types of potential instruments that could be used in a travel cost model to address the endogeneity problem. His empirical experiment with a simple travel cost model suggests that the bias due to the endogeneity may not be trivial. Randall (1994) also discusses the problems with the price variable used in travel cost models, including the difficulty sorting out the recreation and residential location decisions. Our framework overcomes the issues raised by Parsons and Randall. In the process it illustrates the implementation challenges that may well explain why McConnell's conclusions did not lead to a larger number of applications of a revised hedonic model.

IV. METHOD

The types of recreation that have received the most attention in the recreation demand literature probably have little influence on residential location choices. Most studies have considered full-day or multiple-day trips with significant travel costs for getting to the sites. The recreation sites of interest in our analysis involve local recreation. That is, these are short trips to recreation destinations with short on-site stays. The time-cost of accessing these local sites can vary substantially within an urban area. As a result, local recreation opportunities may influence a household's choice of a residential location and these decisions will be reflected in the housing values in different parts of the city.

Our framework uses a distinction in static models that is often intended to reflect differences in costs of adjustment. It classifies choices based on a priori assumptions about which choices would be more difficult and costly to change. This formulation is what usually underlies the long-run/short-run terminology adopted when static models are used to illustrate how adjustment and adaptation can influence the conclusions of comparative static analysis. The long-run/short-run formulation permits a conceptual division to be made between different margins of choice. In this context, a choice margin refers to a resource allocation decision made by an individual or household that leads to the acquisition of both a private good and the services of a non-market good. Long-run choices involve the selection of a neighborhood and the purchase of housing. Short-run choices involve trips to local recreation sites for short outings. The short-run choices are made conditional on the long-run residential location decision. It is this conditionality that is isolated through the specification of one choice as long-run and the other as short-run. Once the location choice is made, a household allocates remaining time and money resources to market goods, leisure, and recreation site usage. Since the location choice influences the choice set for short-run decisions, it seems reasonable to expect that when deciding on a residential location the household considers the portfolio of amenities conveyed by each location, including its accessibility to recreation and the quality of the accessible recreation opportunities.

To represent these decisions more formally, we assume a two-stage household decision process. Preferences are a function of recreation trips to local sites $x(q)$, a numeraire good z, and housing services $h(\mathbf{a}, q)$ where $\mathbf{a}$ is a vector of housing attributes and q is a measure of environmental quality. The vector $\mathbf{a}$ is broadly defined to include all structural, neighborhood, and spatial characteristics of the house, including distances to the available recreation sites. The preference function is given by

$$U = U(x(q), h(\mathbf{a}, q), z, \varepsilon), \quad [1]$$

where ε is an error term denoting individual (or household) heterogeneity that is unobserved by the analyst.[6] For short-run

[6] Household and individual will be treated as synonymous.

decisions involving $x(q)$ and z, $h(\mathbf{a},q)$ is treated as quasi-fixed. If m^* is the household's annual income and $p_h(\mathbf{a},q)$ is the annual cost of a unit of housing, the short-run decision problem is described by

$$\max_{x,z} U(x(q), z|h(\mathbf{a}, q)) \quad s.t. \quad m = p_x x(q) + z, \quad [2]$$

where $m = m^* - p_h(\mathbf{a},q)$ is income net of housing costs and p_x is the distance-dependent price of a recreation trip. The first-order conditions for this problem imply solutions for the recreation demand and market goods conditional on the housing choice. The conditional indirect utility function for the short run problem is denoted by $V = V(p_x, m, q, \varepsilon)$.

Recreation demand models can be used to recover an estimate of V which is then used to compute the realized ex post benefits from visits to the recreation sites. The Hicksian surplus from a pattern of annual recreation that is selected with given prices and quality conditions is implicitly defined by

$$V(p_x, m, q, \varepsilon) = V(p_x^c, m + CS, q, \varepsilon), \quad [3]$$

where p_x^c denotes the Hicksian choke price for visits to the recreation site and CS is compensating surplus. The change in compensating surplus due to a change in q is defined by

$$V(p_x, m, q^0, \varepsilon) = V(p_x, m + \Delta CS, q^1, \varepsilon), \quad [4]$$

where q_0 and q_1 denote the original and new values for q, respectively. Equations [3] and [4] imply household-specific surplus measures $CS(q,\varepsilon)$ and $\Delta CS(q^0,q^1,\varepsilon)$ that are functionally dependent on both observed and unobserved household heterogeneity.

To see how additional choice margins can be incorporated into the analysis consider how the value of trips at a given quality level might influence other decisions. Equation [3] provides a summary of the gains due to the household's ability to take trips to the recreation site. It is the ex post benefit from the access and quality conditions of recreation trips from the individual's chosen housing location. In making a residential choice, the framework assumes that at the time of the decision households consider what these recreation benefits would be for each possible neighborhood being considered. If recreation opportunities and/or environmental quality vary spatially, each area provides different potential for recreation benefits. As a result, the expected recreation benefits can be interpreted as an attribute of the location. These expected benefits from recreation at a given residential location are given by

$$ECS(q) = E[CS(q, \varepsilon)]. \quad [5]$$

In this relationship, the expectation operator is with respect to the factors associated with the heterogeneity across households in the location.[7] Equation [5] is not a household-specific measure. It measures the average recreation benefits that would be expected by choosing to live in one location compared to no access. Of course, in practice the choice is based on each neighborhood's relative value, so the default of no access becomes irrelevant. The expectation is across diverse households conditional on the level of q at each specific location. Using a long-run perspective, we hypothesize that this value would be capitalized into housing prices in equilibrium.

The long-run component of our model considers the housing choice. Households evaluate many attributes of a house and its location including how different spatial locations convey different potential for local recreation outings. Since recreation decisions are made conditional on the location choice, we replace $x(q)$ in the preference function with $ECS(q)$ when evaluating the housing choice stage. This function implies that for each value of q associated with a location, the household considers the future potential recreational benefits and conditions its choice on these and the other features conveyed by that

[7] In this expression, the expectation refers to ε. In practice, we will average over both observed and unobserved sources of heterogeneity.

location. More formally, the objective function in the long-run is

$$\max U = U(ECS(q), h(\mathbf{a}, q), z, \varepsilon),$$

$$\text{subject to: } m^* = p_h(\mathbf{a}, q) + p_x\tilde{x} + z, \qquad [6]$$

where $\tilde{x}$ is the optimized value of x given q.

With the actual values of x and z assumed selected conditional on location, the value of $h(\mathbf{a}, q)$ is determined through the spatial choice of **a** and q recognizing the connection through $ECS(q)$. The first-order conditions in this case show that in choosing a location, the household balances the benefits of a higher level of q with the marginal increase in housing cost:

$$\frac{\frac{\partial u}{\partial ECS}\cdot\frac{\partial ECS}{\partial q}+\frac{\partial u}{\partial h}\cdot\frac{\partial h}{\partial q}}{\frac{\partial u}{\partial z}} = \frac{\partial p_h}{\partial q}. \qquad [7]$$

At the margin, households choose a residential location such that the marginal value of increased ecosystem services from the expected recreation activities plus the incremental benefits from the services that are directly available at the location are balanced against the marginal purchase price.

To implement this logic, assume an urban watershed is divided into J areas corresponding to well-defined real estate markets. The total number of recreation sites in the watershed is K, and the quality associated with a given site k is q_k. The spatial layout of the landscape and existing amenity levels convey a similar portfolio of access to recreation opportunities for each resident in a market area j. Given observations on visits to local sites by the residents of the area, it is possible to estimate a random utility model of site choice. For simplicity assume the indirect utility for a visit by person i to site k is linear and given by

$$V_{ik} = \alpha_k + \beta t_{ik} + \delta q_k + \varepsilon_{ik},$$

$$i = 1,\ldots, N, \quad k = 1,\ldots K, \qquad [8]$$

where t_{ik} is a measure of the time cost for visiting site k, (α, β, δ) are parameters to be estimated, and ε_{ik} is a random error term distributed type I extreme value. With this distribution for the error term estimation of the site choice model in [8] is straightforward, and the expected utility per trip for a person in the sample is

$$EV_i = \ln\left[\sum_{k=1}^{K}\exp(\hat{V}_{ik})\right] + C, \qquad [9]$$

where $\hat{V}_{ik}$ is the predicted deterministic component of utility for person i and C is a constant. Under the linear specification for utility the average compensating variation per trip (expressed in units of time) for an individual is obtained by dividing the expression in equation [9] by $\hat{\beta}$.

The expected utility available to a person from the K recreation sites varies across the watershed due to the variation in the time needed to access the sites. Closer proximity to sites of higher quality will, on average, convey a higher per trip utility level. However, equation [9] is an individual-specific reflection of the expected utility available from the portfolio of sites and their attributes. It is not an appropriate index for measuring the overall market reflection of the potential to derive benefits from recreational outings to local sites

Markets could be expected to take account of information that buyers could learn as part of evaluating alternative potential neighborhoods and that sellers would consider when marketing their homes against potential competitors. This assessment would not reflect individual heterogeneity in the recreation benefits. Instead, it would be a composite index, such as an overall average, of the potential to generate recreation benefits for the residents of a neighborhood. In some respects the logic that underlies the definition of this index might be seen as parallel to what is used in defining price indexes. This parallel offers some helpful intuition but there are also important distinctions. The first follows from the fact that there are no mechanisms that assure that these indexes describing the accessibility of a particular home's location to constant quality opportunities for local recreation will be equalized, as we might expect for private goods and services traded in the same market. The second arises because we are not imposing conditions for consistency on the index. For example, one consistency condition holds when a price index times the corresponding quantity index for an aggregate of a set of heterogeneous goods equals total expenditures on the aggregate good.[8]

The definition for the average that we propose is given by

$$ECS^j = N_j^{-1} \sum\nolimits_{i=1}^{N_j} \ln\left[\sum\nolimits_{k=1}^{K} \exp\left(\hat{V}_{ik}\right)\right] \Big/ \beta, \quad [10]$$

where N_j is the number of person-trips originating from market area j. By averaging out all observed and unobserved household heterogeneity [10] provides a "quality adjusted recreation access index" for representing the recreation opportunities conveyed by a given neighborhood.

A focus on the aggregate is possible because the sum of an independent set of decisions (across individuals or choice occasions for the same individual) yields the same measure for the Hicksian value of access as would be derived by assuming choices arose from a representative individual with a specific nonlinear preference function (see Anderson, De Palma, and Thisse 1988). Thus relying on the RUM logic for our empirical model is consistent with describing an individual's recreation choices as if they took place at the intensive margin.[9] This format is what underlies CS in equation [3] and ECS in equation [5]. Equally important, we can use this indirect utility function to describe the housing choices for a representative consumer and thereby consistently motivate the hedonic analysis as well (see Anderson, De Palma, and Thisse 1992).

It is possible to use the access index in conjunction with a hedonic model to measure how recreation opportunities are reflected ex ante in housing prices. For example, define the hedonic price equation for home sales occurring in the watershed by the semi-log form,[10]

$$\ln p = \alpha_0 + \sum_{l=1}^{s} \beta_l \mathbf{a} + \gamma_1 ECS^j + \gamma_2 q(d) + u, \quad [11]$$

where $q(d)$ is a function describing the neighborhood amenity effect of a resource q. We hypothesize it will be related to some index of the distance d to the site. Estimation of equation [11] allows separate identification of the direct and indirect effects on housing prices of ecosystem services. In special cases when the effects are small and localized, one can assume that the equilibrium price schedule which is being described by the hedonic price equation would not change with a change in external factors influencing these non-market services. Then, when the error term is assumed to be due to unobserved characteristics, it is possible to directly calculate the exact welfare measure as a simple difference between equilibrium prices under baseline and changed environmental conditions (Palmquist 1992). For our two policy applications discussed in Section 8 below we maintain these assumptions. The annual compensating surplus measure for property i in sub-market j arising from a change in

[8] For an early but comprehensive review of the relationship between economic and non-economic approaches to the definition of index numbers see Allen (1975). See pp. 44–47 for a discussion of the various "tests" for properties of index numbers.

[9] This connection at the aggregate level is important to our analysis because it implies we can describe the choice of sites for local recreation within a discrete choice framework, recognizing they are not likely to be coordinated over the course of a year. Rather, the decision to visit a park to walk the dog depends on specific circumstances at the time it is done. Nonetheless, when considered from the seasonal perspective the aggregate of these choices over individuals can be consistently represented as if it were a marginal choice. Moreover, the linear form for V_{ik} yields an indirect utility function for the representative agent that contains the same log sum relationship and has the same analytical form for aggregate welfare measure (see Anderson, De Palma, and Thisse 1988, equation 8).

[10] Cropper, Deck, and McConnell's (1988) simulation experiments suggest that when the independent variables in hedonic models are replaced with proxy variables or the specifications are likely to be incomplete, simpler specifications for the price function such as the semi-log have superior properties based on estimates of the marginal willingness-to-pay.

the recreation index due to a change in q is given by

$$\begin{aligned} CS_i &= \theta \times \left(p_i^0 - p_i^1\right) \\ &= \theta \times p_i^0 \times \{1 - \exp[-\gamma_1(ECS^j(q_0) \\ &\quad - ECS^j(q_1))]\}, \end{aligned} \qquad [12]$$

where θ is an annualization factor, p_i^0 is the observed sale price for property i under baseline conditions, and p_i^1 represents the price (including the original regression error term) for property i under the new quality level. In more general cases where the hedonic price schedule changes or some of these assumptions are not met, it is possible to approximate and possibly bound willingness to pay measures for changes in watershed quality.[11]

V. DATA

Our approach requires spatially explicit data on home sales, recreation decisions by homeowners, and water quality for the area of our application, Wake County, North Carolina. As part of a larger project examining water quality in the county and state, we constructed a database that integrates property sales data obtained from the Wake County Revenue Department, survey data obtained from a sample of homeowners in the county, and data from individual water quality monitoring stations assembled from a variety of state, municipal, and private sources.

Records for approximately 100,000 private home sales occurring between 1992 and 2000 are contained in our database. Table A-1 in the Appendix provides a description of a subset of the structural and neighborhood variables coded for each property in the data. The level of resolution in structural and other attributes is more complete than in most hedonic studies. Fulcher (2003) and Palmquist and Fulcher (2006) provide a detailed description and analysis of these data, suggesting specifications for the structural and neighborhood variables that we employ here as well. We use sales from 1998 and 1999, totaling more than 26,000 observations.[12] The mean prices for sales during these years are \$179,221 and \$184,574, respectively. Homes have on average 1,933 square feet of heated living space, 2.5 bathrooms, are 11 years old, and sit on 0.46 acre lots.

The component of our database describing household behavior was obtained through a mail survey sent to Wake County homeowners between May 2003 and September 2003. The objective of the questionnaire was to gather household specific information for a proportion of the homes represented in our sales data, allowing us to link location decisions to other household activities, and the economic characteristics of the residents. To select the sample we used the Wake County home sales records to identify a subset of owner-occupied properties. Properties were randomly selected subject to four filters. First, we excluded properties that sold for less than \$50,000. Second, the county was divided into four quadrants based on an aggregation of the MLS zones described above. Nine thousand properties were drawn such that they were evenly distributed across the

[11] Our formulation treats the hedonic price function's parameter estimates as approximately equal to the true values. There are a number of other interpretations and strategies for estimating the unobserved heterogeneity associated with the hedonic function under baseline conditions. We evaluated several alternative prediction strategies including methods that adjust for bias due to the nonlinear form of the price function. Use of these alternative prediction methods and associated welfare measures made no significant difference to the welfare effects reported below.

[12] We limited our analysis to these two years because during 1999 Wake County undertook a reassessment of property values for tax purposes. This process takes place in the county at seven-year intervals. It can result in large changes in property taxes due to a realignment of the assessed values of older homes with their market values. As a result, following a reassessment sale prices of houses experiencing these changes can be affected. Preliminary estimates of hedonic models immediately after the reassessment confirmed this discrete change in the market price schedule. Our survey was designed to contact households who purchased homes in Wake County where we have the corresponding record of the housing sale. As a result we restricted the sample to housing sales that preceded the reassessment period.

four aggregate real estate zones. Third, we included checks to assure that the hydrological division of the county was also reasonably well represented by the sales data. The sampled properties were evaluated to assure a sufficient number of observations fell in each of the CH2MHill sub-hydrologic units. For each sub-hydrologic area we determined if the initial draw of 9,000 properties resulted in at least 20 observations from the area. For the areas that did not meet this criterion, we randomly selected additional observations to raise the number in each hydrological area to 20. For areas with an insufficient number of sales, we simply selected all that met our criteria. Finally, property owners' names and addresses were verified using the current Wake County property tax records. Only properties for which the sales record from our hedonic database could be cross-linked to the currently listed owner were included in the final sample. This resulted in 7,554 matched names and addresses, each of whom was sent a mail survey following the Dillman (1978) protocol with two mailings and a reminder postcard. We had a 32% response rate that provided slightly more than 2,000 completed surveys.[13]

We collected two types of recreation data based on feedback from two focus groups conducted as part of the design of the survey questionnaire: (1) information on state-wide visits to lakes, streams, and coastal areas; and (2) information on "local outings." We define local outings as short excursions to sites close to home involving at most a few hours of combined on-site and travel time. Our hypothesis is that the quality of environmental sites used for outings close to home is more likely to influence property values than that for the sites at more distant locations. For our recreation analysis we therefore consider the influence of watershed quality on visits to sites within Wake County. Forty-eight water recreation sites were identified in the county.[14] Our survey provides information on 1,187 respondents who reported making trips of this type between May and November 2002. Records on over 14,000 local trips are available for analysis, with each participating household taking an average 12 trips.

The water quality component of the database combines technical indicators of ambient water quality from 12 separate sources.[15] For this application, we use readings from monitoring stations located in Wake County and focus on chemical measures. The specific variables used for the RUM analysis are total suspended solids

[13] Our relatively low response rate led to concerns about non-response bias. To investigate the degree to which this may be present we compared the proportion of completed surveys to socio-economic characteristics at the census block group level using a grouped logit model. The results suggest people in blocks with a higher proportion of white residents, older homes, and recent arrivals to the area were slightly more likely to return the questionnaire. There was no significant effect due to median income or median house value. Thus, while whites may be slightly over represented in our sample of home owners, there is little evidence of systematic bias in the sample that would compromise our ability to gauge homeowners' use of water recreation resources.

[14] Our survey included a map with a legend listing sites identified a priori by us, as well as space for respondents to identify sites not included in the list. Water recreation was broadly defined to include both contact and near-shore uses of area resources.

[15] Chemical monitoring data were obtained from the North Carolina Department of Environment and Natural Resources for both public and private monitoring networks. These include monthly readings from ambient monitoring stations throughout the county between 1994 and 2000 for 61 variables. Pollutant loadings from major NPDES point sources were collected from electronic and paper sources. Nine variables were collected from the monthly reports of these sources for the Neuse River. Four types of biological summaries are available. Single samples collected on benthic and aquatic habitat characteristics in August 2001 by CH2MHill for Wake County are summarized in our database. Periodic readings for the state benthic communities were collected by North Carolina Division of Water Quality from 1982 to 2003, for Neuse River Basin sites and from 1983 to 2001, for the Cape Fear River Basin. Additional data sources are as follows. Chemical data for four variables describing water quality for major lakes in the Neuse and Cape Fear watersheds are available periodically from 1981 to 2002. The U.S. Geological Survey (USGS) also reports chemical and flow data for sites within the upper Neuse and Cape Fear basins monthly from 1989 to 2001. All these databases can be linked either through the latitude and longitude of the sampling location or other identifying information to our various geographic area definitions.

(measured in lab nephelometric turbidity units), total phosphorus (measured in milligrams per liter), and ambient dissolved oxygen (measured in milligrams per liter).

VI. ESTIMATION AND RESULTS

RUM Estimation

Estimation of a RUM model requires specification of the choice set, calculation of the implicit price of a visit to each site, and attachment of environmental quality characteristics to each site. There are two possibilities for defining an object of choice in the choice set: (1) a specific point in space based on a named destination such as a park with a lake; or (2) a spatial unit defined by physical hydrology. The former is better suited for understanding visitor use and benefits for a specific site. The latter is preferred when the focus is more on water quality conditions in a general area because the technical definition is designed to represent the location where the water quality readings are measured. Defining choice alternatives based on watersheds aligns the spatial resolution in the choice model with the physical conditions that give rise to variation in water quality levels. By dividing the study area into high-resolution watersheds, the full variability in water quality across the landscape can be exploited in the model, and choices are more likely to reveal distance/quality tradeoffs. For this reason, we focus our primary attention on a watershed-based choice set. Our evaluation of the sensitivity of the results considers the effects of a site-specific choice set and is discussed separately.

We define the choice set to be the set of hydrological (CH2MHill) zones described in Section 2. Trips observed in the sample were assigned to one of the 80 zones. The RUM model's objective is to explain the choice of one of these zones for a local trip as a function of the implicit price and watershed quality in the zone. We evaluate the effects of water quality in two ways. The first directly includes measures of water quality in the specification of the conditional indirect utility for each site. The second includes alternative specific fixed-effects in the indirect utility function that capture all features of the sites (observable and unobservable) and estimates the effects of water quality variables in a second-stage analysis. Our primary results are based on the first approach. Section 7 discusses alternative site definitions and measures of the effects of site characteristics as part of robustness checks for the model. The resource cost of a visit is the round trip time needed to travel to the zone, calculated between the person's address and the center of each hydrological zone. GIS software was used to make these calculations for all sampled households and all zones. The average round-trip travel time for trips observed in our sample is 35 minutes.

The CH2MHill study of the watersheds in Wake County provided a qualitative expert assessment for each of the hydrological units included in our choice set. Nevertheless, due to the limited variability in the outcome of their assessments, we focus on technical measures of ambient water quality to parameterize our quality variables. Our database includes readings for total suspended solids (TSS), total phosphorous (TP), and dissolved oxygen (DO) taken in the county after January, 1998. Monitoring station readings were linked to a hydrological zone based on the location of the station generating the reading. The empirical distribution of all available readings attached to a hydrological zone was then used to generate summary measures. For phosphorous and suspended solids the 90th percentile in each zone is the summary measure, while for dissolved oxygen the 25th percentile is used. Table 1 contains a summary of these measures across the 80 hydrological zones, as well as a summary of watershed size.[16]

[16] To our knowledge, our database provides the richest characterization of urban water quality used in an economic model. Nonetheless the monitoring station network is not sufficiently dense to individually cover every hydrological zone. Of the 80 zones in our model, 33 are covered by a monitoring station, necessitating aggregation to cover the remaining. Our aggregation strategy followed the USGS definitions for increasing

TABLE 1
RUM Model Specification and Estimated Parameters

Variable	Description	Estimate (t-Value)
Travel time	Time in minutes for round trip from respondent's home to center of each hydrological unit	−0.0750 (−145.27)
Size	Size of hydrological unit in square miles. Mean (std. dev.): 12.55 (9.36)	0.1027 (106.60)
TSS	Summary of total suspended solids. Calculated for each hydrological unit as 90th-percentile of empirical distribution of readings. Mean (std. dev.): 65.36 (102.92)	−0.0016 (−21.03)
TP	Summary of total phosphorous. Calculated for each hydrological unit as 90th-percentile of empirical distribution of readings. Mean (std. dev.): 0.846 (0.132)	−1.914 (−30.17)
DO	Summary of dissolved oxygen. Calculated for each hydrological unit as 25th-percentile of empirical distribution of readings. Mean (std. dev.): 6.52 (0.857)	0.465 (43.79)

Our empirical specification for the conditional indirect utility function for a visit to a site in hydrological zone k is

$$V_k = \beta time_k + \delta size_k + \gamma_1 TSS_k + \gamma_2 TP_k + \gamma_3 DO_k + \varepsilon_k, \quad k = 1, \ldots, 80, \qquad [13]$$

where the error terms are distributed type I extreme value. Estimates of the utility function parameters are shown in Table 1. The estimates are statistically significant and consistent with prior expectations. In general, people visit areas of the county that are closer to their home, have lower levels of TP and TSS, and higher levels of DO.[17] Accounting for the different units in which the pollutants are measured, under baseline conditions TP has the largest disutility effect relative to TSS and DO.

Hedonic Estimates

The RUM model provides the characterization of preferences for recreation and water quality that is used to construct our quality adjusted recreation index. The MLS zones in the county serve to define the neighborhoods for measuring the recreation access index. This index, defined in equation [10], provides a quality-adjusted measure of the average benefits from a trip originating from each zone. Inclusion of the index in our hedonic specification links a quality-adjusted measure of the expected accessibility to local recreation to the current choice of home location.

We use a non-linear function of distance to the nearest water body to proxy the residential amenity affect of water resources in the county. In conventional property value models, location on, or near a lake is assumed to convey amenity services to the homeowners. To compute our distance measure we obtained a GIS shape file containing all lakes in the county. The distances between each house and all lakes were calculated and the distance to the nearest lake was determined. Since the amenity effect is likely to diminish with greater distance we use the function,

$$lakedist = \max\left[1 - (d/d_{max})^{1/2}, 0\right], \qquad [14]$$

to create the distance variable, where d is distance in miles and d_{max} is the cutoff point, set to 1/2 mile for this application. The index is between zero and one and is convex. Twenty-two percent of properties

watershed size (i.e., 14-, 11-, and 8-digit aggregate units). For each zone missing a monitoring station we assigned a covered zone located in the same 14-, 11-, or 8-digit hydrological unit with preference given to the lowest level of aggregation available.

[17] The chemical measures tend to proxy conditions at sites perceptible to individuals. For example, suspended solids tend to affect visible water clarity. Phosphorous levels are predictors of algae blooms and water smell, while dissolved oxygen is a predictor for the health of aquatic life.

TABLE 2
HEDONIC ENVIRONMENTAL VARIABLES AND ESTIMATED PARAMETERS

Variable	Description	Estimate (*t*-Value)
Lake distance index	Proxy for amenity impact of lake proximity $=\max[1-(d/d_{max})^{1/2}, 0]$, d = distance to the nearest lake, d_{max} = ½ mile	0.016 (3.23)
Index of recreation access	Average value of *ECS* from RUM model calculated from trips occurring in each MLS zone	0.0174 (6.41)

in the sample are within a half mile of the nearest lake.

Estimates from the hedonic model for lake distance and the recreation index are shown in Table 2, with the remaining parameter estimates given in Table A-1 in the Appendix. The results are consistent with prior expectations. Both the quality adjusted recreation access index and proximity to lakes capitalize into housing prices as expected. Thus, changes in quality adjusted access conditions (either through closer proximity or better water quality) can be measured with the hedonic model. This finding is consistent with our hypothesis that the ecosystem services we associated with watersheds seem to influence preferences in different ways. The results are also suggestive of the importance of considering these different channels for household response and adjustment for benefits assessment.

VII. ROBUSTNESS CHECKS

Our evaluation of the sensitivity of our results to implementation decisions considered a number of variations in the models. Our overall findings support the modeling structure. It appears to be quite robust to a wide range of alternative specification choices. Several aspects of this analysis deserve further discussion. The first is related to Parsons' (1991) discussion of possible price endogeneity in travel cost models. Parsons raised the issue with a traditional travel cost model, where bias in the estimate of the price coefficient can have a large impact on the welfare measures. In our model, the welfare impacts are captured in the hedonic estimation rather than the recreation demand. The RUM stage of our model is only used to generate a quality-adjusted index of access to local recreation. Nonetheless, if the travel time parameter in the RUM model were affected by endogeneity, the index might be affected as well. To gauge the extent to which this may be a problem in our model we estimated the model using a sub-sample of people who were new arrivals to the county at the time they purchased their houses. New arrivals (who are less familiar with the county's geography than long-time residents) may be less likely to choose a location based primarily on access to recreation sites. Thus, the simultaneity issues suggested by Parsons' argument should be reduced in this sub-sample. In spite of a much-reduced sample size we find estimates of the RUM parameters that are nearly identical to their full-sample counterparts. This finding could be because the new arrivals were equally concerned with recreation, or that the endogeneity issue is not significant. Either way, our index represents the choices buyers face in making their location decisions, and our welfare measures are based on those choices.

The second issue relates to the choice set used for the RUM model.[18] There are several issues in structuring a definition for the choice set for the model of local recreation decisions. One of the most important concerns the implied spatial linkage of water quality measures to each choice alternative. Our final model uses a hydrologic definition for choice alternatives because this formulation offered the most

[18] For a detailed discussion of a similar issue in market research, the framing of the consideration set for choice models, see Horowitz and Louviere (1995).

TABLE 3
COMPARISON OF HEDONIC ESTIMATES USING DIFFERENT RUM MODELS

RUM Model Use for Index	Hedonic Regression–Recreation Index Coefficient	
	Estimate	t-Statistic
80 watershed site RUM (in paper)	0.0159	5.85
23 watershed site RUM	0.01379	9.25
23 watershed site RUM–fixed effects	0.01620	21.47
48 named site RUM	0.02514	16.07
39 named site RUM	0.02831	17.52
39 named site RUM–fixed effects	0.02249	26.03

authentic link between the spatial definition of the site and quality. As we noted there are 80 such choice alternatives in the county. Our sample only visited 23 of these locations. The time costs of an outing and existing quality attributes of the other 57 alternatives may explain why they were not visited. Alternatively, they may simply not be part of homeowners' consideration set. The former rationale suggests we should include them in the choice set for the model while the latter suggests not.

A completely different logic would suggest that we use named sites and not hydrologic units as choice alternatives. This perspective seems more likely to correspond to the framework people use. It is the way they reported their recreation outings in our survey. It has the disadvantage of providing a less reliable basis for linking the water quality measures since the monitoring network is defined based on the hydrologic system. It was not intended to characterize water quality at specific lakes or river reaches. As with the hydrologic definition for choice alternatives, only a subset of the sites was visited by our homeowners: 39 of the 48 named sites for local outings.

Finally there are two strategies we identified as possible ways of reflecting the quality attributes associated with ecosystem services for these alternatives—including the measures of water quality in the RUM specification directly (as in equation [8]) or using alternative specific constants in the RUM model and then, in a second stage, estimating how the fixed effects are influenced by the water quality measures. There is not an unambiguous basis for deciding which was best. Our final results adopt the most complete specification of choice alternatives with what we considered to be the most reliable measure for the water quality characterizations of each choice alternative.

Our robustness analysis considered six alternative specifications for the RUM model: (1) three versions of the hydrological site definition (all 80 zones, the 23 visited zones, and a 23-zone model with fixed effects and the second-stage model for measuring the effects of site attributes); and (2) the analogous three versions for the named site framework. In each case the models were used to construct our index of the quality-adjusted potential for local recreation from each neighborhood. Table 3 summarizes the results for the alternative specifications of our hedonic model. The estimates of the effects for other structural and neighborhood variables were not influenced by which model was used to construct the recreation index. Three conclusions follow from this comparison. First, the characterization of what is a choice alternative does not appear to influence the relevance of both the quality of ecosystem services and local recreation to property values. Second, and equally important, the implementation decisions linking quality to choice alternatives whether hydrologic or named sites are also not important to this conclusion. Finally, the role of quality and access remains influential to housing prices when we reduce the choice set to only the sites visited.

Some caveats should be noted. The relative size of the estimated parameters from the hedonic models across the various formulations used to develop the index for quality-adjusted local recreation does not have a direct interpretation. As we alter the choice set and the choice alternative definition, the marginal effect of a change in water quality also changes. As a result, the realized marginal effect on the indexes will be different. So a direct comparison of how these modeling decisions influence marginal values of the hedonic model is not possible. Equally important, a comparison cannot be made for a given policy scenario because the spatial structure of the recreation-choice model influences how the policy is translated into numerical changes in each model. Thus, the same policies might appear to have different implications due to this translation and not as a result of the effects of the measurement and model implementation issues.

A further qualification stems from the judgments about which water quality measures are important to site choices in the various RUM versions. These conclusions were influenced by the definitions used for the choice alternatives, choice set, and modeling strategy (i.e., the use of fixed effects). The variations in results could be interpreted based on the co-linearity in the pollution measures and the limited degrees of freedom available for some modeling approaches. Nonetheless, it would be a mistake to conclude that all were equally decisive in terms of households' local recreation decisions.[19]

Before turning to the policy analyses used to illustrate the model in the next section, two interrelated qualifications should be noted. First, we do not attempt to compare our estimates with what would be derived from applying a repeated RUM analysis of the same local recreation choices. To do so in an informative way would require some resolution of questions about the time horizon connecting ex ante expectations reflected in the hedonic capitalization with the ex post, single season, orientation of the conventional recreation model. Our quality adjusted index of accessibility is an instantaneous measure of the availability of local recreation. Second, our analysis assumes the changes in quality or in site availability are not large enough to modify the hedonic price equilibrium. We selected examples that seem likely to meet this condition. Larger changes affect whether existing households would want to alter their choices and affect the population induced to enter or leave a region. This latter feature changes the population that is considered as a potential visitor to recreation sites. Thus, the same equilibrium process influencing the hedonic matching has implications for recreation models. It is another reflection of how non-market factors can be involved in limiting who is a market participant and therefore the character of the market equilibrium (see Phaneuf, Carbone, and Herriges 2007 for further discussion).

VIII. POLICY ANALYSES

As we noted at the outset, an important motivation for our model is to expand the range of environmental policies that can be subjected to a benefit-cost analysis. The methodological limits imposed by conventional techniques are especially important for evaluating changes in ecological services related to watersheds. To illustrate how our composite model can be used to address these issues we considered two types of examples. The first stems from the *Raleigh News and Observer*'s lead article on June 30, 2005. It described the rapid growth of several communities in Wake County. Betwee'n 2000 and 2004, the fastest growing town in North Carolina was Morrisville (in western Wake County) with 122% growth. Five towns in Wake County grew by more than one-third during those four years. Such growth can bring water quality problems. To illustrate this point, we adapt the information in this news account to consider how the relationship between water quality and property values would

[19] An appendix available from the authors reports these model estimates.

interact in our model.[20] In related research (Atasoy, Palmquist, and Phaneuf 2006), we have studied the effects of residential construction and residential land use on water quality using spatial econometrics and a micro-panel data set for Wake County.[21] These results can be used to predict the effect on water quality due to the rapid growth in some of these communities. The predicted changes in water quality can then be used in our choice margins model to infer changes in property values. It is, of course, important to acknowledge that this process considers only one effect of growth.

Morrisville on Crabtree Creek grew by 6,376 people between 2000 and 2004 leading to the 122% growth. Morrisville lies in hydrologic unit W15 (a larger spatial aggregate than the CH2MHill zones used here) in Atasoy, Palmquist, and Phaneuf Since the data in that study ended in 1999, the new growth immediately follows the study period. The population growth was converted to new houses dividing by 2.3 persons per residence. This prediction for the increment to housing stock was then converted to new houses per square kilometer in the hydrologic unit to match the variable definition used in the Atasoy, Palmquist, and Phaneuf water-quality model. The spatial econometric results from the water-quality model were then used to predict the change in total phosphorous from the change in housing stock. The additional houses by the end of 2004 are predicted to increase total phosphorous in the hydrologic unit by 30%. It would also be transported to downstream hydrologic units, but the decay is fairly rapid. There would be a 2.1% increase in the next downstream hydrologic unit, and it becomes negligible further from the original change.[22] These predictions are based on the housing stock once construction was complete. Because the rate of construction in Morrisville between 2000 and 2004 was far outside the range of the data used in Atasoy, Palmquist, and Phaneuf we have not predicted the effects of the construction on water quality.

The predicted pollution changes were linked to the CH2MHill zones lying in the affected hydrological zones to analyze the estimated welfare effects of the changes. Column 2 of Table 4 shows the average effect on property values for each of the 19 MLS zones included in the study. These were calculated using the equation [12] and an interest rate of 5% (to annualize the values) for the predicted difference. Assuming the change we consider is sufficiently small that the hedonic price function does not shift, the figures provide an estimate of the annual household-level welfare measure for the water quality reduction. The welfare impacts vary spatially between the MLS zones. The largest effects were about \$16 and \$19 per year in the areas most directly affected and fell to an average of less than a dollar in the zones that were farther removed from the growth. The variability between these two extremes reflects the underlying hydrology and population distribution in the county. The largest effects are found in the areas of the projected growth, population centers near the growth areas, and the downstream neighborhoods.

A second community that is rapidly growing is Wake Forest on Smith Creek, where 4,539 residents were added for 35% growth over the four years. Because of the spatial layout, the houses per square kilometer are substantially lower for Wake

[20] Not all of the areas of rapid growth could be used in these scenarios. The land in some of the communities was in two or more drainage basins, and the reported growth could not be allocated between the basins. Therefore, any scenario would have been based on arbitrary allocations of the growth. This was not true of the growth in Morrisville and Wake Forest, which is discussed below.

[21] In Atasoy, Palmquist, and Phaneuf (2006) we use water-quality monitoring data for total nitrogen, total phosphorous, and total suspended solids over a five-year period. We control for agricultural sources and point sources of pollution. In-stream transport of pollutants is captured by a spatial lag. The variables of primary interest are new residential construction and the existing housing stock.

[22] Atasoy, Palmquist, and Phaneuf (2006) also considered TSS and found that the existing housing stock did not affect TSS, although housing construction did have a significant effect, as expected.

TABLE 4
WELFARE BOUNDS FOR GROWTH SCENARIOS[a]

MLS Zone	Morrisville Growth Scenario ($)	Wake Forest Growth Scenario ($)	Lake Lynn Recreation Scenario ($)	Lake Lynn Amenity Scenario
1	4.27	0.09	12.38	—
2	4.49	0.08	15.81	2.13
3	1.02	0.05	2.81	—
4	3.35	0.01	4.80	—
5	15.73	0.02	3.69	—
6	1.03	0.02	1.88	—
7	3.25	0.20	8.32	—
8	1.33	0.16	4.55	—
9	1.37	0.00	1.47	—
10	18.58	0.00	1.86	—
11	0.54	0.03	1.81	—
12	0.16	0.07	0.53	—
13	0.12	0.06	0.40	—
14	0.30	1.11	1.05	—
15	2.99	0.00	1.52	—
16	0.36	0.01	0.45	—
17	0.88	0.00	0.66	—
18	0.47	0.00	0.88	—
21	0.65	0.60	2.23	—

[a] Average dollars per year per homeowner.

Forest. Most of the growth took place in hydrologic unit W4 in the Atasoy, Palmquist, and Phaneuf study. The increase in houses is predicted to cause a 3.5% increase in total phosphorous in the hydrologic unit. For this scenario the level of construction is comparable to the range of our earlier data, so we can predict the effect of the actual construction of houses on the pollutant loadings as well. If the construction was spread evenly over the four-year period, total phosphorous would increase by 4.5%. New construction also increases total suspended solids and would result in a 3% increase. Finally, in-stream transport would result in a 0.56% increase in TP and a 0.1% increase in TSS in the next hydrologic unit downstream.

Column 3 of Table 4 shows the predicted mean welfare effects of this Wake Forest scenario for the MLS zones in the county. As with the Morrisville scenario, there is substantial variation in the welfare measures across MLS zones. The size, however, is more than an order of magnitude smaller. MLS zones 14 and 21 contain the projected growth and have the largest annual welfare decreases of $1.11 and $.60 per year, respectively.

Our second example uses a different type of scenario that focuses on the amenity effects of a lake on nearby homes. Almost all the lakes in Wake County are manmade. We wanted to consider the impacts that the presence of a lake has for county residents. These impacts take two forms: people with houses close to the lake gain amenities from its proximity, while all residents in the county potentially receive local recreation services. Lake Lynn, in the northern part of the county, was selected as an example for our valuation exercise. The 54-acre lake has both public access and neighboring houses. The lake is large enough that it receives visits, but it is not one of the major reservoirs in the county. It ranks 19th in size of among the 52 officially named lakes in Wake County. The houses close to the lake are fairly typical of those in our sample, with a mean sale price of $213,315 and a range between $117,000 and $368,000 in 1999 dollars.

We consider both the recreation losses and the amenity consequences if Lake Lynn were not available. The mean recreation losses are reported in Column 4 of Table 4. These losses again vary throughout the county and the magnitude depends on the proximity of the MLS zone to the lake, ranging from a mean of about \$16 per year to less than a dollar. On the other hand, the loss in amenity value from having a house that was within one-half mile of Lake Lynn is more localized. Column 5 of Table 4 shows the mean effects of the loss. Since the amenity effects only occur within a one-half mile of the lake, the average effect in the MLS zone is small, about \$2, and there is no effect in the other MLS zones. However, the mean value obscures the magnitude of the impacts on some individuals. The mean loss for houses within one-half mile of the lake is about \$35 per year and the maximum amenity loss at the closest house was estimated at \$266 per year or about \$5,000 in value. By comparison, the individual maximum annual loss of recreation value was \$41.13 for Lake Lynn.

Thus, this example illustrates how urban lakes and streams generate benefits that accrue to a much larger population. Amenities arising from proximity to the resource itself can be much larger for the closest houses, but these are limited in number. This distinction is important because the amenities that are usually measured are related to the nearby homes. However, when recreation is also considered, it is apparent that the aggregate effects of local recreation on property values can dominate these amenity effects.

IX. IMPLICATIONS

There is widespread policy interest in measuring the economic value of enhancements in ecosystem services. Addressing the challenges posed by these policy needs requires methods capable of incorporating the multiple, spatially delineated pathways that these services take in influencing people. Past applications might lead a reader to believe that revealed-preference methods were not up to the task. In this paper, we employ three data sources and a new strategy for linking models to address this problem. This structure demonstrates how recreation site choices and property value data can be used together to gauge how the services provided by an urban watershed are capitalized into housing values. We find evidence that proximity to water resources, access to recreation sites, and the water quality at these sites are positively related to property values. Our analysis exploits a distinction between two choice margins to isolate these effects.

Developing the model required new data collection designed to map housing markets and neighborhoods into the different spatial definitions for the hydrological areas that comprise watersheds. Publicly available data do not have the resolution required to link housing choices, recreation site selections, household characteristics, and watershed attributes. As a result, new data collection activities were required as well as efforts to establish consistency in the geographic roles of economic and hydrologic data. Using the resulting model, we illustrate how to evaluate the environmental costs of rapid suburban housing growth in Wake County. Our policy examples suggest there is substantial variation in the welfare impacts of decreases in water quality, both in magnitude and across space from the different growth scenarios. They also suggest that both the local recreation value and the amenity value of urban watersheds are significant.

At this stage, our analysis provides a proof of concept that consistent use of spatial linkages, together with an assumed hierarchy in individual choices, can help to recover separate roles for several of the environmental services we associate with urban watersheds. Our estimates for the incremental environmental costs of residential growth to existing homeowners are plausible. Nonetheless, these results should be interpreted as a first step in the process of enhancing the spatial dimensionality of non-market valuation methods.

APPENDIX

TABLE A-1
Remaining Variables from Hedonic Estimation Model

Variable	Description	Estimate (*t*-Statistic)
age	Age of structure, calculated as sale year-year built	−0.001 (−18.12)
baths	Number of bathrooms	0.0135 (9.51)
acreage	Lot size in acres	0.0469 (41.37)
regheatarea	Main heated living area in square feet	0.0002 (136.52)
detgarage	Dummy variable indicating presence of detached garage	0.0543 (13.39)
fireplaces	Number of fireplaces	0.0614 (29.55)
deck	Deck area in square feet	0.0001 (19.34)
floordum1	Dummy variable indicating presence of hardwood floors	−0.0099 (−3.26)
scrporch	Screened porch area in square feet	0.0002 (18.12)
atticheat	Attic heated area in square feet	0.0001 (32.69)
bsmtheat	Basement heated area in square feet	0.00007 (16.3)
garage	Garage area in square feet	0.0002 (57.03)
poolres	Dummy variable indicating presence of residential swimming pool	0.0309 (4.4)
bsmtdum1	Dummy variable indicating presence of full basement	0.0973 (26.2)
bsmtdum2	Dummy variable indicating presence of partial basement	0.0928 (26.92)
walldum1	Dummy variable indicating presence of brick walls	0.012 (5.49)
yrdum99	Dummy variable for 1999 sale	0.026 (19.62)
encporch	Enclosed porch area in square feet	0.0002 (10.29)
opnporch	Open porch area in square feet	0.0001 (16.83)
condadum	Dummy variable indicating house is of condition A (highest)	0.0948 (27.08)
condcdum	Dummy variable indicating house is of condition C	−0.1054 (−24.49)
condddum	Dummy variable indicating house is of condition D	−0.2388 (−18.26)
commute	2000 census block mean commute time	0.0018 (15.48)
grade	Numeric grade assessed by revenue department	0.0063 (122.28)
value	Median house value for 2000 census block group	8.00E-07 (49.58)
percent	Percentage owner occupied housing in 2000 census block group	−0.0001 (−3.94)
taxrate	Property tax rate per $100 in value	0.0226 (6.33)
Constant		10.332 (913.56)
R-squared	0.926	
Dep. variable	ln(price)	
Number of observations	26,305	

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