Estimating the impact of water quality on surrounding property values in Upper Big Walnut Creek Watershed in Ohio for dynamic optimal control

Hongxing Liu, The Ohio State University, liu.2386@osu.edu
Sathya Gopalakrishnan, The Ohio State University, gopalakrishnan.27@osu.edu
Drew Browning, The Ohio State University browning.149@osu.edu
Patrick Herak, The Ohio State University patherak@gmail.com
Gajan Sivandran, The Ohio State University sivandran.1@osu.edu

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2014 AAEA Annual Meeting, Minneapolis, MN, July 27-29, 2014.

Abstract

Non-point source pollution and its impact on water quality are of great importance to policy makers, residence and farmers. This paper uses a hedonic property value model to investigate the marginal implicit values of water quality change in Hoover Reservoir in the Upper Big Walnut Creek (UBWC) watershed, Ohio. The estimates are fed into a simple dynamic optimization model which maximizes social welfare while taking into account the damage from production as well as the production profits. This paper uses the Soil and Water Assessment Tool (SWAT) to simulate the quality and quantity of the surface and ground water and uses ArcGIS to link housing transactions in Franklin County and Delaware County with disaggregated flow of nutrient runoff in the watershed. The econometric results indicate that the marginal damage for a one mg/L increase in nitrogen (N) and phosphorus (P) loadings are $7,713.41 and $27,624.05 respectively, and the increase of property value of a one meter increase of secchi depth water clarity is $95,132.07. This paper investigates the effects of multiple water quality parameters on both waterfront and non-waterfront properties, using the yearly maximum loading, sediment, and dissolved oxygen, as well as yearly average secchi disk depth as measurement. A simple dynamic optimization model is included to show the tradeoff between production profits and water quality.

Keywords

Hedonic property model, water quality, dynamic optimization model.

1. Introduction

1.1 Background

Non-point source pollution and its impact on water quality in freshwater lakes and rivers are serious concerns for policy makers, scientists and residents that rely on these sources for drinking water. Eutrophication – the process of natural or artificial addition of nutrients, particularly nitrogen (N) and phosphorous (P), in a water body – and the emergence of "dead zones" characterized by low dissolved oxygen are increasingly threatening aquatic systems including lakes, rivers, and oceans (Ludwig, Carpenter, and Brock 2003; Nicholls and Hopkins 1993), necessitating policy intervention to improve water quality, control the nutrient input, and preserve aquatic habitats.

In practice, excessive fertilizer use in agriculture can lead to high nutrient loading in the streams draining into the Hoover Reservoir, which can cause the water quality decline and in turn reduce the biodiversity and recreational and commercial benefits of the lake. It also increases the costs for water treatment to provide drinking water or to supply water for manufacturing processes. So there is a trade-off between benefits from polluting activities and costs of ecosystem services foregone due to damage of water quality.

To improve water quality in Hoover Reservoir, United States Department of Agriculture (USDA) and the State of Ohio have launched a $13.2 million Conservation Reserve Enhancement Program (CREP), which installs 3,500 acres of filter strips, riparian buffers, hardwood trees, wetlands and wildlife habitat practices, with the goal of reducing nutrients and agricultural chemical runoff in the Hoover Reservoir by 30 percent. In order to justify and evaluate the effectiveness of such policy initiatives, reliable estimates of the benefits from improved water quality are an essential first step. It is also a key step to understand the pattern of how water quality changes with agricultural practices to gain insights for long-term policy design that can optimally address tradeoffs between agricultural productivity and water quality.

1.2 Literature review

This problem has both dynamic and spatial features that make it interesting. The dynamic aspect of this problem comes from the cumulative feature of the nutrient in the water body, which means that it is more of the concentration of nutrient in the water body than just the instantaneous flow that determines the actual water quality. Besides the intertemporal aspect, the heterogeneity of space may also be of prime consideration. The spatial characteristics of soil and water body vary by space as well as by time, and are functionally interdependent over space, which makes the whole process spatial and dynamic. For example, the P loading from agricultural land at a specific location within the watershed depends on the water delivery ratio, distance to water body, the land management, as well as on characteristics of the land, such as the soil P content and the erosion and runoff potential including soil texture and slope gradient. Moreover, the spatial heterogeneity is not fixed over time because of the cumulative and diffusive feature of agricultural pollution, so we need to take into account the interdependent relationship over time and space in a linked system.

Previous works have looked at the impact of water quality on housing values and found that water clarity, nutrient loading (Netusil, Kincaid, and Chang 2014; Poor et al. 2001) and perceptions of environmental quality (Poor et al. 2001) impact residential property values. Some of them only look at the effect of single water quality parameter (Leggett and Bockstael 2000; Epp and Al-Ani 1979), some of them only look at waterfront properties (Leggett and Bockstael 2000; Michael, Boyle, and Bouchard 2000). However, the lack of historical records of observable water quality data at fine spatial resolution makes the studies limited in specific areas. For the water quality variables, none of the previous works have used the yearly maximum of nutrient loadings as an index.

One important feature of this paper is the way I deal with the lack of data and the spatial heterogeneity problem. In this paper, the water quality data in the rivers and in the Hoover Reservoir are simulated from SWAT, which is, as Gassman et al. (2007) describes, "a basin scale, continuous time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds". SWAT takes into account weather, hydrology, plant growth, nutrients, pesticides, as well as other spatial differentiated features including distance to the water body, slope, and soil properties. It is widely used to study non-point source pollution control and regional management in watersheds

Another important feature of this paper is that the estimates in the hedonic analysis are then used as a water quality level index in the damage function in the dynamic optimal control model. Although the model is still simple and tentative, it helps us to draw some insights from the tradeoff between agricultural productivity for long-term policy design. This paper is also unique in that it uses the yearly maximum of nutrient loading level instead of the average, which makes more sense because that is the time when most environmental hazardous events would happen and when people can notice the water quality change. Furthermore, this paper investigates the effects of multiple water quality parameters, including nutrient loading, dissolved oxygen, sediment, and water clarity. Both waterfront and non-waterfront properties are included in the dataset.

2. Data and method

2.1 Study area

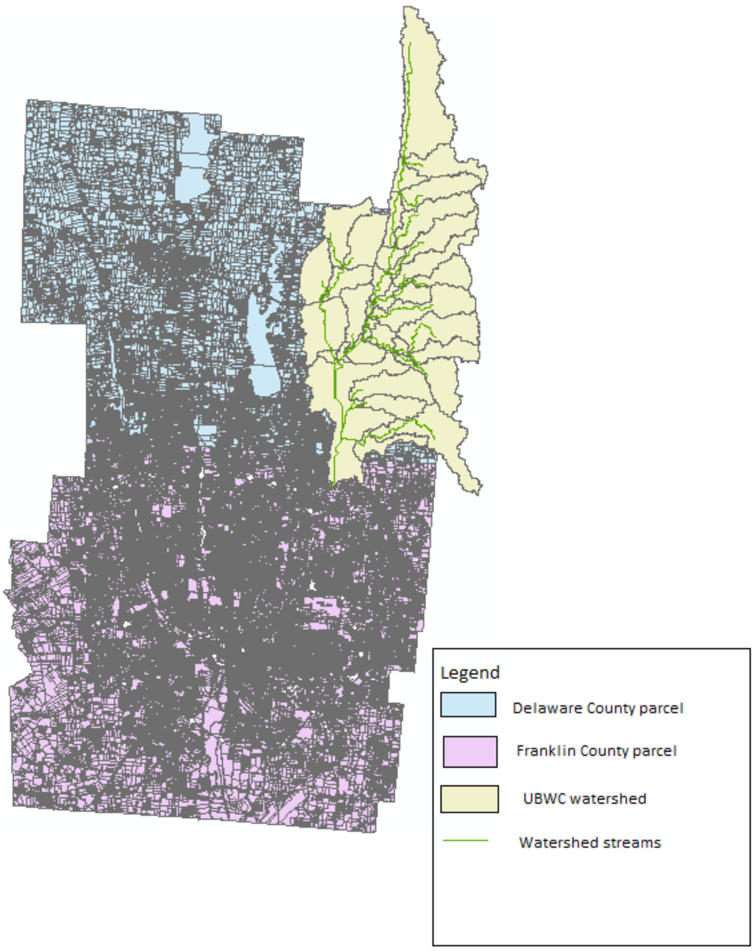

Figure 1. Map of UBWC watershed and properties

This study is conducted in the Upper Big Walnut Creek (UBWC) watershed, which is one of the 12 benchmark watersheds in the United States being evaluated as part of the Agricultural Research Service's (ARS) component of the Conservation Effects Assessment Project (CEAP) (Mausbach and Dedrick 2004). Its perennial and intermittent streams drain into the Hoover Reservoir, which serves as a drinking water supply for approximately 800,000 residents in Columbus and surrounding communities. The UBWC watershed is a predominantly agricultural area in central Ohio with cropland accounting for 60% of the land use. Excessive fertilizer use can lead to high nutrient loading in the streams draining into the Hoover Reservoir, causing algal blooms, which are associated with high chlorophyll a, low water clarity, and low dissolved oxygen, and which impact water quality greatly. This loading is also magnified by agricultural practices such as tile drainage techniques.

2.2 Housing data

The unique data set this paper uses combines the housing transaction data with disaggregated flow of nutrient runoff and spatially resolved data of hydrological characteristics generated using SWAT in the UBWC watershed. There are in total 281,951 single family arm-length real estate transactions from 1990 to 2013 in Franklin County and Delaware County, Ohio. The SWAT model divides the UBWC watershed into 36 reaches based on their river characteristics. I use ArcGIS to associate the properties in Franklin and Delaware County with the characteristics of the nearest reach. The SWAT model provides simulated water quality data on nitrogen and phosphorus loading, dissolved oxygen, sediment, and secchi disk depth measurement.

Summary statistics are shown in Table 1. The dataset consists of three types of data: 1) the structural characteristics (S) of the parcels; 2) the neighborhood characteristics (N) and; 3) water quality data (W). The structural characteristics including housing transactions data are gathered from the auditor’s offices of Franklin County and Delaware County. Neighborhood characteristics consist of distance to nearest landmarks including street and pond are calculated using ArcGIS. Water quality variables are obtained from SWAT model and they are interacted with distance to the nearest reach or Hoover Reservoir to estimate the influence of runoff. I use the yearly maximum value of nitrogen and phosphorus loadings, sediment, and dissolved oxygen level to indicate water quality. The reason is that most environmental hazardous events take place when the loading is high, and that is also the time when people can notice the water quality change and housing price could pick up the change. For water clarity, I use the yearly average secchi depth as most previous studies do because water clarity is one of the most direct ways for people to observe water quality change. Based on Poor et al. (2001), scientific measurement is preferred, or equally preferred to subjective measures. Dummy variables for transaction year and census block are also included to control for the fixed effect.

Table 1 Variable explanations and summary statistics, 1990-2013

Type	Variables	Explanation	Units	mean	Std. dev
Structural characteristics	Real price	The sales price translated to real dollar by CPI	Dollar	313553.3	583279.2
	Age	Starting from the year the house was built to the year of transaction	Year	37.904	29.263
	Bathrooms	Number of bathrooms	Number	1.625	0.634
	No of story	Number of stories	Number	1.525	0.493
	Air conditioning	Whether or not the house has air-conditioning	Dummy	0.764	0.425
	Garage capacity	The garage capacity of the house	Number	1.133	1.028
	Total square footage	Total square footage of the house	Square foot	1741	724.9
	Fireplace	Whether or not the house has a fire place	Dummy	0.518	0.586
	Acres	The total acreage of the parcel	Acres	0.376	3.014
Neighborhood characteristics	Street	Distance to nearest street	Mile	0.00483	0.00274
	Hoover Reservoir	Distance to Hoover reservoir	Mile	10.515	4.886
	Reach	Distance to the nearest reach	Mile	10.346	4.841
	Pond	Distance to the nearest pond	Mile	8.187	5.708
Water quality	Maxsed	The yearly maximum sediment in the rivers	Metric ton	172.2	100.0
	Maxdisox	The yearly maximum dissolved oxygen in the rivers	Kg	16342.48	54045.44
	Maxn	The yearly maximum loading of nitrogen in rivers	Mg/L	97635.0	133549.2
	Maxp	The yearly maximum loading of phosphorus in rivers	Mg/L	10960.38	16374.59
	Maxresn	The yearly maximum loading of nitrogen in Hoover Reservoir	Mg/L	11.579	1.255
	Maxresp	The yearly maximum loading of phosphorus in Hoover Reservoir	Mg/L	1.188	0.136
	Secchi depth	Yearly average secchi disk depth	Meter	0.710	0.035

2.3 Hedonic method

A hedonic property value model is used to investigate the marginal implicit values of the water quality attributes. Assume the property buyers make decisions based on utility-maximizing and the market is in equilibrium and the price of the ith property can be represented by

$$\mathrm{P}_i = \mathrm{P}(\mathrm{S}_i, \mathrm{N}_i, \mathrm{W}_i)$$

S, N, and W are the structural characteristics, neighborhood characteristics and water quality characteristics respectively. This paper then takes the semi-log form as most hedonic studies do (Leggett and Bockstael 2000; Poor, Pessagno, and Paul 2007). The basic regression model estimated is as follows:

$$\mathrm{lnprice}_i = \alpha + \beta_{1i}S + \beta_{2i}N + \beta_{3i}W + \varepsilon_i$$

α, β_1, β_2 *and* β_3 are the coefficients to be estimated and ε_i is a random error term.

3. Result analysis

3.1 Result table

Most of the estimates have the signs as expected and are consistent with other previous studies. The water quality coefficient estimates are shown in table 2 and the full regression result table is shown in appendix A. The estimates are transformed into estimated price change using the mean sales price ($313,553.3). To keep the same magnitude, the coefficient estimates for sediment and dissolved oxygen are multiplied by 1,000, 000, but the dollar values are not changed.

Table 2. Regression results for water quality variables

Variable	Coefficients	Dollar value
Max sediment	0.0286** (0.014)	$0.009
Max dissolved oxygen	0.0001* (0.000)	$0.000031
Max n in the reservoir	-0.0246*** (0.002)	$7,713.41
Max p in the reservoir	-0.0881*** (0.024)	$27,624.05
Secchi disk depth	0.3034*** (0.089)	$95,132.07

Note: Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

3.2 Estimated effects on sale price

Most of the estimates have the signs as expected and are significant. For the housing structural characteristics, age has a negative effect on the property's sale price, but at a diminishing rate. The number of bathrooms, the number of stories, garage capacity, and the presence of air-conditioning and fireplace all have significantly positive effects on sale price. Total square footage and acreage also have significantly positive effect, but at a decreasing rate.

The impact of the distance to the nearest street is positive but not significant in this study. This might be due to the lack of variation in the distance to the street. Future studies should try this analysis with distance to nearest highway or major road.

Distance to Hoover Reservoir is of significantly negative impact on the sale price, and the square term is positively significant, which means people are willing to pay more to live near the Hoover Reservoir, but only up to some distance. Distance to nearest pond has a significantly negative influence on sale price, which shows the public's preference for water and justifies the importance of water quality control. Distance to nearest river has a significantly positive impact, but the implication is not clear. It might be that people prefer living away from the river because of the water quality level is not satisfactory, or that the impact of being near rivers has been countered by other factors. Therefore, more future studies are needed.

For water quality, the nutrient loadings in the rivers do not have a significant impact on the sale price, which could be of the same reason as previously mentioned, and requires more studies. But other than that, all the estimates are of the expected signs and are significant. Sediment decreases the nutrient loading and dissolved oxygen is essential for the biodiversity in the water body so that they both have positive impacts on sale price, but the impacts are small in this study. Nitrogen and phosphorus loadings contribute to eutrophication, algae blooms, and other environmental problems. Their effects are negative and very significant. Secchi disk depth represents water clarity, and has the most influential effect. It is most direct for observation and a good indicator for water quality.

All in all, the estimation results show that the impact of water quality on sale price is huge, which justifies the government investment in conservation and water pollution control programs. Given the significant results from this study and the fact that farmers are not likely to consider pollutions in their production decisions, more regulations on the use of fertilizers are needed to maintain the benefits of water services.

4. Dynamic optimal control model

4.1 Optimization model

In this part I use a very simple economic model to abstract the essence of dynamic optimal control problem. I assume the regulator tries to choose the amount of fertilizer (f) to use in order to maximize social welfare taking both production profit and water quality into account. Production yield and benefits increases with fertilizer input, but at a decreasing rate. The nutrient loading (N) is an index for water quality which combines the effects of all water quality variables, including sediment, dissolved oxygen, nitrogen and phosphorus loading, and water clarity. It increases with the input of fertilizer and decreases at a natural rate due to sediment and outflow. The maximization problem is set up as follows:

$$\max \pi = \int_0^T [pq_t - cf_t - d - \alpha N_t] dt$$

$$\mathrm{s.t.}\, \dot{\mathrm{N}} = \beta f - \gamma N$$

$$\mathrm{N}(0) = N_0, \mathrm{N}(\mathrm{T}) = N_T$$

p is the price of the agricultural product, q_t is the yield sequence, c is the cost of fertilizer input, d is other cost associated with the production process, αN_t is the damage function, which only depends on the nutrient loading in the water, not the pollution runoff flow. α should be calculated as a weighted average of impacts from water quality change estimated from the hedonic analysis. I assume the initial water quality level of the water body (N_0) is a starting point and the terminal level (N_T) is a policy goal.

4.2 Hamiltonian and necessary conditions

To simplify the model, I assume the yield function to be

$$q = af - bf^2 + e$$

which means that fertilizer input increases production output but at a diminishing rate. For simplicity, time subscript t's are suppressed unless it is required for an unambiguous notation. The current value Hamiltonian can be written as follows:

$$H = p(af - bf^2 + e) - cf - d - \alpha N + \lambda(\beta f - \gamma N)$$

The associated necessary conditions are:

1) $\frac{\partial H}{\partial f} = 0 \Leftrightarrow pa - 2pbf - c + \lambda\beta = 0$

2) $\dot{\lambda} - \delta\lambda = -\frac{\partial H}{\partial N} \Leftrightarrow \dot{\lambda} - \delta\lambda = \alpha + \lambda\gamma$

3) $\dot{N} = \beta f - \gamma N$

Solving out the problem, I find:

$$\lambda = -\frac{\alpha}{\delta + \gamma} + k_1 e^{(\delta+\gamma)t}$$

$$f = -\frac{\alpha\beta}{2bp(\delta + \gamma)} + \frac{a}{2b} - \frac{c}{2bp} + \frac{k_1 \beta e^{(\delta+\gamma)t}}{2bp}$$

$$\mathrm{N} = -\frac{\alpha\beta^2}{2bp\gamma(\delta+\gamma)} + \frac{a\beta}{2b\gamma} - \frac{c\beta}{2bp\gamma} + \frac{k_1\beta^2 e^{(\delta+\gamma)t}}{2bp\gamma} + k_2 e^{-\gamma t}$$

Substitute in the initial and terminal conditions, and denote $-\frac{\alpha\beta^2}{2bp\gamma(\delta+\gamma)} + \frac{a\beta}{2b\gamma} - \frac{c\beta}{2bp\gamma}$ as A, I find

$$k_2 = \frac{N_0 e^{(\delta+\gamma)T} - N_T - A(e^{(\delta+\gamma)T} - 1)}{e^{(\delta+\gamma)T} - e^{-\gamma T}}$$

$$k_1 = \frac{(N_0 - k_2 - A)2bp\gamma}{\beta^2}$$

Therefore the regulator can decide an optimal path of fertilizer amount from time 0 to T, which maximizes the social welfare and achieves the target nutrient level $N_T$at the end of the time period.

4.3 Analysis

This is a very simple first step model to show the essence of the optimal control problem, but even with such a simple model, I still get very complicated analytical solution, which in a way represents the complexity of this optimal control problem. From the transition function, we can see that at steady state, when

$$\dot{N} = 0 \Leftrightarrow \beta f - \gamma N = 0$$

higher fertilizer input will lead to higher nutrient loading level and lower water quality. If the goal of water quality control is low nutrient level and high water quality, then the fertilizer standard should be set low as well.

In future studies, more complications could be added in the model to better represent real world situation: 1) Spatial heterogeneity could be represented by a buffer zone between crop land and water body, or by the choice of location to plant crops; 2) Multiple crop types could be included and rotations can be used for land restoration; 3) Uncertainties including weather and the response of lake to eutrophication are also a big concern to this problem. Weather can exogenously affect both the production yield of agriculture and the time lag between the fertilizer input and the change in water quality level. Depending on the response of lake to eutrophication, lakes can be reversible, irreversible or hysteretic where the latter two cannot turn back to oligotrophic states just by reducing nutrient input. As pointed out by Carpenter, Ludwig, and Brock (1999), if nutrient inputs are stochastic, lags occur in implementing nutrient input policy, or decision makers are uncertain about the lake responses to altered nutrient input, then the regulators should apply the precautionary principle and lower the input targets.

5. Discussion and policy implications

Evaluating water quality change is very important for understanding the impact of farming decisions on water resources. The hedonic analysis in this paper is a case study of the UBWC watershed, but the results are mostly consistent with previous studies (Netusil, Kincaid, and Chang 2014; Poor et al. 2001). It shows that water quality has a very big impact on the surrounding housing property values, which justifies the government actions to reduce polluting activities and improve water quality. The dynamic model has wider significance in that it is simple enough to draw the essence of the dynamic optimal control problem yet not to over complicate it with too many features.

One solution to this agricultural externality is setting a pollution standard which requires all farmers reduce the input of fertilizers by certain amount and subsidies might be needed to compensate for the reduction in output. Similarly, regulators could design optimal taxes to make farmers control the fertilizer level by themselves and still achieve the optimal level. However, in practice, policy instruments are not likely to be continuous based on the amount of fertilizer or the location of the crop field. It is more feasible to implement zonal policies than trying to control for the fertilizer inputs that vary continuously across space and over time. So lots of previous works (Carpenter, Ludwig, and Brock 1999; Smith, Sanchirico, and Wilen 2009) suggest that regulators design policies that are based on a zonal system, where the zones can be a set of dispersed locations united by the similar environmental vulnerability allowing adjusting taxes or subsidies to each zone and over time. When the regulators do not have complete information about the damage, private production or cost functions, a zonal system of tradable permits which can be traded within or between zones can be implemented to achieve the optimal amount of fertilizer decided by regulators and the value of the permits can change over time based on the amount of admissible discharge of nutrient (Goetz and Zilberman 2000).

However, in real world, even zonal policies that vary over time are hard to implement. It is hard for the farmers to accept a tax or subsidy that is constantly changing over time. One proposed way to solve this problem is to fix the zones and implement the average of the optimal tax or subsidy over time. But apparently this is not even second best and we need further study to test for its validity.

6. Conclusion

This paper has some major contributions. The first one is that this paper couples economic model with SWAT simulations, which makes up for the lack of micro level water quality data. It also takes into account the soil and water quality characteristics including spatial features. This method could be applied to investigate the impact of water quality change in areas where finer spatial level data was not available previously or to test the impact of different land management methods. The second one is that the hedonic analysis is conducted on many water quality parameters including nitrogen and phosphorus loading, dissolved oxygen, and secchi disk depth. This paper uses the yearly maximum value of the nutrient loading, sediment, and dissolved oxygen because that is the time when most environmental events would happen and that is when people are most likely to notice the water quality change. The third one is that the results from the hedonic analysis all feed into the dynamic optimal control model as a weighted index, so that the water quality is more comprehensive and counter effects are taken into account. The fourth one is the dynamic optimal control model draws some insights of water quality control policies where a sequence of fertilizer amount is chosen to maximize the social welfare taking into account the trade-off between benefits from agricultural activities and costs of ecosystem services foregone due to damage of water quality.

There are more works to be done in the future work of this study. First, as mentioned above, more studies need to be done on whether applying the average optimal tax over time on the fixed zones would be a good policy instrument or not. Second, more studies need to be done to study the impact of living near the rivers and the water quality change in the rivers. Third, in this model I assume single product, so future work could add one more control variable that represents different types of crops. Fourth, sometimes farms, especially those near the water body, do care about water quality, and I can try to incorporate that into the models in the cost or benefit functions. Moreover, in this paper, the SWAT model takes into account the soil and water characteristics including locations in the hedonic analysis and in the future, more of the spatial features would be taken into account. Also, complexities including uncertainty should be added into the model to make it make more sense in real world.

Acknowledgement

This paper is funded by the OARDC Interdisciplinary SEEDS Grant 2013。

Appendix A

Variables	coefficient	Variables	coefficient
Age	-0.0038*** (0.000)	Max sediment	0.0286** (0.014)
Square of age	0.0000*** (0.000)	Max dissolved oxygen	0.0001* (0.000)
Number of bathrooms	0.0483*** (0.002)	Square of dissolved oxygen	-0.0000** (0.000)
Number of stories	0.0300*** (0.003)	Max N in river	0.0000 (0.000)
Air-conditioning	0.1205*** (0.003)	Max P in river	-0.0000 (0.000)
Total square footage	0.0003*** (0.000)	Max N in Hoover Reservoir	-0.0246*** (0.002)
Fire place	0.0428*** (0.002)	Max P in Hoover Reservoir	-0.0881*** (0.024)
Acres	0.0201*** (0.001)	Average secchi disk depth	0.3034*** (0.089)
Square of acres	-0.0000*** (0.000)	Interaction between distance and reach N	-0.0000 (0.000)
Distance to street	0.9757 (0.695)	Interaction between distance and reach P	-0.0000 (0.000)
Distance to Hoover Reservoir	-0.1126*** (0.009)	Interaction between distance and Reservoir P	0.0075*** (0.001)
Square distance to Hoover Reservoir	0.0000*** (0.000)	Interaction between distance and Reservoir N	0.0019*** (0.000)
Distance to nearest reach	0.0648*** (0.009)	Constant	11.1166*** (0.104)
Distance to pond	-0.0257*** (0.005)		
Observations	281,951	R-squared	0.703

Note: Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Dummy variables for year fixed effect and census block effect are included.

References

Carpenter, S. R., D. Ludwig, and W.A. Brock. 1999. Management of eutrophication for lakes subject to potentially irreversible change. *Ecological applications* 9:751-771.

Epp, D.J., and K.S. Al-Ani. 1979. The effect of water quality on rural nonfarm residential property values. *American Journal of Agricultural Economics* 61:529-534.

Gassman, P.W., M.R. Reyes, C.H. Green, and J.G. Arnold. 2007. *The soil and water assessment tool: historical development, applications, and future research directions.* Center for Agricultural and Rural Development, Iowa State University.

Goetz, R.U., and D. Zilberman. 2000. The dynamics of spatial pollution: The case of phosphorus runoff from agricultural land. *Journal of Economic Dynamics and Control* 24:143-163.

Leggett, C. G., and N.E. Bockstael. 2000. Evidence of the effects of water quality on residential land prices. *Journal of Environmental Economics and Management* 39:121-144.

Ludwig, D., S. Carpenter, and W. Brock. 2003. Optimal phosphorus loading for a potentially eutrophic lake. *Ecological applications* 13:1135-1152.

Mausbach, M. J., and A.R. Dedrick. 2004. The length we go measuring environmental benefits of conservation practices. *Journal of Soil and Water Conservation* 59:96A-103A.

Michael, H. J., K.J. Boyle, and R. Bouchard. 2000. Does the measurement of environmental quality affect implicit prices estimated from hedonic models? *Land*

Economics 283-298.

Netusil, N.R., M. Kincaid, and H. Chang. 2014. Forthcoming. Valuing water quality in urban watersheds: A comparative analysis of Johnson Creek, Oregon and Burnt Bridge Creek, Washinton.

Nicholls, K. H., and G.J. Hopkins. 1993. Recent changes in Lake Erie (north shore) phytoplankton: cumulative impacts of phosphorus loading reductions and the zebra mussel introduction. *Journal of Great Lakes Research* 19:637-647.

Poor, P. J., K.L. Pessagno, and R.W. Paul. 2007. Exploring the hedonic value of ambient water quality: A local watershed-based study. *Ecological Economics* 60:797-806.

Poor, P. J., K.J. Boyle, L.O. Taylor, and R. Bouchard. 2001. Objective versus subjective measures of water clarity in hedonic property value models. *Land Economics* 77: 482-493.

Smith, M. D., J.N. Sanchirico, and J.E. Wilen. 2009. The economics of spatial-dynamic processes: applications to renewable resources. *Journal of Environmental Economics and Management* 57:104-121.