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The Spatial Extent of Water Quality Benefits in Urban Housing Markets

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Abstract: Federal efforts are increasingly targeting surface water quality in urban watersheds throughout the U.S., as demonstrated by recent litigation between the EPA and the State of Florida. While the cost of achieving federal standards is ultimately borne by taxpayers, pollution abatement may generate diverse and wide-reaching taxable benefits. This study investigates the effects of enhanced water quality on property prices in urban housing markets. Hybrid specifications of hedonic price models employed in water quality and proximity valuation studies are estimated, and several hypotheses about the implicit value of water quality are tested. Findings indicate i) the value of increased water quality depends upon surface water size and declines rapidly as proximity to the waterfront diminishes, though the mean effect remains significant at several hundred meters; and ii) when housing density is considered, the aggregate benefits derived in the broader housing market may dominate those realized by waterfront homeowners.

KEYWORDS: Hedonic pricing; water quality; pollution abatement, proximity, amenity value
Subject Areas: Water Pollution, Valuation Methods, Benefit-Cost Analysis

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I. Introduction

The Clean Water Act (CWA) has directed billions of dollars into the management of US surface waters since 1972. Despite these expenditures, nearly 50 percent of rivers and streams and 66 percent of lakes and reservoirs in the U.S. were classified as impaired for one or more uses in 2009 (U.S. Environmental Protection Agency, 2010a). Section 303(c) of the Clean Water Act (CWA) directs states to adopt water quality regulations to protect designated uses of water bodies, but relatively little is known about the potential benefits because the impacts are diverse, non-market in nature, and require site-specific information. The benefits derived from recreational usage of water bodies (swimming, fishing, and boating) have typically been estimated with travel cost models and contingent valuation surveys (e.g. Morgan and Owens, 2001; Iovanna and Griffiths, 2006; Van Houtven et al., 2007; Viscusi et al., 2008; Egan et al., 2009). While the open-space amenity value of proximity to surface waters in residential housing markets has been well-documented (e.g. Palmquist and Fulcher, 2006), the property price effects of improvements in the aesthetic, recreational and ecosystem services related to enhanced water quality have received limited attention in policy studies of water management programs.

The use of hedonic property models for measuring the price effects of changes in environmental quality has been extensive (Palmquist, 2005). In the case of water resources, several studies over the years have reported that water quality significantly affects waterfront property prices. However, the methodology remains under-utilized for analysis of water management programs, as noted by Palmquist and Smith (2001) nearly a decade ago. One conjecture is that the size and extent of the housing market impacts are small by comparison to the surplus effects realized by the population of recreational users (Olmstead, 2010). Thus, it may suffice to consider the latter in assessing the benefits of water management programs, though there is little evidence supporting or rejecting this conjecture in the literature. While recreational use benefits may dominate in rural areas with low housing density, this relationship is more uncertain in urban housing markets.

Concerns regarding the spatial distribution of the welfare effects of pollution abatement in residential housing markets are analogous to those of market extent (or scope) in the recreation demand and contingent valuation literatures (Smith and Kopp, 1980; Sutherland and Walsh, 1985; Smith, 1993; Bateman et al., 2006; Vajjhala et al., 2008). Similarly, the spatial distribution of welfare effects has been an important theme in hedonic property studies of air quality (Boyle and Kiel, 2001; Bayer et al., 2009) and proximity to hazardous waste sites in residential housing markets (Mendelsohn et al., 1992; Jackson, 2001; Deaton and Hoehn, 2004; Cameron, 2006). If the property price effects of pollution abatement span beyond the waterfront, then measuring their spatial extent is critical for measuring the aggregate benefits of water management programs.

Several questions arise regarding the spatial extent of the benefits of water pollution abatement in residential housing markets. The present study formalizes three of these as hypotheses that are tested through hedonic price models. First, are there *edge* effects from improvements in water quality, whereby waterfront properties benefit from their unique location on the boundary separating the water body from developed areas? Second, are there *proximity* effects, whereby the marginal value of water quality diminishes as distance to the affected water body increases? And if so, then how far do the effects extend into surrounding areas? Third, are there *size* effects, whereby the price effects of abatement efforts are dependent upon the size of the water body? While these remain open issues in the literature, the generation of edge, proximity, and size effects through public expenditures on water quality management may have broader policy implications for state and federal efforts to establish water quality standards and the funding for these programs.

Estimating the marginal value of surface water quality and testing for edge, proximity and area effects require data on a relatively large number of water bodies and sufficient variation in water quality over the study area and sample period. However, in moving beyond the waterfront there must also be sufficient variation in the proximity of properties to the waterfront and of the size of the lakes within the housing market. To satisfy these data requirements, the present study employs a unique dataset containing 54,000 property sales distributed around more than 125 monitored lakes in a metropolitan housing market (Orange County (Orlando), Florida) over the period 1996-2004.

The remainder of the paper is organized as follows. Section II reviews the hedonic studies of water quality and proximity valuation. In section III the edge, proximity, and size effect hypotheses are formalized along with the applicable marginal implicit prices. Section IV describes the study area and summarizes the property sales and water quality datasets used in estimation. After conducting joint tests of spatial dependence and functional form, the estimated spatial-hedonic models and marginal implicit prices are presented in Section V. Results indicate that i) the value of increased water quality depends upon surface water size and declines rapidly as proximity to the waterfront diminishes, though the mean effect remains significant at several hundred meters; and ii) when housing density is considered, the aggregate benefits derived in the broader housing market may dominate those realized by waterfront homeowners. Section VI concludes with a discussion of the policy implications and avenues for future research.

II. The Hedonic Valuation of Water Resources

The hedonic pricing model was formalized in early work by Griliches (1971) and Rosen (1974) and has been refined over the years for characterizing the prices of competitively traded heterogenous goods (Ekeland et al., 2004; Parmeter and Pope, 2009). In the case of residential housing markets, the goods are a composite of the attributes of the physical property and surrounding landscape that can be exchanged at prices reflecting aggregate market conditions. Hedonic models have a long history for estimating the effects of spatially distributed environmental goods and bads on residential property values, spanning from air and water pollution to hazardous waste to the recreational access and open-space aesthetics provided by public lands and water resources; see Boyle and Keil (2001), Palmquist and Smith (2001), and Palmquist (2004) for reviews.

Two themes have prevailed in hedonic studies of water resources. The first is that, similar to air pollution, the degradation of surface waters can depreciate surrounding property values. Research efforts have mostly focused on estimating the benefits of water quality for waterfront properties on lakes and rivers. David (1968) was the first to investigate the relation between the sales prices of lakefront properties and subjective, qualitative ratings of water quality (poor, moderate, and good) in Wisconsin and found mean prices were positively related to higher water quality. Subsequent studies by Brashares (1985), Michael et al. (2000), Poor et al. (2001), Gibbs et al. (2002), Krysel (2003) and Horsch and Lewis (2009) all reported that lakefront property prices were positively related to various measures of water quality with water clarity (Secchi disk) the most commonly used indicator.[1] Similar relationships were reported by Epp and Al-Ani (1979) and Leggett and Bockstael (2000) for riverfront property prices although the water quality indicators were more diverse reflecting the broader range of pollutants, sources and political jurisdictions (Sigman, 2002) that may impact these water bodies.

The second theme in the literature is that surface waters provide open-space, recreational use, and aesthetic values that are capitalized into the sales prices of residential properties in proximity to a waterbody. Brown and Pollokowski (1977), Milon, Gressel, and Mulkey (1984), Lansford and Jones (1995), and Anderson and West (2006) all report positive amenity values from proximity to a water body and these values extend several hundred meters into the surrounding neighborhood. Palmquist and Fulcher (2006) and Cho et al. (2009) also report positive price effects for proximity to a water body but they note that the magnitude of these effects may vary over time.

While the literature over the past forty years has consistently shown that surface waters produce amenity values that are capitalized into residential property prices, water quality and proximity valuation studies have typically been conducted independently of one another. The few exceptions relied on water quality data that were aggregated over sites so that individual differences across water bodies could not be identified. Dornbush and Barrager (1973) evaluated the impact of pollution abatement programs on residential properties in areas adjacent to water bodies in four states over the period 1960 - 1970. They concluded that abatement in highly polluted water bodies increased property values hundreds of meters from the waterfront. Poor et al. (2007) estimated a hedonic model using property sales in a county adjacent to the Chesapeake

Bay. Marginal implicit prices were significantly related to ambient pollutant concentrations (total suspended solids and dissolved nitrogen) across the watershed. Phaneuf et al. (2008) developed a model combining stated and revealed preferences of residential homeowners for urban surface water quality using a ‘recreation access index’ adjusted for ambient water quality within a watershed as an explanatory variable in the hedonic model. Findings for a sample of North Carolina homeowners indicated that the mean price of non-waterfront properties was significantly related to recreational access. None of these studies, however, identified the differences in water quality effects for waterfront and non-waterfront properties or how the water quality effects vary with proximity to specific water bodies.

While there is evidence that pollution abatement can have wide-reaching effects on residential property prices, the potential impacts of water quality changes have not been fully evaluated using the hedonic pricing model. The results from such applications could have significant practical information for cost-benefit analysis of water management programs in compromised watersheds. A timely example is the January 2010 proposal by the US EPA to establish numeric nutrient standards for surface waters in the State of Florida to meet the requirements of Section 303(c) of the Clean Water Act (EPA, 2010b).[2] The State of Florida, like many other states, has a large proportion of lakes, rivers and estuaries that are impaired by nutrients that impact aquatic life, ecosystem health, and the various benefits provided by these water resources (Florida Department of Environmental Protection, 2008; State-EPA Nutrient Innovations Task Group, 2009). Understanding the spatial extent and magnitude of benefits from water quality improvements in specific water bodies is necessary to evaluate alternative standards and to design strategies to fund implementation programs.

III. Hypotheses and Model Specification

This study focuses on the relationship between water quality in lakes and the related property price effects in the metropolitan Orange County, FL housing market. In this section, the hypotheses are presented and hedonic property price models that nest the hypotheses are specified for estimation and inference in the next section. The hypotheses are:

H^1: *The Edge Effect*: The mean marginal implicit value of surface water quality differs between waterfront properties and properties located off the waterfront, other factors held constant.

H^2: *The Proximity Effect*: The mean marginal implicit value of surface water quality diminishes as the property distance to the waterfront increases, other factors held constant.

H^3: *The Size Effect:* The mean marginal implicit value of surface water quality is an increasing function of the size of the water body, other factors held constant.

The hypotheses propose that the marginal value of enhanced surface water quality depends on the type and location of the property and the landscape covered by the surface water. The first postulates that waterfront properties benefit from their unique location relative to properties located off the waterfront. The second postulates that the benefits realized by non-waterfront properties depend on their distance from the waterfront. And the third postulates that the marginal value depends on the size of the surface water.

To specify the hedonic property model and related implicit prices, we assume households are freely mobile to choose housing bundles that maximize utility over structural characteristics, environmental amenities, and other locational attributes within the Orange County housing market (Kuminoff, 2009). To allow the implicit price of water quality to vary between properties and between water bodies, water quality enters the property price model through multiple interaction variables. The model is specified as double-log, as discussed later in the section, and the surface waters are defined as naturally occurring lakes. The model is written:

$$\begin{aligned} \ln(Price) = \beta_0 + \beta_1 Lakefront + \beta_2 \ln(WQ) + \beta_3 Lakefront * \ln(WQ) + \beta_4 \ln(Distance) + \\ \beta_5 \ln(Distance) * \ln(WQ) + \beta_6 \ln(Area) * \ln(WQ) + \gamma' X + \varphi' Z + \psi' L + \delta' T + \varepsilon \end{aligned} \quad (1)$$

where *Price* references the sales price; *Lakefront* is a dummy variable distinguishing lakefront from non-lakefront properties; *WQ* is a continuous measure of water quality in the nearest lake at the time of sale; *Distance* is a measure of the property proximity to the waterfront; and *Area* is the surface water coverage of the nearest lake. The terms ***X*** and ***Z*** are vectors of property attributes and landscape attributes, and ***L*** and ***T*** are vectors of dummy variables to control, respectively, for unobserved effects of individual lakes and time periods.

The marginal implicit values of the property attributes are obtained by partially differentiating (1). In the case of water pollution, the desired value is the change in the expected property price caused by a change in water quality. The expected marginal value may be written:

$$\frac{\partial E(Price)}{\partial WQ} = \frac{E(Price)}{WQ}\left(\beta_2 + \beta_3 Lakefront + \beta_5 \ln(Distance) + \beta_6 \ln(Area)\right) \quad (2)$$

The implicit value is a function of the hypothesized edge, proximity, and size effects. The edge effect hypothesis entails a test of the null H_0: $\beta_3 = 0$. Positive edge effects exist if $\beta_3 > 0$, and other factors held constant, the lakefront premium of a unit increase in water quality is equal to

$\beta_3 Price/WQ$. The proximity and size effects depend, respectively, upon β_5 and β_6. Partially differentiating (2), the size of the proximity effect at a given distance from the nearest lake may be expressed:

$$\frac{\partial^2 E(Price)}{\partial WQ \partial Distance} = \beta_5 \frac{E(Price)}{WQ * Distance} \tag{3}$$

The proximity effect entails a test of the null H_0: $\beta_5 = 0$. Positive proximity effects exist and the marginal value diminishes at a non-constant rate as distance to the waterfront increases if $\beta_5 < 0$. Similarly, the effect of surface water size on the marginal implicit value may be written:

$$\frac{\partial^2 E(Price)}{\partial WQ \partial Area} = \beta_0 \frac{E(Price)}{WQ * Area} \tag{4}$$

The size effect entails a test of the null H_0: $\beta_6 = 0$. Positive size effects exist and the marginal value increases with waterbody size if $\beta_6 > 0$. Given available data, the parameters and covariance matrix may be estimated in order to test the three hypotheses and to estimate the relationships between water quality and property prices summarized in (2)-(4).

Two final modeling issues are potential spatial autocorrelation and functional form specification. Spatial autocorrelation can be induced by unobserved neighborhood and landscape attributes common to property sales located within close proximity to one another, as well as the influence of recent nearby property sales. This concern has been raised in several hedonic property studies, with spatial lag and spatial error econometric models estimated to test and correct for spatial dependence in the errors.[3] The findings are mixed, with some studies reporting improvements in fit (Gelfand et al., 2004; Case et al., 2004) and others reporting results that are robust to the error specification (Leggett and Bockstael, 2000; Kim et al., 2003; and Muller and

Loomis, 2008). For completeness, estimation is performed under the null of zero spatial correlation and with the spatial lag specification. An inverse distance-based spatial weights matrix required for estimation of the spatial lag model is defined for property sale *i* as all sales located within 200 meters of *i* that occurred 6 months before or 3 months after the sale of *i*.[4] The functional form of the regression also must be specified. While there is no theoretical basis for the functional form, Cropper et al. (1988) suggest that semi-log and double-log models are superior to more complicated models in the face of mis-specification and proxy variables. Both regular Box-Cox tests and spatially-robust Box-Cox tests using double-length regression (DLR) tests (Le and Li (2008) and Le (2009)) favored the double-log specification appearing in expression (1).

IV. Data and Estimation Results

A. Data

The urban housing market is defined as Orange County (Orlando), Florida. The county contains more than two hundred natural lakes, and more than one hundred thousand property sales occurred over the 1996-2004 sample period.[5] The sales data were obtained from the Orange County Property Appraiser (OCPA) and were restricted to single-family residences. The data include detailed property information, such as historic sales prices, dates of construction and permitted improvements, the sizes of the structure and parcel, and the number of bedrooms and bathrooms. The data were geo-coded and overlaid in GIS with a shape file from the Orange County Environmental Protection Division (OCEPD) describing all lakes in the county. Lakefront and non-lakefront properties were identified, and the distance between the centroid of each property and the edge of the nearest lake was measured. All single-family residential property sales located within 1,000 meters of a lake (35% of all residential sales) were retained for estimation, yielding a dataset containing 1,496 lakefront and 53,216 non-lakefront sales around 146 natural lakes.[6]

The water quality data were obtained from the OCEDP and three municipalities. The data contain annual average concentrations of nitrogen, phosphorous, and dissolved oxygen and the Secchi depth of the lakes. Consistent with several studies discussed in section II and for ease of interpretation, water quality is proxied by Secchi depth.[7] The water quality data were merged with the sales data, and properties that sold in a given calendar year were assigned the mean annual Secchi depth at the nearest lake. Lastly, the data were merged with block level socio-demographic variables from the 2000 Census to control for attributes of the neighborhood and surrounding landscape.

Summary statistics on the property sales data are reported in Table 1. Lakefront and non-lakefront properties on average had similar numbers of bedrooms and bathrooms, but the lakefront properties were larger and older and sold for greater amounts. The mean waterfront sale was located on a lake covering about 520 acres, whereas the mean non-waterfront sale was located about 470 meters from a lake covering about 280 acres.[8] In both cases the mean sale was located about 5.5 miles from downtown Orlando. The geo-coordinates of the properties are also included as regressors. As demonstrated by Cameron (2006), these control for property location within the housing market and also allow location effects to be tested. Neighborhood controls include the block-level median household income and proportions of the population that were Caucasian, African-American, and over 65 years of age. Lastly, Table 1 summarizes the distribution of sales over the sample period; overall, similar proportions of lakefront and non-lakefront properties sold annually.

Summary statistics on the lake and water quality data are summarized in Table 2. The number of lakes varies annually from 125 to 146, reflecting missing annual water quality records at several lakes.[9] The mean annual Secchi depth is consistently about 5 feet over the sample period and ranges from about one foot to more than eighteen feet over the lakes. Table 2 also summarizes the composition of the lakes by their surface water acreage. Similar to Secchi depth, the amount of landscape covered by the lakes varies considerably over the sample. The average lake covered about 250 acres and the lakes range in size from about one acre to more than 1,800 acres.

B. Estimation Results

Maximum likelihood estimates of three versions of the hedonic property price model specified in (1) are reported in Table 3.[10] The first (Model 1) includes water quality and property distance as separate regressors and imposes exclusion restrictions on the proximity and size effect coefficients ($\beta_5 = \beta_6 = 0$). The second (Model 2) relaxes the proximity effect restriction by adding the interaction variable *ln(Secchi Depth)*ln(Distance)* but maintains the restriction upon the size effect ($\beta_6 = 0$). And the third specification (Model 3) adds the size effect interaction variable *ln(Secchi Depth)*ln(Area)* and corresponds to the unrestricted version of the model expressed in (1). The respective specifications of the spatial lag models are referenced by Model 1S, Model 2S, and Model 3S in Table 3.

The results in Table 3 indicate that the coefficient estimates are robust to the error specification and the spatial lag coefficient (ρ) is small but significant in Models 1S-3S.[11] The estimated *Lakefront* coefficients indicate a significant price premium is derived from being located on the waterfront. Considering the interaction variable *ln(Secchi Depth) *ln(Lakefront)*, the null of zero edge effect H_0: $\beta_3 = 0$ is rejected at the 1% level in all cases, indicating that the mean marginal value of surface water quality differs significantly between lakefront and non-lakefront properties. The proximity effect hypothesis entails a test of the null H_0: $\beta_5 = 0$ associated with the interaction variable *ln(Secchi Depth)*ln(Distance)* in Models 2 and 3. As shown in Table 3, the estimated coefficients are negative across all model specifications, and the null of zero proximity effect is rejected at the 1% level in all cases. Note also that the distance coefficients alone are negative and significant in Models 2 and 3 indicating that both proximity to a lake and the water quality in the lake are important. Finally, the size effect hypothesis for the null H_0: $\beta_6 = 0$ associated with the variable *ln(Secchi Depth)*ln(Area)* is rejected at the 1% level. The amount of landscape covered by the surface water has a significant positive effect on the marginal implicit value of water quality.

In addition, note at the bottom of Table 3 the importance of controlling for individual lake- and time-specific effects across model specifications. For example, 94 (95) of the 145 lake-dummy coefficients and all eight of the time-dummy coefficients were significant in Model 3 (Model 3S) at the 1% level.[12] Table 3 also shows that property location within the county can affect property prices as indicated by the significant *ln*(*Latitude*) and *ln*(*Longitude*) coefficients. To test whether the price effects of surface water quality also depend upon the location of the property, Models 3 and 3S were re-estimated with interactions between Secchi depth and the geo-coordinates of the property (expressed as natural logs). Results in both cases indicated that the null of zero location effect could be rejected at the 1% level. These results strongly indicate that water quality effects on property prices are dependent on the physical and locational characteristics of each water body.

V. The Implicit Value of Urban Water Quality

The estimation results indicate that the amenity value of water quality depends on the type and location of the property and the size of the surface water. In this section, the models are used to estimate the implicit value (marginal willingness to pay (MWTP)) of increased water quality for representative lakefront and non-lakefront properties and the aggregate benefits for all properties surrounding three lakes. In the process, the lakefront premium and the proximity and size effects of water quality are estimated.

Estimates of the expected marginal value of a one foot increase in Secchi depth (approximately 17% from the mean) are obtained from Models 3 and 3S by substituting the sample means of the independent variables and estimates of the respective coefficients and of $E(Price \mid \boldsymbol{X})$ into expression (2).[13] Given the double-log specification, $E(Price \mid \boldsymbol{X}) = \prod_{j=1}^{k} X_j^{\beta_j} E(e^{\varepsilon})$. Estimates are obtained using the smearing approach proposed by Duan (1983).[14]

Beginning with the edge effect in Table 4, the results indicate that a unit increase in Secchi depth is associated with about a \$5,500 (or 1.2%) increase in the price of the mean lakefront property versus about a \$700 (or 0.3%) increase in the price of the mean non-lakefront sale. Thus, whether viewed in absolute or relative terms, enhanced surface water quality has a notably larger impact on lakefront property prices.

The mean proximity effect of a one meter increase in distance to the waterfront on the marginal implicit price was estimated in 200 meter increments from the waterfront. As reported in Table 4, the mean effect realized by properties located immediately beyond the waterfront was small in absolute and relative terms compared to waterfront properties and diminishes rapidly as distance from the waterfront increases. For example, the mean implicit price decreases by about one-fourth in moving from 100 to 200 meters from the waterfront. At 600 meters the implicit value has fallen by more than fifty percent, and at 1,000 meters it is about one-sixth of the value. Thus, while there is a significant distance gradient, positive price effects extend hundreds of meters into the surrounding community.[15]

The mean size effect of a one acre increase in lake size on the marginal implicit price can also be evaluated. The final section of Table 4 compares the estimated mean implicit price between lakefront and non-lakefront properties surrounding lakes covering 100 acres and 1,000 acres. Results for waterfront properties indicate that a marginal change in lake size has a small positive effect on the implicit value of water quality: a tenfold increase in lake size is associated with about a $1,000 (or 20%) increase in the marginal implicit price. In contrast, relatively larger size effects are found to be realized by non-waterfront properties, with the mean implicit price differing about $700 (or 300%) between the 100 acre and 1,000 acre lakes.

Overall, enhanced surface water quality positively impacts the price of properties located throughout the study area. Although the price effect for the mean sale occurring off the waterfront is smaller relative to the mean waterfront sale, residential housing surrounding public waters can be relatively dense in urban watersheds. It follows that the aggregate benefits could in fact exceed those realized by waterfront properties. To illustrate this point, the aggregate effects of a one foot increase in Secchi depth are estimated for three representative lakes that vary in size and water clarity: in 2004, Lake Silver covered 70 acres and had a Secchi depth of 5.8 feet; Lake Mann covered 271 acres and had a Secchi depth of 2.2 feet; and Lake Conway covered 1,625 acres and had a Secchi depth of 10.5 feet. The location of all lakefront properties and non-lakefront properties located within the 1,000 meter boundary around each lake was identified and the distance between each property and the respective lake was measured using the geo-coded tax role described in section III. The marginal implicit price of a one foot increase in Secchi depth was estimated for each property using Model 3S and then summed across properties to estimate the aggregate benefits.[16]

Table 5 describes the characteristics of the lakes and the number of homes in the surrounding community and reports estimates of the aggregate price effects. For comparison, estimates are reported separately for lakefront properties and non-lakefront properties located within 500 meters and 1,000 meters of the respective lake. The number of lakefront properties around each lake is a small fraction of the total properties; for example, about 5%, 8%, and 16% of all properties located within 500 meters of Lakes Mann, Silver, and Conway, respectively, are lakefront properties. Despite the small fraction of total properties, the aggregate benefits for lakefront properties are comparable to properties within 500 meters at Lake Silver and larger in Lake Conway, but they are only one-third of the aggregate benefits within 500 meters at Lake Mann. At 1,000 meters, however, the estimated benefits derived collectively by the non-lakefront properties exceed the lakefront benefits in all three lakes. Thus, the individual benefits of water quality improvements vary within the urban watershed, and the total benefits could be considerably underestimated if only waterfront properties are defined as the beneficiaries of pollution abatement programs.

VI. Discussion and Conclusions

Water quality remains a significant public concern in the United States despite long-standing federal and state laws to regulate and control pollution from point and nonpoint sources. A sizable percentage of all water bodies are classified as impaired but the full extent of the problem is not known because only one-quarter of all rivers and streams and approximately 40 percent of lakes and reservoirs have been assessed (U.S. Environmental Protection Agency, 2010a). In some water bodies, habitat degradation may be a more important source of impairment than pollutants (U.S. Environmental Protection Agency, 2009). Recent efforts to expand and strengthen water quality improvement programs using total maximum daily loads (TMDLs) and numeric water quality standards (e.g. State-EPA Nutrient Innovations Task Group, 2009) are hindered by the limited information on the potential benefits for specific water bodies. The benefits of improved water quality accrue in the form of enhanced recreation, aesthetic enjoyment, and ecosystem services. In past literature, it was assumed that water quality benefits were enjoyed primarily by waterfront property owners and recreational users. This article explored the extent of property owner benefits by including both lakefront and non-lakefront homes in a large spatial hedonic analysis across multiple lakes in a metropolitan setting.

Three hypotheses about the effect of water quality on surrounding residential properties were tested using water clarity (Secchi disk) as the indicator of water quality. First, a waterfront edge effect supported previous studies that identified an increasing price premium for residing next to a water body with cleaner water. Second, the proximity effect established that property prices around a water body reflect both the value of residing closer to the water body and to water with a higher quality. This result should not be surprising, but previous research has not directly tested the effect of water quality on the value of proximity. Third, the area of a lake also affects the implicit price, with water quality in larger lakes valued more than water quality in smaller lakes. Overall, the results of this article provide considerable evidence that non-lakefront property owners are impacted by water quality changes in nearby water bodies and these impacts should be integrated in future hedonic property analyses in which proximity to surface waters is an environmental amenity.

These results also provide several important policy implications. One of the main objectives of environmental amenity valuation is to inform cost benefit analysis. In two of the three examples of the implicit value of water quality improvements (Table 5), including the gains to non-lakefront properties would more than double the total estimate of water quality benefits. The non-lakefront component represents a considerable share of the total benefits and indicates that restricting the analysis to waterfront homes alone would understate the value of water quality improvements for the surrounding community.

Furthermore, the shape and magnitude of the implicit price gradient for water quality could be used to design more effective funding mechanisms for water quality management programs. These programs typically require sources to incur costs to limit emissions into a water body or rely on general revenues to provide financial incentives (State-EPA Nutrient Innovations Task Group, 2009). In the case of water bodies with surrounding residential communities, property tax levies that reflect underlying implicit prices for water quality improvements could be used to fund management programs. For example, one taxing mechanism for lake improvement activities in Orange County, FL is a municipal service taxing unit (MSTU) fee as part of the property taxes for each home in a neighborhood surrounding a lake. These MSTU fees are similar to recycling collection and fire protection service fees and are instituted through a majority vote by the neighborhood. If approved, every home in the MSTU faces the same ad valorem property tax increase.[17] If the MSTU is smaller than the surrounding community receiving benefits from water quality improvements, there is the problem of free riding by those outside the MSTU. If the MSTU is large, those at the periphery may be disproportionally taxed in relation to the differential that could be attributed to property price appreciation from improved water quality. It would be more efficient to tax homes proportional to the underlying implicit values for water quality improvements based on lake proximity and waterfront status. A more efficient tax structure may also increase participation in MSTU programs.

Alternatively, property price appreciation from improved water quality will yield additional municipal property tax revenues if appraisal values reflect market conditions and tax rates do not change. The incremental tax revenues provide a funding source for water quality management programs and suggest that these programs may be self-financing in metropolitan settings where the welfare gains are spread across the community.

While this article provides new evidence on the spatial distribution of water quality benefits in an urban setting, two concerns remain that should be addressed by future research. First, this study has only used water clarity as the indicator of water quality. Other indicators that are more often used for setting water quality standards such as nutrient levels or trophic state may imply different implicit price gradients and benefits (e.g. Walsh, 2009, Ch. 2). Second, urban housing markets are complex, multidimensional surfaces that can only be approximated by parametric functional forms and price gradients. Future research should consider alternative estimation methods that address the interplay between spatial amenities and housing preferences as well as the potential sorting of home owners across neighborhoods as a response to the presence of water bodies with different levels of water quality.

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Table 1. Summary Statistics on Residential Property Sales in Orange County, Florida: Lakefront and Non-Lakefront Homes (1996-2004)

		Lakefront (N =1,496)		Non-Lakefront (N =53,216)	
Variable	Units	Mean	Standard Deviation	Mean	Standard Deviation
Property Characteristics					
Sales Price	2002 Dollars	452,646	370,668	199,982	201,111
Heated Area	Square Feet	2,770	1,296	1,962	950
Area of Parcel	Square Feet	30,002	30,488	11,581	11,737
Number of Bedrooms	--	3.6	1.0	3.3	0.8
Number of Bathrooms	--	2.8	1.1	2.2	0.9
Home Age	Years	24.1	13.5	18.6	15.1
% With Pool	--	20.1	---	20.7	---
Spatial Characteristics					
Distance to Nearest Lake	Meters	42.4	23.7	467.1	267.7
Area of Nearest Lake	Acres	519.3	635.2	278.1	445.2
Distance to CBD	Meters	8,824	5,124	9,266	5,150
Latitude Coordinate	Degrees	654,757	7,415	653,224	7,941
Longitude Coordinate	Degrees	505,616	5,124	505,665	6,272
Census Block Characteristics					
% of Population White	--	88.6	--	77.9	--
% of Population Black	--	4.9	--	12.5	--
% of Population > 65	--	15.2	--	11.1	--
Median Household Income	2002 Dollars	67,355	30,343	58,876	24,863
Distribution of Sales by Year					
% of sales in 1996	--	10.4	--	9.2	--
% of sales in 1997	--	11.1	--	10.9	--
% of sales in 1998	--	12.9	--	12.1	--
% of sales in 1999	--	14.0	--	13.4	--
% of sales in 2000	--	11.0	--	11.4	--
% of sales in 2001	--	8.9	--	9.9	--
% of sales in 2002	--	11.3	--	9.9	--
% of sales in 2003	--	11.0	--	11.0	--
% of sales in 2004	--	9.4	--	12.2	--

Table 2. Summary Statistics on Orange County Lakes Over the Sample Period

		Secchi Depth (Feet)		Lake Size (Acres)	
Year	Lakes	Annual Mean	Standard Deviation	Annual Mean	Standard Deviation
1996	143	5.86	3.45	247.59	409.56
1997	146	6.18	3.73	233.36	395.20
1998	144	5.23	2.81	250.47	415.62
1999	146	5.25	3.04	261.55	433.89
2000	137	5.23	3.20	212.77	376.90
2001	134	5.27	2.84	279.12	437.90
2002	126	4.95	2.90	376.70	533.05
2003	129	5.23	2.69	380.08	530.39
2004	125	5.33	2.69	329.64	489.73

Table 3. Selected Hedonic Estimation Results

Dependent Variable: Ln(*Price*)	Model 1		Model 2		Model 3		Model 1S		Model 2S		Model 3S	
Independent Variables	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE
Lakefront	0.087*	0.026	0.143*	0.028	0.146*	0.028	0.087*	0.019	0.143*	0.020	0.146*	0.020
ln(*Distance*)	-0.062*	0.002	-0.035*	0.004	-0.035*	0.004	-0.062*	0.001	-0.035*	0.004	-0.035*	0.004
ln(*Secchi Depth*)	0.017*	0.003	0.117*	0.017	-0.028	0.032	0.017*	0.004	0.118*	0.014	-0.030	0.031
ln(*Secchi Depth*)**Lakefront*	0.116*	0.015	0.080*	0.016	0.078*	0.016	0.116*	0.010	0.081*	0.011	0.079*	0.011
ln(*Secchi Depth*)**ln*(*Distance*)	---	---	-0.017*	0.003	-0.017*	0.003	---	---	-0.017*	0.002	-0.017*	0.002
ln(*Secchi Depth*)**ln*(*Area*)	---	---	---	---	0.011*	0.002	---	---	---	---	0.012*	0.002
ln(*Latitude*)	-0.627*	0.106	-0.629*	0.106	-0.644*	0.106	-0.634*	0.011	-0.636*	0.003	-0.651*	0.053
ln(*Longitude*)	0.369*	0.070	0.351*	0.070	0.339*	0.069	0.376*	0.066	0.358*	0.066	0.346*	0.067
Spatial Lag Coefficient (ρ)	---		---		---		0.001*	0.000	0.001*	0.000	0.001*	0.000
Lake Fixed Effects	Yes		Yes		Yes		Yes		Yes		Yes	
Coefficients Significant at 1%	98		113		112		104		104		91	
Time Fixed Effects	Yes		Yes		Yes		Yes		Yes		Yes	
Coefficients Significant at 1%	8		8		8		8		8		8	
Pseudo R^2	0.893		0.894		0.894		0.893		0.893		0.893	

Notes: *, **, and *** denote significance at the 1%, 5%, and 10% levels. The full set of estimation results is available in an appendix upon request.

Table 4. Estimated Mean Marginal Implicit Prices of Increased Water Clarity (2000 Dollars)

Scenario: One Foot Increase in Secchi Depth	Model 3	Model 3S
Edge Effects		
Lakefront Properties	$5,594.80	$5,663.08
	(573.75)	(411.89)
Non-Lakefront Properties	717.50	728.23
	(126.34)	(124.23)
Proximity Effects		
100 Meters from Lake	1,440.96	1,460.46
	(172.64)	(147.72)
200 Meters from Lake	1,115.64	1,131.20
	(141.96)	(129.03)
400 Meters from Lake	790.32	801.94
	(126.89)	(123.43)
600 Meters from Lake	600.02	609.34
	(127.78)	(127.09)
800 Meters from Lake	465.00	472.68
	(132.87)	(132.59)
1,000 Meters from Lake	360.27	366.68
	(139.08)	(138.33)
Size Effects		
Lakefront Properties		
100 Acre Lake	4,908.61	4,959.93
	(558.74)	(392.28)
1,000 Acre Lake	5,867.79	5,942.83
	(588.21)	(430.73)
Non-Lakefront Properties		
100 Acre Lake	396.72	400.01
	(97.47)	(103.49)
1,000 Acre Lake	1,118.75	1,138.80
	(187.48)	(178.70)

Table 5. Aggregate Property Price Effects of a 17 Percent Increase in Secchi Depth at 3 Selected Lakes

	Lake Characteristics		Lakefront Properties		Non-Lakefront Properties: Within 500 Meters of Lake		Non-Lakefront Properties: Within 1000 Meters of Lake	
Lake Name	Size (Acres)	Secchi Depth (Feet)	Total Properties	Aggregate Benefits	Total Properties	Aggregate Benefits	Total Properties	Aggregate Benefits
Silver	70	5.8	62	$971,452	695	$728,822	1,928	$1,079,068
Mann	271	2.2	63	$698,144	1,254	$1,991,001	2,635	$3,219,550
Conway	1,625	10.5	669	$5,441,246	3,414	$5,057,007	6,300	$7,433,382

Appendix A. The Distribution of N = 53,216 Non-Lakefront Property Sales within 1,000 Meters of a Lake

Distance to Nearest Lake	Number of Property Sales	% of Total Sales	Cumulative % of Total Sales
< 100 meters	3,344	6.28	6.28
100 to 200 meters	7,005	13.16	19.45
201 to 300 meters	7,095	13.33	32.78
301 to 400 meters	6,671	12.54	45.32
401 to 500 meters	6,402	12.03	57.35
501 to 600 meters	5,701	10.71	68.06
601 to 700 meters	4,859	9.13	77.19
701 to 800 meters	4,216	7.92	85.11
801 to 900 meters	3,877	7.29	92.40
900 to 1,000 meters	4,046	7.60	100

Appendix B. Comparison of Estimated Implicit Prices of a One Foot Increase in Secchi Depth Between Model Specifications

Scenario: One Foot Increase in Secchi Depth	Model 1	Model 2	Model 3	Model 1S	Model 2S	Model 3S
Edge Effects						
Lakefront Properties	$4,911.14 (561.45)	$4,957.46 (561.10)	$5,594.80 (573.75)	$5,033.94 (400.26)	$5,008.83 (393.86)	$5,663.08 (411.89)
Non-Lakefront Properties	619.91 (129.35)	356.56 (96.50)	717.50 (126.34)	$465.99 (101.86)	$358.86 (103.57)	728.23 (124.23)
Proximity Effects						
300 Meters from Lake	---	$566.52 (100.71)	$925.34 (130.78)	---	$571.34 (103.41)	$938.59 (123.96)
600 Meters from Lake	---	237.88 (99.31)	600.02 (127.78)	---	238.77 (106.90)	609.34 (127.09)
Size Effects						
Lakefront Properties						
100 Acre Lake	---	---	$4,908.61 (558.74)	---	---	$4,959.93 (392.28)
1,000 Acre Lake	---	---	5,867.79 (588.21)	---	---	5,942.83 (430.73)
Non-Lakefront Properties						
100 Acre Lake	---	---	396.72 (97.47)	---	---	400.01 (103.49)
1,000 Acre Lake	---	---	1,118.75 (187.48)	---	---	1,138.80 (178.70)

Note: Standard errors are reported in parentheses.

Notes

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[1] Secchi depth is a measure of surface water clarity (or transparency) obtained when a trained technician lowers a *Secchi disk* into the water body and records the level at which the disk disappears from sight.

[2] Separate water quality criteria were proposed for lakes, streams, springs and clear streams, and canals in four Florida regions. Criteria for lakes include limits on nitrogen, phosphorous, and chlorophyll *a* (EPA, 2010b).

[3] The spatial lag model is written $Y = \rho WY + X\beta + u$ and the spatial error model is written $Y = X\beta + \varepsilon$, where Y is the dependent variable, W is the 'nearest neighbor' spatial weights matrix, X is a vector of regressors, u is iid normal random error, $\varepsilon = \lambda W\varepsilon + u$, and β, ρ, and λ are parameters. Estimates of ρ and λ may be used to test for spatial dependence in the errors. See Anselin (1988) and LeSage (1999) for technical details on spatial econometric models.

[4] Several definitions of the weights matrix were investigated by varying the spatial (distance) and temporal components; changing either affects the number of nearest neighbors around each property. For the weights matrix used in the empirical application, the mean property has 5.6 nearest neighbors. This specification approximates local appraisal practices.

[5] Orange County covers 627,723 acres, of which 168,276 acres (or 26.8%) were designated as residential development and 60,069 acres (or 9.6%) were designated as public waters (lakes, ponds, and rivers) in 2004 (see Milon, Scrogin, and Weishampel, 2009).

[6] Tradeoffs must be confronted in selecting a distance boundary within which to sample property sales. Restricting the boundary censores the data if the price effects of water quality or proximity extend beyond the boundary. However, as the boundary around lakes increases, some properties will eventually lie within the boundaries around two or more lakes. The 1,000 meter boundary adopted here is similar to those chosen in the proximity valuation studies discussed in section II and was selected to mitigate both concerns. Specifications that included proximity to more than one lake revealed no significant relationships.

[7] Water pollution in the lakes is the product of non-point pollution sources such as stormwater runoff because there are no point sources, such as adjacent sewage treatment plants or factories, that emit into any of the 146 lakes (FDEP, 2006).

[8] The distribution of the 53,216 non-lakefront property sales located within 1,000 meters of a lake are summarized in Appendix A.

[9] Missing water quality data for individual lakes were most often due to irregular sampling schedules, budget cuts, or incomplete records. For comparison, estimation was also performed with the subset of 100 lakes that appear in all years of the sample. The results were similar to those obtained with the complete set of lakes. Estimation results for the two samples are available in an appendix upon request.

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[10] In all models, waterfront and non-waterfront properties were pooled. Properties in both groups share many unobservable neighborhood characteristics so separating the data would severely restrict the spatial regression analysis. The models were estimated in Stata and Matlab.

[11] Likelihood ratio tests (LeSage, 1999) also rejected the hypothesis of no spatial dependence.

[12] The full set of estimation results for the hedonic property price models are available in an appendix upon request.

[13] The marginal implicit prices from the spatial lag model are obtained by scaling (2) by $1/(1 - \rho)$; see Kim et al. (2003) for technical details. In all cases, the standard errors of the estimated implicit prices were obtained with the delta method. For comparison, estimates from Models 1 and 2 and Models 1S and 2S are reported in Appendix B.

[14] Duan (1983) demonstrated that if ε is assumed to be independent and identically distributed, then $E(e^{\varepsilon})$ may be consistently estimated by $N^{-1}\sum_{i=1}^{N} e^{\hat{\varepsilon}_i}$ where $\hat{\varepsilon}$ are the residuals.

[15] Several alternative functional forms were also estimated to evaluate the shape of the implicit price function but the qualitative results were the same.

[16] Given the double-log specification, the implicit price of a marginal increase in water quality is a function of property price as shown in (2). To calculate the implicit price for each property within the 1,000 meter boundary, the 2004 assessed values from the OCPA were used. The State of Florida requires that assessed value is an annual determination of the fair market value (Florida Statutes, Chapter 192.001).

[17] As of 2009, only 5 of the 146 lakes included in this study had MSTU's.