Validating Spatial Hedonic Modeling with a Behavioral Approach: Measuring the Impact of Water Quality Degradation on Coastal Housing Markets

Mahesh Ramachandran, Ph.D.
Environmental Economist
Cape Cod Commission
mramachandran@capecodcommission.org
3225 Main Street
Barnstable, MA 02630

Selected Paper prepared for presentation at the 2015 Agricultural & Applied Economics Association and Western Agricultural Economics Association Annual Meeting, San Francisco, CA, July 26-28

Abstract:

Human perception of water quality that determines utility and behavior may not correspond to often used science-based measures, leading to mismeasurement of implicit prices in hedonic models. This paper seeks to estimate the effect of water quality degradation on the sale price of coastal single-family residential properties using a spatially explicit hedonic approach, while validating the measure of water quality using a behavioral approach. The results show that a combined approach of hedonic modeling and behavioral validation is an important preliminary step in addressing omitted variable and perception biases present in traditional hedonic modeling approaches.

Subject Codes: Environment and ecology (Q5); Q510 Valuation of Environmental Effects

Keywords: Hedonic; coastal; spatial; behavioral; water quality

There are few studies addressing the effects of water quality on coastal property markets using the hedonic price approach. Leggett and Bockstael (1998) state two reasons for the absence of hedonic studies on water quality in the environmental economics literature: First, the measures of water quality commonly used are impossible for homeowners to observe, or do not directly impair their enjoyment; and second, the absence of sufficient spatial and temporal variation in a confined geographic space to allow that allows for the estimation of values without triggering the multiple markets issue. Poor et al., 2001, P.484, made a similar observation stating, "While these data may be scientifically accurate, individual consumers are more likely to make purchase decisions based on their subjective perceptions of [quality], which may or may not be correlated with scientific measures. Unless these scientific measures serve as a suitable proxy for relevant perceptions, the use of these measures in hedonic property-value models may create an error-in-variables problem for the estimation of implicit prices of environmental quality (Lang and Jones 1979; Atkinson and Crocker 1987)."

This issue persists with recent contributions to the literature. The variables used to measure water quality include clarity (Poor et al, 2007), Total Suspended Solids, Total Nitrogen and Total Phosphorous (Phanuef et al, 2008), and composite indicator (Walsh and Milon, 2015). While water clarity (Secchi depth) is easily observable by the recreational users, the ecological benefits if clarity are ambiguous: mountain lakes affected by acid rain can be clear, yet devoid of lifeform (Leggett and Bocksteal, 1998). Artell (2014) applies a "usability index" based on expert judgement taking into account chemical and nutrient levels as well as turbidity. However, converting scientific measurements into categorical variables based on usability still does not consider water quality as perceived by recreational users whose "usability" is not directly taken into account. On the other hand, using subjective measures of water quality based on survey of residents to generate water quality variable for the hedonic model as in Young (1984) introduces selection bias in addition to rendering the coefficient estimate without scientific validity, thereby not informing policy aimed to reduce specific pollutants.

Regardless of the approach chosen to inform regulatory policy such as stated versus revealed preferences or single versus composite water quality indices, neglecting to capture the "human element" of the preference function will undermine the public policy relevance of the literature. In addition, failing take into account behavioral aspects of preferences introduces methodological issues such as perception bias, errors-in-variables, and multicollinearity, leading to mismeasurement of the value of water quality.

This paper seeks to estimate the effect of water quality degradation on the sale price of coastal single-family residential properties using a spatially explicit hedonic approach while validating the measure of water quality using a behavioral approach that incorporates residents' perceptions. The study site chosen for testing this methodology contains spatial and temporal variation in water quality measurements, while still being confined to a smaller location, reducing significant multiple market issues.

Description of Study Site: Nitrogen Pollution and Coastal Economy

According to EPA, more than 100,000 miles of rivers and streams and close to 3.1 million acres of fresh and salt-water bodies in the United States have poor water quality from Nitrogen and phosphorus pollution, usually attributed to agricultural fertilizer runoff and septic systems. This pollution is both visually apparent through reduced water clarity and scientifically measurable as low water quality.

Degraded waters have a devastating impact on communities that depend on healthy coastal ecosystems and high water quality as the basis for their tourism and vacation-based economies. One such community is Cape Cod, Massachusetts, whose coastal residential property market is the study site in this paper.

Cape Cod's tourism-based economy depends on clear, attractive beaches and coastal waters. For homebuyers on the Cape, especially those purchasing vacation homes, ocean views and access to water-based recreation can be a key factor in their purchase decision. Home sale prices determines a town's property tax base, which is the largest revenue source for a community to fund schools, public safety, infrastructure and other essential public services.

Most houses on the Cape use on-site septic systems. Nitrogen leaches out of these systems, seeping into groundwater and ultimately reaching the surrounding coastal waters. Fertilizer for lawns represents another source of Nitrogen pollution. Excessive Nitrogen in water leads to eutrophication, where an overgrowth of Nitrogen-fed algae makes water appear murky and harms the ecosystem. Eutrophication is a problem in the majority of Cape Cod's saltwater estuaries. Low water quality and eutrophication can reduce the appeal of water-based recreation, and dull the appearance of ocean views. Growth in the housing market over time increased the number of septic systems and amount of fertilizer, leading to declining water levels across the Cape.

For an enhanced understanding of how crucial clean water is for the Cape, as part of the present study 650 year-round residents chosen randomly across the Cape were surveyed about their water-based recreational activities. Their responses to the questions about how they currently use Cape Cod's waters, and how poor water quality might change their behavior, are shown in Figure 2. From a list of options, a plurality of participants (36%) said they most enjoyed water vistas, followed by swimming (24%), boating (21%) and fishing (14%). When asked how they might change their behavior in response to worse water quality in the future, 27% of the survey participants said they would not change their behavior, and 22% said they were uncertain or did not know. The majority of respondents (51%) said they would change how they used the Cape's waters. Of this 51%, 31% responded that they would change their recreational behavior or stop doing that activity, 12% would stop using the water for recreation all together, and 8% would consider leaving the Cape for a location with better quality water.

This survey demonstrates the importance of clean water for the Cape's economy. Lower-quality water from excess Nitrogen would impact or reduce the appeal of water-dependent recreational activities. As eutrophication sets in, water becomes cloudy and algae filled, harming both the visual and recreational appeal. Eutrophication also harms fishing by lowering aquatic oxygen concentration, which suffocates fish and reduces animal life in the area. Because the survey did not include seasonal residents or visitors, their recreational water use and responses to lower quality were not captured. The willingness of 20% of year-round residents to stop using the water or move elsewhere would be magnified if visitors were included, as visitors can easily choose to visit other locations. Given the Cape's tourism-based economy, a loss of visitors could be catastrophic to the region.

In general, coastal properties tend to be higher in value than non-coastal homes. Consequently, a reduction in their value is likely to send a shock across the regional economy. Multiple markets make the estimation of a broader regional economic effect a challenge; however, the immediate local effect on property sale price could be directly estimated using a hedonic approach. A third of the Cape's households live within 10-minute walking distance, and even a marginal impact on the values of coastal properties, could have a significant impact on the regional economy. Therefore, to understand the impact of water degradation on coastal property prices, the present study restricted the focus to waterfront residential properties within 10 a minute walking distance, or 1000m, from the waterfront (Figure 1). The Three Bays watershed is 12,458 acres in area. There are 6,731 households in Three Bays watershed, roughly 5.2% of the households on the Cape. Of these 2,435 households live within a 10-minute walking distance from the water – the sample population for the present study.

Like much of Cape Cod, the Town of Barnstable's Three Bays watershed saw a dramatic increase in residential property development between 1950 and the present (Figure 2). About 55% of the growth in residential property development in the Three Bays watershed happened between 1970 and 1990, and about 36% of the growth happened between 1980 and 1990. A consequence of this residential growth is the increase in the number of fertilized lawns and septic systems and, subsequent increased Nitrogen outflow into the Three Bays waterbody.

As seen in Figure 2, there are large clusters of property development higher up the watershed and development closer to the water. Seepage from septic systems higher in the watershed contaminates the groundwater, which in turn drains into the embayment near Prince Cove in the northern portion of the embayment. This has resulted in an impairment of the embayment's water overtime.

Figure 1: Study Site

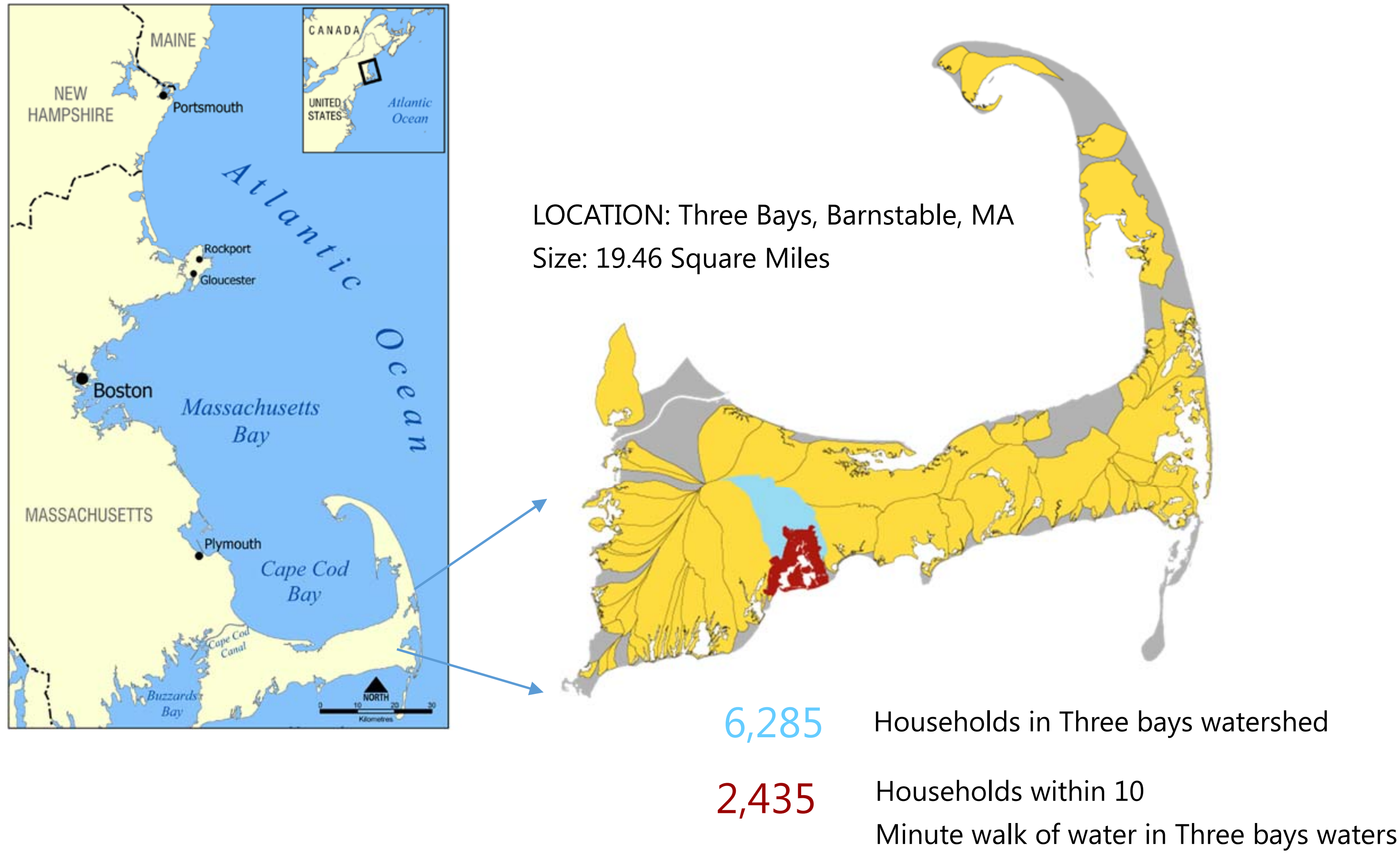


Figure 2: Development in the Three Bays watershed

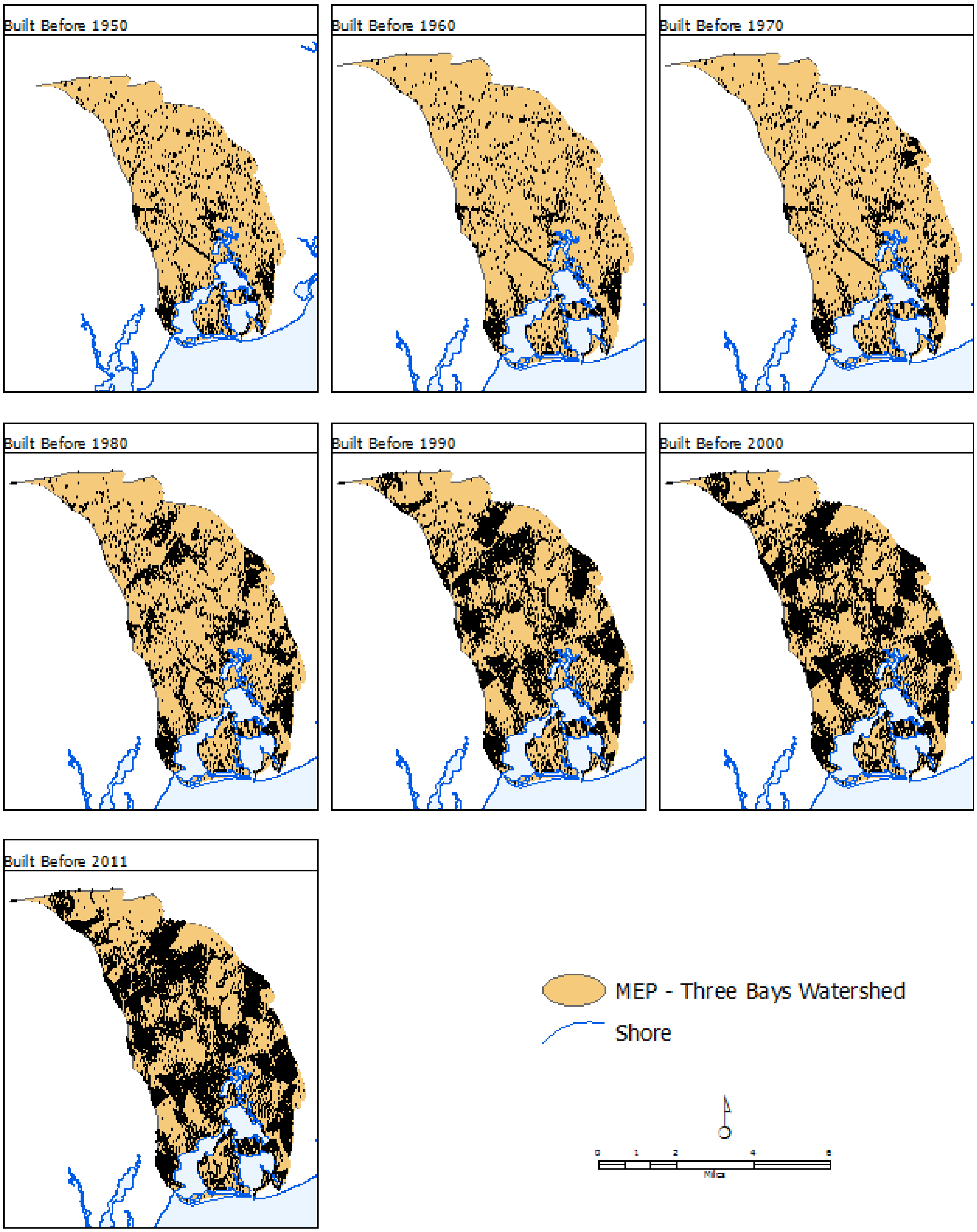
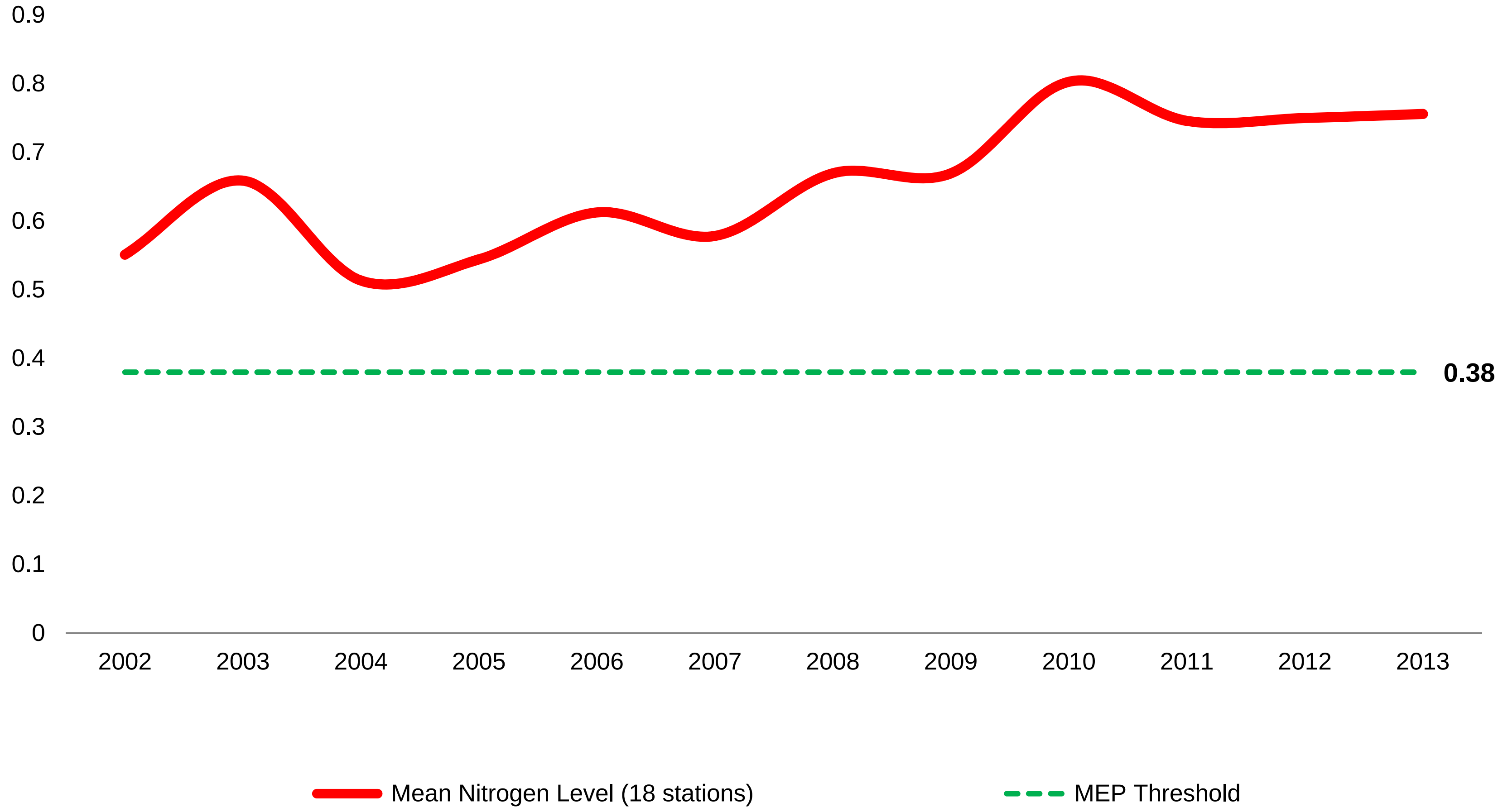


Figure 3: Trend in Nitrogen levels over time in Three Bays water (MgL)

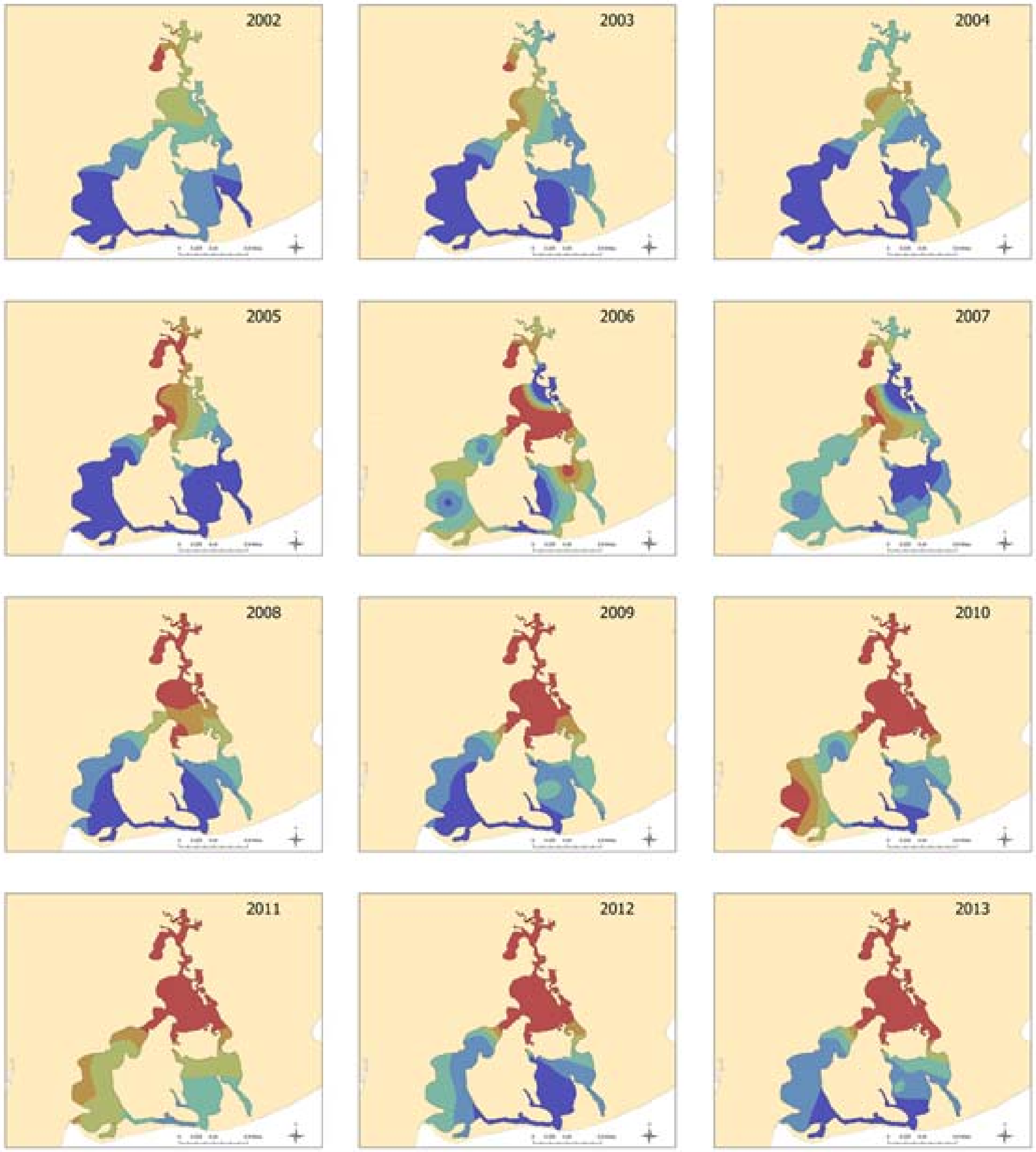


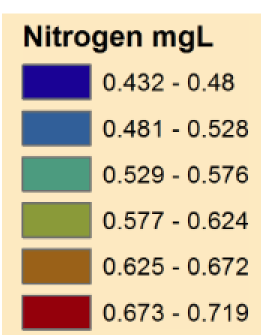
Trend in Water Quality in Three Bays

The Three Bays Estuary is one of 36 Nitrogen affected embayments on the Cape facing major water quality degradation issues. There are 18 water quality monitoring stations in the Three Bays embayment. Water quality monitoring data from the Barnstable Department of Public Works, Water and Sewer is used to calculate the Nitrogen concentration for each of the 18 stations, for each year between 2002 and 2013. Figure 3 presents the average Nitrogen concentration in the embayment compared to the threshold set by the Massachusetts Estuaries Project for Three Bays. The average Nitrogen concentration in 2002 was 0.5510 milligram per liter (MgL), and steadly increased since then. The average concentration in 2013 was 0.7559 MgL. The observed average Nitrogen concentration in the embayment has consistently been higher than the MEP set threshold for the water body of 0.38 mgL overall, and 0.40 mgL in the shallower regions of North Bay (pg, 154, Massachusetts Estuaries Project: Linked Watershed –Embayment Model to Determine Critical Nitrogen Loading Thresholds for Three Bays, Barnstable, Massachusetts, Final Report – April 2006). Figure 4 shows the changes in water quality over time and across regions within the embayment (see appendix for Kriging methodology), highlighting the north-south variation in the Nitrogen concentration and the over time.

An increase in aquatic Nitrogen concentration levels above the threshold will lead to more primary plant production in the Bays waters, increasingly negatively affecting recreational uses such as swimming, boating and water views.

Figure 4: Trend in Nitrogen Levels in Three Bays water





Massachusetts Estuaries Project's Threshold for healthy water = 0.38 Mg/L. The entire embayment exceeds the Nitrogen threshold during the study period.

Water Quality Measurement: Science based versus Perceived Water Quality

In hedonic model, water quality is measured by Nitrogen concentrations levels, a scientific measure of a specific nutrient pollution in the water. However, recreational uses of water are driven by its perceived quality. As a first step in bridging the gap between the perception and scientific measure of water quality, focus groups were gathered to understand how study site residents perceived water quality.

Recreational use depends on the location of a resident in relation to the water, and the duration the household of residence, both of which allow them to observe the changes the water quality. To account for this a double-layer design of the focus groups was implemented. The first layer captures the geographic variation in the location of the household in the relation to water, using waterfront and near-waterfront and north-south locations to mimic the Nitrogen concentration levels in figure 4. The second layer is the duration of the residency of the households, divided into long-term residents (10 years or more) and residents within the last ten years. In addition, seasonal residents were included, defined as households own property in the study area and tend to use it as a second home on weekends and for summer recreation.

In collaboration with a local non-profit, Three Bays Preservation Organization, the series of four focus groups were conducted. Participants shared their opinions in discussions about the area's current status, local housing development, changes in water quality, and how they use the embayment for recreation. Residents were asked to mark where they swam or went boating and their observations on water quality, past and current, on a map. Individually marked maps where then combined to create a "Meta-Map" that shows residents' collective perception of the water quality in different parts of the Three-Bays and their recreational use. Participants were not aware of the measured levels and variations in the Nitrogen concentrations across the embayment.

Table 1: Double – layer Focus-Group design

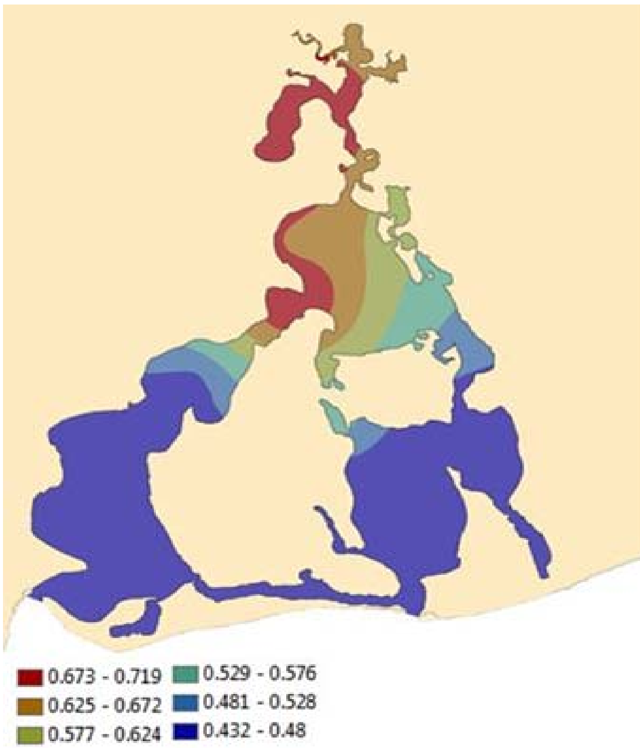
Residency\ Proximity	Owner occupied - Long-time residents (More than 10 years)	Owner occupied - New home owners (Less than 10 years)	Seasonal Residents
Water-Front	X	X	X
Near Water Front	X	X	X

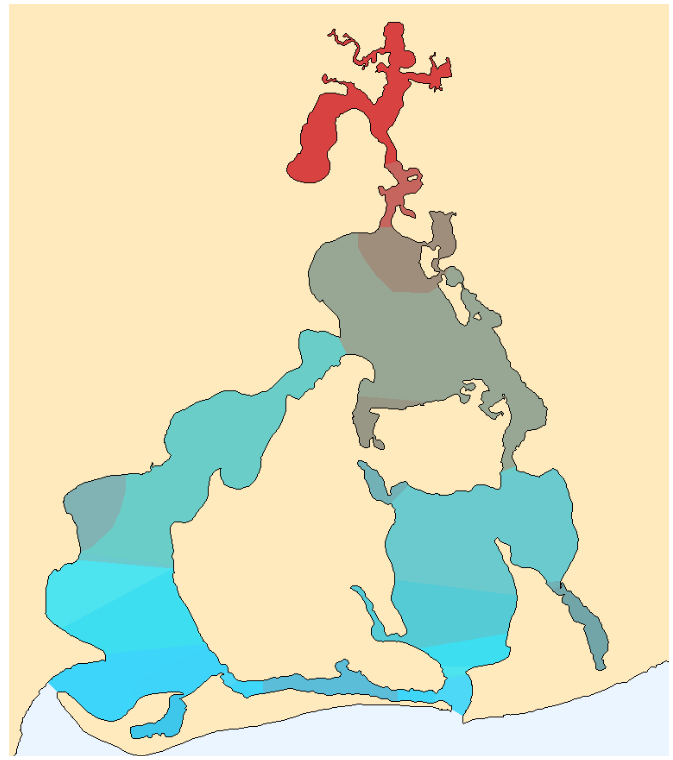
All groups reported that parts of the embayment are unsuitable for swimming or fishing during the summer due to low water quality and eutrophication. Erosion of the coast and issues with sendimentation was another common issue. Most participants cited increased housing development across the Cape, particularly in the upper Three Bays watershed, as the primary cause of water quality degradation. Some of the participants offered that there is increased "culture of lawn" as compared to 30 years ago. The increase in lawns and resulting increase in fertilizer use could be a contributing factor to eutrophication, as fertilizer run-off could add to the nutrient pollution in the water.

The focus group participants regularly use the Three Bays embayment for various recreational purposes and intimately aware of the changes in water quality over time and its seasonal variations. Participants in the focus groups are aware of different factors affecting clarity and choose their recreational uses based on the type of clarity issues they face. They understand, for instance, that clarity affected by sediment during certain times of the day may not be bad for swimming, while algae and related issues might discourage swimming. This behavioral aspect is important in understanding recreational behavior and consequent economic impact.

Figure 5 shows a comparison of the maps of measured Nitrogen concentrations and perceived water quality for recreational purposes by residents. The map created by focus group participants who rated perceived water quality was similar to the water quality readings from the sensors in the embayment. Each map demonstrates the same pattern of most-to-least Nitrogen pollution on a north-south axis, suggesting residents' perceived water quality corresponds with measured Nitrogen levels and validating the use of measured Nitrogen levels for this study's hedonic model. We could infer that the Three Bays residents are well aware of the water quality issues in their embayment, and that their perception of water quality, corresponds with the science based water quality measures, reducing the potential error-in-variables and perception biases present in traditional hedonic modeling approaches.

Figure 5: Scientific measure (Nitrogen Concentrations) versus perceived water quality by Three Bays Residents





Nitrogen concentration gradient created based 18 station data from Three Bays

Nitrogen mg/L

Meta-Map created from focus groups participants responses

Poor | Improves seasonally | Okay | Great

Hedonic Model & Data

Value of residential property is a function of several attributes, such as size, location, and proximity to environmental amenities. In contrast to conventional economic valuation where the value of a good is calculated for the whole of the good, the hedonic approach regards a good as a set of attributes and considers the value of a good as a function of each attribute. The hedonic price method developed theoretically by Rosen (1974), is based on the idea that any differentiated product, including a residential property, can be seen as a bundle of characteristics. In the Rosen framework, the price of any unit of a quality-differentiated good is a function of the levels of the characteristics embodied in the good.

$$\boldsymbol{value\ of\ a\ good} = \{(value\ of\ attribute\ 1) * (quantity\ of\ attribute\ 1)\} + \{(value\ of\ attribute\ 2) * (quantity\ of\ attribute\ 2)\} + \cdots + \{(value\ of\ attribute\ N) * (quantity\ of\ attribute\ N)\}$$

The value that consumers attach to the attributes will be reflected in the price of the differentiated product. The price of an individual attribute is called the implicit or hedonic price of that characteristic, because it cannot be observed in a real market. For example, all else same, how much value does proximity to a park or scenic view adds to a property's value? If the hedonic price function can be accurately estimated, then the slope of the function with respect to a characteristic, such as ambient environmental quality, evaluated at the individual's optimal choice, represents that individual's marginal willingness to pay for the characteristic. Hedonic price analysis is widely used for differentiated goods such as cars (Irandoust, 1998), computer equipment (Doms and Forman, 2005) and agricultural products

(Langyintuo et al., 2004). The method has been extensively used for housing and in particular the valuation of environmental amenities.

Holding other attributes constant, the change in the price of a house that results from a change in any particular attribute is called the hedonic price or implicit price of an attribute. It assumes that sales price (y) is a function of D which represents the proximity of properties to environmental amenities such as waterfront and beaches, H, housing characteristics; L, other locational amenities, and N, neighborhood characteristics (Hess and Ameida 2007). The conceptual hedonic regression model is:

$$\widehat{y_i} = f(D, H, L, N)$$

Several variables (housing sales price, age of structure, and distance to waterfront) are transformed:

$$ln(\hat{y}_i) = b_0 + \sum_{h \in H} b_h x_h + b_n x_n + b_d \ln(x_d) + \epsilon_i$$

where the dependent variable $\widehat{y_i}$ is the natural logarithm of the adjusted assessed price for each house i, and x_h is a vector of asset-specific characteristics of the properties, x_n is a locational vector (locational dummy variables), $\ln(x_d)$ is a log transformation of distance to amenities and ϵ_i is a normally distributed random error with mean zero.

In order to understand the potential effect of water quality degradation on property values, the present study used a combination of geostatistical analysis, focus groups, and GIS-based hydrological modelling. Data was drawn from property sales and assessment data, water quality sensors in the Three Bays embayment, and Barnstable County's GIS division. The inconsistency in the availability of data on all three fronts restricted the analysis to the period between 2005 and 2013. The site chosen for the study was the Three Bays watershed, in the town of Barnstable. There are 6,731 households in the study area, or about 5.2% of all households on the Cape. Of the 6,731 households, one third (2,435) are one kilometer/half mile from water, or within a 10-minute walk, as displayed in Figure 1. To map Nitrogen levels across the Three Bays embayment, this study gathered data from eighteen government-owned water quality measurement stations around the embayment and used a kriging method to generate a map displaying Nitrogen concentration across the embayment over the study period (Figure 4). Figure 6 shows a scatterplot of Nitrogen concentration and property sale prices. The correlation between these variables is -22 %, indicating a potential inverse relationship in the ensuing regression estimation.

The estimated models contain single-family home sale prices and water quality in natural logs, allowing for estimation of the elasticity. The summary of the hedonic model estimation is presented here. Table 2 shows maximum likelihood estimations of the four variations of the hedonic property price model specification. The purpose of four variations is to test the sensitivity of the model to specification changes. The first model tests some general characteristics of the neighborhood and location: waterfront location, distance to the water, general market trends, and quality of construction. The subsequent two models include amenities such as water quality and distance to the nearest public beach. The final model adds more detailed property attributes (i.e. number of rooms in the home and age of the home) to fine-tune the control in the model. Not all property attributes are included in the same model, due to multicollinearity issues.

Hedonic Estimation Results

Does Nitrogen level affect property sale prices in Three Bays study site? After controlling for property attributes, macroeconomic and other time trends, amenities such as distance to water, public beaches, and location on the waterfront, the quality of water as measured by Nitrogen concentration levels does seem to negatively influence property sale prices at the 99% confidence level. After controlling for other factors described above that affect home sale prices, for every 1% decrease in water quality (or increase in Nitrogen by 1%) home sale prices in the study site decreases between 0.41% and 0.81% (average 0.61%) at 99% confidence level.

How do locational amenities affect the home sale price in the study site? Every 1% proximity to the water increases home sale prices between 0.10% to 0.29% (average 0.19%). After controlling for other factors, being located right on the waterfront increases the home sale prices by 90% compared to other properties within the study area. Proximity to public beaches seems to have very small (0.006%) positive effect on sale price; however it is not statistically significant. The insignificance of the effect of proximity to public beaches is not surprising since most waterfront properties have private beaches or a waterfront suitable for most recreational activities that might be shared with the neighbors and friends within the neighborhood.

Quality of construction, as expected, increases property sale prices. Compared to an home graded as “average” quality, a home graded as “luxury” commands a sale price that is higher by

122% and a home graded as "superior" commands a sale price that is 218% higher than an average home, all other characteristics including neighborhood and amenities being similar.

Table 2: Hedonic model estimations

	Model (1)	Model (2)	Model (3)	Final Model
Water quality (Nitrogen levels)	-	-0.668***	-0.673***	-0.607***
		(-7.69)	(-7.22)	(-5.95)
Waterfront	0.858***	0.839***	0.829***	0.900***
	(9.54)	(9.83)	(9.59)	(9.75)
Distance from water	-0.205***	-0.231***	-0.229***	-0.199***
	(-4.27)	(-5.05)	(-4.96)	(-3.99)
Distance to nearest public beach	-	-	0.00108	0.00588
			(0.04)	(0.20)
Number of rooms in the home	-	-	-	0.0319***
				(3.45)
Age of the home	-	-	-	0.0000821
				(0.13)
Macroeconomic Influences and Market trend (Time fixed effects)	*Binary variables for 8 years (2005 - 2013)*			
Initial quality of construction of the property	*Binary variables for 19 levels of property quality*			
Constant	14.25***	14.05***	14.02***	13.63***
	(41.41)	(42.87)	(36.60)	(33.19)
N	634	634	634	531
R-squared	68.00%	71.30%	71.30%	72.30%
*** p<0.05 ** p<0.01 *** p<0.001**	Z statistics in parentheses			

Implications

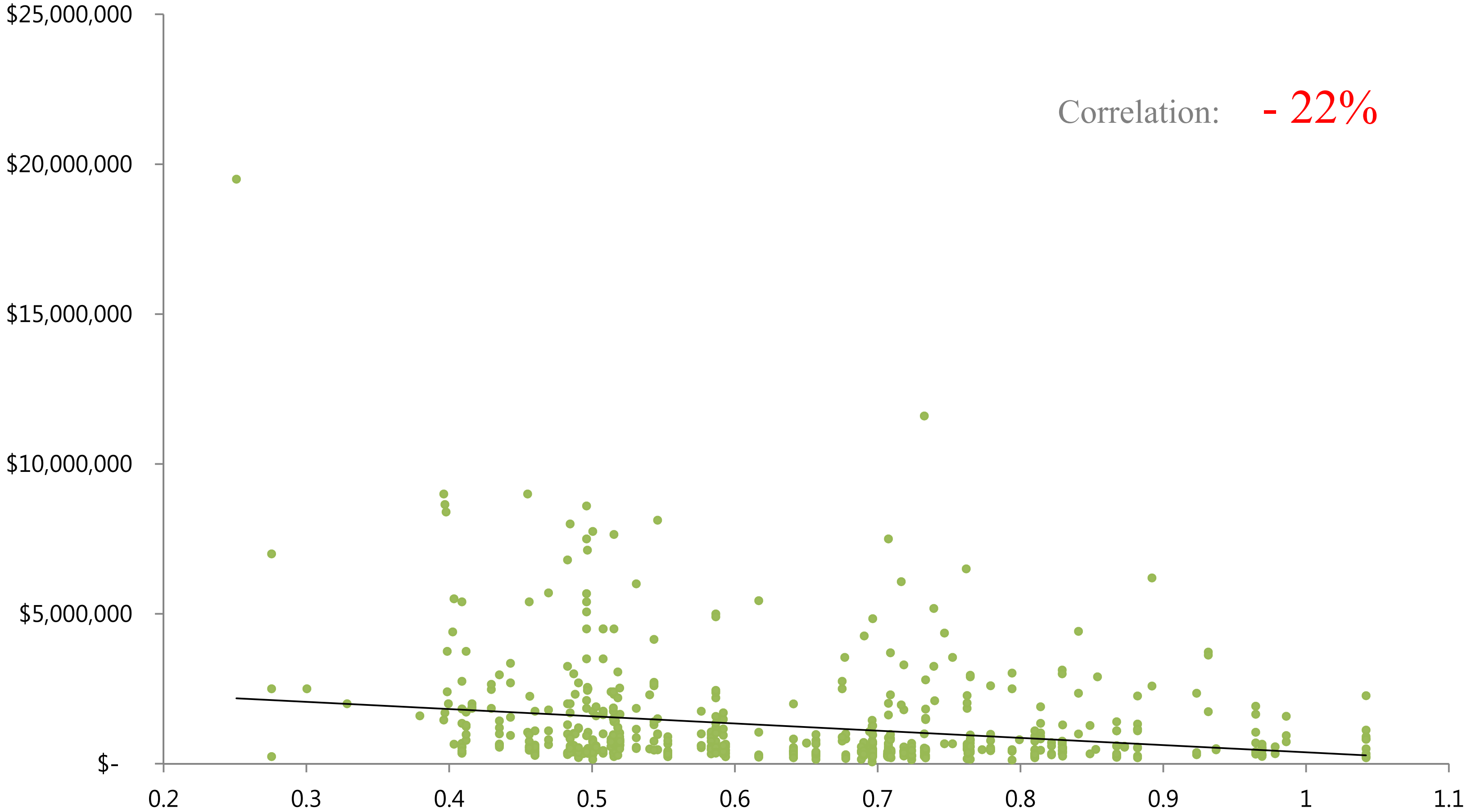
During the time period of the study (2005-2013) water quality declined (or Nitrogen concentration increased) by 15.84%. For the above findings of a 0.61% decline in value per 1% drop in water quality, the jump in Nitrogen concentration translates into a noticeable fiscal impact on the community, both in terms of decreased sale price and consequent impact on the assessed value.

For example, if theoretical efforts to curb the discharge of Nitrogen into the Three Bays watershed had resulted in a modest 3% decrease in total Nitrogen levels in 2005, the average single-family home sale price in the study area would have been $16,774 to $32,957 higher in 2013. That translates into potential sale value loss (and consequent assessed value loss) in the range of $41 to $80 million in the study site alone. This estimated loss in assessed value means $295,715 to $581,019 in shifted property tax burden for 2013. The amount of shift in the burden would depend on the relative assessed value changes between near-waterfront and inland properties. The current study of waterfront properties in Three Bays serves to illustrate the point that a decrease in water-quality can have a significant impact on property values that affects not just the property owner, but all the taxpayers within the town.

Conclusion

This combined approach of hedonic modeling and behavioral validation is an important preliminary step in addressing omitted variable and perception biases present in traditional hedonic modeling approaches. From a policy perspective, the paper's findings of a statistically significant link between water quality and coastal property sale prices can assist regional policy makers with decision-making by showing estimated home value losses resulting from lower water quality, values that have critical property tax implications for regions economically dependent on water quality such as Cape Cod.

Figure 6: Single Family Home Sale Prices Vs Nitrogen concentration Levels



References:

Alvarez, Sergio and Serhat Asci. 2014. Estimating the Benefits of Water Quality Improvements Using Meta-Analysis and Benefits Transfer. Southern Agricultural Economics Association, 2014 Annual Meeting, February 1-4, 2014, Dallas, Texas.

Ara, Shihomi, Elena Irwin, and Timothy Haab. 2006. The Influence of Water Quality on the Housing Price Around Lake Erie. American Agricultural Economics Association, 2006 Annual Meeting, July 23-26, 2006, Long Beach, California.

Artell, Janne. 2014. Lots of Value? A spatial hedonic approach to water quality valuation. Journal of Environmental Planning and Management 57(6): 862-882.

Barrager, Stephen M. 1974. The Impact of Water Resources Quality Changes on Surrounding Property Values. Journal of the American Water Resources Association 10(4): 759-765.

Bin, O., and J. Czajkowski. 2013. The Impact of Technical and Non-technical Measures of Water Quality on Coastal Waterfront Property Values in South Florida. Marine Resource Economics, 28(1): 43-63.

Boyle, KJ, et al. (1998). Lakefront Property Owners' Economic Demand for Water Clarity in Maine Lakes. Miscellaneous Report 410. University of Maine: Maine Agricultural and Forest Experiement Station.

Braden, John B., Arianto A. Patunru, Sudip Chattopadhyay, and Nicole Mays. 2004. Contaminant Cleanup in the Waukegan Harbor Area of Concern: Homeowner Attitudes and Economic Benefits. Journal of Great Lakes Research, 30(4): 474-491.

Braden, John B., Xia Feng, and DooHwan Won. 2011. Waste Sites and Property Values: A Meta-Analysis. Environmental Resource Economics, 50(2): 175-201.

Bradhares, E. N. 1985. Estimating the Instream Value of Lake Water Quality in Southeast Michigan. Diss. University of Michigan.

Cho, Seong-Hoon, Roland K. Roberts, Seung Gyu Kim. 2011. Negative externalities on property values resulting from water impairment: The case of the Pigeon River Watershed, Ecological Economics, Volume 70, Issue 12, 15 October 2011, Pages 2390-2399, ISSN 0921-8009, http://dx.doi.org/10.1016/j.ecolecon.2011.07.021.

Clapper, Julia and Steven B. Caudill. 2014. Water quality and cottage prices in Ontario. Applied Economics 46(10): 1122-1126.

Crompton, John L. 2004. The Proximate Principle: The Impact of Parks, Open Space and Water Features on Residential Property Values and the Property Tax Base. Second Edition. Ashburn, Virginia: National Recreation and Park Association.

d'Arge Ralph C. and Jason F. Shogren. 1989. Okoboji Experiment: Comparing Non-Market Valuation Techniques in an Unusually Well-Defined Market for Water Quality. Ecological Economics, 1(3): 251-259.

David, Elizabeth L. 1968. Lakeshore Property Values: A Guide to Public Investment in Recreation. Water Resources Research 4(4): 697-707.

Dornbusch, D.M., and S.M. Barrager. 1973. Benefit of Water Pollution Control on Property Values. EPA-600/5-73-005. Washington, DC: U.S. Environmental Protection Agency.

Dotzour, Mark G. 1997. Groundwater Contamination and Residential Property Values. Appraisal Journal, 65: 279–287.

Epp, D.J. and K.S. Al-Ani. The effect of water quality on rual nonfarm residential property values, American Journal of Agricultural Economics 61 (3): 529-534.

Faith, Linnae. 2011. Measuring the Economic Benefits of Water Quality Change: Literature Review and Meta-Analysis (Master's Thesis). Department of Agricultural, Environmental, and Development Economics, The Ohio State University.

Feather, T, et al. 1992. Valuation of Lake Resources through Hedonic Pricing. IWR Report 92-R-8. US Army Corps of Engineers Water Resource Support Center,Fort Belvoir, VA.

Fisher, W., N. Starler, and A. Fisher. 1976. Environmental Impact on Property Values Along New York's Lake Erie Coastline. Journal of Great Lakes Research, 2(1): 78-88.

Gibbs, J, et al. 2002. An Hedonic Analysis of the Effects of Lake Water Clarity on New Hampshire Lakefront Properties. Agricultural and Resources Economics Review 31(1): 39-46.

Horsch, Eric J. and David J. Lewis. 2009. The Effects of Aquatic Invasive Species on Property Values: Evidence from a Quasi-Experiement. Land Economics, 85(3): 391-409.

Hsu, T. 2000. A hedonic study of the effects of lake—water clarity and aquatic plants on lakefront property prices in Vermont (abstract only). University of Maine. Master Thesis.

Kashian, R, et al. 2006. Lake Rehabilitation and the Value of Shoreline Real Estate: Evidence from Delavan, Wisconsin. Review of Regional Studies 36(2): 221-238.

Kirshner, D., and D. Moore. 1989. The effects of San Francisco Bay water quality on adjacent property values. Journal of Environment Management 29: 263–274.

Krysel, C, et al. 2003. Lakeshore Property Values and Water Quality: Evidence from Property Sales in the Mississippi Headwaters Region. Submitted to the Legislative Commission on Minnesota Resources.

Leggett, C and Bockstael, NE. 2000. Evidence of the Effects of Water Quality on Residential Land Prices. Journal of Environmental Economics and Management 39: 121-144.

Liu, Hongxing, Sathya Gopalakrishnan, Drew Browning, Patrick Herak, and Gajan, Sivandran. 2014. Estimating the impact of water quality on surrounding property values in Upper Big Walnut Creek Watershed in Ohio for dynamic optimal control. Agricultural and Applied Economics Association, 2014 Annual Meeting, July 27-29, 2014, Minneapolis, Minnesota.

Mazzotta, Marisa, Elena Besedin, and Lauren Parker. 2010. Memorandum: Literature Review on the Effect of Water Quality Impacts on Residential Property Values.

McMillen, Daniel P. 2003. Economic Benefits of the Grand Calumet River Remediation Project: Evidence from the Gary Housing Market. A Report Prepared for the Delta Institute.

Michael, HJ, et al. 2000. Does the Measurement of Environmental Quality Affect Implicit Prices Estimated from Hedonic Models? Land Economics 76(2): 283.

Morgan, O. Ashton, Stuart E. Hamilton, and Victoria Chung. 2010. Water Quality and Residential Property Values: A Natural Experiment Approach. Appalachian State University, Department of Economics Working Paper.

Netusil, Noelwah R., Michael Kincaid, and Heejun Chang. 2014. "Valuing water quality in urban watersheds: A comparative analysis of Johnson Creek, Oregon, and Burnt Bridge Creek, Washington." Water Resources Research 50(5): 4254-4268.

Poor, P, et al. 2001. Objective Versus Subjective Measures of Water Clarity in Hedonic Property Value Models. Land Economics 77(4): 482-493.

Poor, P, et al. 2007. Exploring the hedonic value of ambient water quality: A local watershed-based study. Ecological Economics 60: 797-806.

Steinnes, Donald N. 1992. Measuring the economic value of water quality: the case of lakeshore land. The Annals of Regional Science 26(2): 171-176.

Tuttle, Carrie M. and Martin D. Heintzelman. 2014. A Loon on Every Lake: A Hedonic Analysis of Lake Water Quality in the Adirondacks. Resource and Energy Economics, forthcoming.

Van Houtven, George, Laurel Clayton, and Michele Cutrofello. (March 2008). Assessing the Benefits of U.S. Coastal Waters Using Property Value Models; Draft Report.

Walsh, P, et al. 2010. The Spatial Extent of Water Quality Benefits in Urban Housing Markets. Working Paper Series. U.S. Environmental Protection Agency: National Center for Environmental Economics, Washington, DC: 35.

Young, C. Edwin. 1984. Perceived Water Quality and the Value of Seasonal Homes. Journal of the American Water Resources Association 20(2): 163-166.

Zhang, Congwen and Kevin J. Boyle. 2010. The effect of an aquatic invasive species (Eurasian watermilfoil) on lakefront property values. Ecological Economics, 70(2): 394-404.

Appendix:

Water Quality Changes over time and across the study site: Kriging Methodology

Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. The procedure generates or interpolates a probability surface that fits best to a scattered set of point values in two-dimensional space. It is different from other interpolation methods supported by ArcGIS as it involves an interactive investigation of the spatial behavior of the point values, from which the best estimation method is selected to map the output surface. Since Kriging presumes a uniform pattern of distribution of point values which is never found in nature, therefore, the spatial variation is quantified by the semivariogram.

Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. The Kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. Kriging is a multistep process; it includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and (optionally) exploring a variance surface. Kriging is most appropriate when there is a known a spatially correlated distance or directional bias in the data.

Kriging is similar to Inverse Distance Weighting (IDW) in that it weights the surrounding measured values to derive a prediction for an unmeasured location. The general formula for both interpolators is formed as a weighted sum of the data:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)$$

where:

$Z(s_i)$ = the measured value at the ith location

λ_i = an unknown weight for the measured value at the ith location

s_0 = the prediction location

N = the number of measured values

In IDW, the weight, λ_i, depends solely on the distance to the prediction location. However, with the kriging method, the weights are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement of the measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus, in ordinary kriging, the weight, λ_i, depends on a fitted model to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location.