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THREE ESSAYS ON THE ECONOMICS OF ECOSYSTEM SERVICES AND LAND USE CHANGE

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THREE ESSAYS ON THE ECONOMICS OF ECOSYSTEM SERVICES AND LAND
USE CHANGE

BY

TINGTING LIU

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

IN

ENVIRONMENTAL AND NATURAL RESOURCE ECONOMICS

UNIVERSITY OF RHODE ISLAND

2014

DOCTOR OF PHILOSOPHY DISSERTATION

OF

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UNIVERSITY OF RHODE ISLAND
2014

ABSTRACT

Over the past few decades, agricultural and forest lands in the northeast US have been lost to residential development. Combined with more intensive farming on remaining lands, these trends have led to losses in valuable ecosystem services from the agricultural and forest landscape. Narragansett Bay is also exhibiting an increasing array of eutrophic-associated symptoms, including low dissolved oxygen, fish kills, eelgrass loss, algae blooms, and loss of submerged aquatic vegetation (Narragansett Bay Estuary Program, 2008).

This dissertation contains three essays to quantify and value the changes in ecosystem services and to evaluate the effectiveness of policy for land use management. Manuscript 1 seeks to illustrate a method for spatially quantifying hydrological ecosystem services (water quality and quantity) related to wildlife habitat and flood risks, as well as the production of ecosystem services (food and fiber) at the watershed scale. I also investigate the effects of stressors faced in the coming decades—land use change and climate change—as well as choices in land management practices on production of these ecosystem services. I demonstrate the approach in the Beaver River watershed in Rhode Island using a spatially-explicit, process-based hydrological model (SWAT). My key finding is that choices in land use and land management practices create tradeoffs across multiple ecosystem services and that the extent of these tradeoffs depends considerably on the scenarios and the ecosystem services being compared. Stressors such as urbanization, increased agriculture intensity and climate change make spatially explicit modeling necessary to understand the complex relationships between efficient land use and the complexity in the function of ecosystems.

My second manuscript examines the direct and spillover effects of residential zoning policy on land development. Zoning has been widely used as a tool to manage residential development. Residential zoning policy regulation, particularly minimum lot size zoning restrictions in one area may affect the land development of the area itself as well as in the adjacent areas. Accounting for both the direct and the potential spillover effects of minimum lot size zoning restrictions is important for land use planning. However, limited research has been done to examine the spillover effect of minimum lot size zoning restrictions on nearby land development. In this study, I estimate the direct and spillover effect of minimum lot size zoning restrictions in Rhode Island. To address the non-random placement of residential zoning, I use propensity score matching and nearest neighborhood matching to preprocess the data. Additionally, to address simultaneity and the presence of spatially correlated unobserved characteristics, I use the soil construction constraint index as an instrumental variable for minimum lot size restriction. Results suggest that minimum lot size restrictions in the neighborhood significantly decrease the probability of urban development outside of the zoned area, up to a 2000 meters radius buffer.

In my third manuscript, I examine the impact of water quality in Narragansett Bay on housing prices in coastal towns and municipalities using a hedonic housing price model. Compared with other water quality related hedonic studies, I combine an improved inversed distance weighted (IDW) interpolation method with water quality region, to best capture the water quality in Narragansett. Additionally, I compare different measures of Chlorophyll concentration as indicators of coastal water quality. Estimation results show that the coastal water quality indicator for Chlorophyll

concentrations has a negative impact on the housing prices, and the negative impact of water quality attenuates with increasing distance from the shoreline. In the comparison of alternative measurements for water quality, I find a substantial difference among the estimations results. I further estimate potential increases in the value of the housing stock associated with different scenarios for water quality improvements in Narragansett Bay.

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PREFACE

This dissertation submitted in partial fulfillment of the requirements for the degree of doctor of philosophy in Environmental and Natural Resource Economics is in the manuscript style format. The dissertation is composed of three manuscripts.

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Introduction

Over the past century, human-dominated land uses have spread rapidly across landscapes all over the world (Food and Agriculture Organization, 2012). In the eastern United States, a major trend is that urbanization is causing both forest and agricultural lands to decline (Zhou, Wang, Gold, & August, 2010). Evidence is accumulating that, among all the factors that influence the provision of ecosystem services, land use change is one of the two major drivers (Schröter et al., 2005). For example, land use changes led to the deterioration in inland and coastal ecosystem services such as biodiversity loss, water contamination, ecosystem degradation, and coastal floods (Tinch, 2011).

This dissertation assesses the effectiveness of policies for land use management, and changes in ecosystem services in Southern New England. As one of the most densely populated states in the US, the portion of Rhode Island that can be considered urban has increased by 74% from 1972 to 2010 while agricultural land and forests have decreased by 24% and 18%. With rampant increases in residential development in Rhode Island, both inland and coastal ecosystems are at risk. Narragansett Bay was listed as one of 20 most contaminated waterways in U.S. (NOAA, 2011). The pollutants include nitrogen and phosphorous emitted as a result of failing septic systems, inadequate wastewater treatment, and agricultural and urban runoff (NOAA, 2011). As a consequence, Narragansett Bay is exhibiting an increasing array of eutrophic-associated symptoms, including low dissolved oxygen, fish kills, eelgrass loss, algae blooms, and loss of submerged aquatic vegetation (Narragansett Bay Estuary Program, 2008).

One challenge in enhancing ecosystem services in Rhode Island is to manage land use more effectively. In the absence of appropriate land use and growth management

controls, increasing urban sprawl has degraded surface and groundwater quality and damaged critical resources (RIDOA, 1991). A series of laws since the late 1980s required municipalities to take into account the effect of existing and projected population growth and land development pressure on local resources. As in many other states in the U.S., Rhode Island has adopted a number of policies, including property tax reform, zoning regulations and ordinances, smart growth policy, and investments in land conservation (Juergensmeyer and Roberts 1003; Gardner, 1977; Daniels and Lapping, 2005; Hollingshead, 1996). However, little research has been done on the effectiveness of residential zoning on development, especially concerning residential zoning's potential spillover effect. Furthermore, there are even fewer studies on the change in ecosystem services and potential benefits captured in housing prices in Rhode Island.

This dissertation contains three essays to quantify and value the changes in ecosystem services and to evaluate the effectiveness of policy for land use management. The first manuscript models the production of multiple ecosystem services and conducting tradeoff analysis under different land use, land management, and climate change scenarios. The second manuscript investigates the direct and spillover effects of minimum lot size zoning restrictions. The third manuscript conducts a non-market valuation of water quality using hedonic housing price approach. The study area extends from inland watershed (first manuscript) to coastal towns and cities (second and third manuscripts) and examines the impact of nutrient reduction, water quality improvement and its impact on the housing prices in Narragansett Bay in southern New England.

The overall goal of the first manuscript is to demonstrate a method for spatially quantifying multiple ecosystem services and the potential tradeoffs at the watershed scale.

I examine the changes in ecosystem services of alternative scenarios based on the key stressors and factors: land use change, land management practices and climate change, using an existing hydrological model and data. First, I quantify key hydrological ecosystem services under the current land cover, land management, and climatic conditions. Second, I develop seven alternative scenarios based on the key stressors (land use change, climate change and changes in land management practices). Then I simulate their effects on the hydrological ecosystem services and crop production. Third, I illustrate how tradeoffs could be examined across ecosystem services that arise from the alternative scenarios, if given sufficient data with which to characterize those ecosystem services deemed relevant to land use policy. Using a GIS mapping approach, I also show how such an analysis could be used to identify particular areas within the watershed that have important combinations of services for the watershed as a whole.

My key finding is that choices in land use and land management practices create tradeoffs across multiple ecosystem services and that the extent of these tradeoffs depends considerably on the scenarios and the ecosystem services being compared. Stressors such as urbanization, increased agriculture intensity and climate change make spatially explicit modeling necessary to understand the complex relationships between efficient land use and the complexity in the function of ecosystems.

The second manuscript focuses on zoning regulations as a public policy to maintain or enhance ecosystem services from the rural-urban landscape. Specifically, I examine the direct and spillover effects of minimum lot size zoning restrictions on land development. Although zoning is in widespread use, little is known of its overall effectiveness, particularly with regards to how the regulation affects its surrounding

development, i.e., spillover effect on the adjacent land. Residential zoning may be effective in terms of controlling development of the zoned area itself (Ihlanfeldt, 2007). However, at the same time, it may push development to nearby areas outside of the zoning areas due to the spillover effect. It may stimulate, instead of discourage, neighborhood land use change if the residential zoning in the neighborhood is less restricted compared to the pixel itself. Examining the overall impact of residential zoning at a smaller scale within different distance radius is therefore an empirical question.

To address the non-random placement of residential zoning, I use propensity score matching and nearest neighborhood matching to preprocess the data. Additionally, to address simultaneity and the presence of spatially correlated unobserved characteristics, I use the soil construction constraint index as an instrumental variable for minimum lot size restriction. The direct effect are consistent among all models regardless of what neighborhood definition is, pixel's minimum lot size zoning restrictions have a negative and significant influence on the pixel's development. Estimation results suggest that minimum lot size restrictions in the neighborhood significantly decrease the probability of urban development outside of the zoned area, up to 2000 meters radius buffers. Results also suggest policy makers should take into account of the spillover effect of minimum lot size zoning restriction when they make their comprehensive plans. For example, to obtain sustainable development, policy makers may want to encourage urbanization in some areas while conserve other places for amenities or future development. In such cases, accounting for the spillover effect of minimum lot size zoning restriction will be important when designing comprehensive zoning plans and also make these regulations more effective.

My third manuscript examines the impact of water quality in Narragansett Bay on housing prices in coastal towns and municipalities of Rhode Island using hedonic housing price model. In comparison to the benefit transfer method (Manuscript one) which transfers dollar values from other studies, hedonic models have an advantage of estimating values based on the actual choices reflected in the housing market (Freeman, 2012). By observing houses that only vary by one characteristic (e.g. an extra unit of Chlorophyll concentration increase ($\mu\text{g/L}$) while holding other attributes constant), the tradeoff can be indirectly derived based on the choice that individual makes (Taylor, 2012).

This study examines the impact of nutrient reduction, water quality improvement and its impact on the housing prices in the Narragansett Bay using hedonic housing price method. I use Chlorophyll concentration as water quality indicator for Narragansett Bay since it can be easily observed by color, odor, or even algae blooms when the level is very high. Compared to the previous literature, which mostly use median or average of water quality indicator, I also investigate the impacts from the extreme events, which are the measurement at the 99th percentile, 95th percentile, and 90th percentile of Chlorophyll concentration.

The results from alternative models using different water quality measurements consistently demonstrate that the water quality in Narragansett Bay has influenced the housing prices in the coastal towns and municipalities. The impact of water quality on house prices decays with distance from the shoreline. The magnitude of the estimated results vary only slightly when using Chlorophyll concentration 99th percentile, 95th percentile, 90th percentile level measurements. However the difference in the estimates is

quite large (40% difference) when the median of Chlorophyll concentration is used as the water quality measurement.¹ Scenario simulation results show that under the nitrogen reduction intervention scenario (25% reduction in Chlorophyll concentration), the potential benefits varies from 64 to 261 million dollars depending on the choice of water quality measurement. Since there is a substantial difference among the estimations of using different measurements of water quality indicators, it suggests that decision makers should be aware of the resulting difference in potential benefits gained by houses near to the affected coastal areas.

It is important to note that the hedonic housing price approach only captures the marginal benefit of marginal changes in water quality that are capitalized into values of houses. There are other benefits from water quality improvement that are not accounted for in this valuation, such as the recreation use by people who live further from the bay, non-use values such as existence values, as well as economic benefits from recovered Rhode Island fishery industry (including shellfish).

Despite this limitation, the scenarios analysis combines both the nitrogen reduction intervention scenario and other alternative scenarios, thus highlighting the potential benefits of improved water quality associated with housing prices.

¹ The coefficients range from -0.030 to -0.037(33% difference), -0.016 to -0.020(25% difference), -0.015 to -0.021(40% difference) for different interactions terms.

Modeling the Production of Multiple Ecosystem Services from Agricultural and Forest Landscapes in Rhode Island

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MANUSCRIPT 1

Modeling the Production of Multiple Ecosystem Services from Agricultural and Forest Landscapes in Rhode Island

Abstract: Over the past few decades, agricultural and forest lands in the northeast US have been lost to residential development. Combined with more intensive farming on remaining lands, these trends have led to losses in valuable ecosystem services from the agricultural and forest landscape. This study seeks to illustrate a method for spatially quantifying hydrological ecosystem services (water quality and quantity) related to wildlife habitat and flood risks, as well as the production of ecosystem services (food and fiber) at the watershed scale. We also investigate the effects of stressors faced in the coming decades—land use change and climate change—as well as choices in land management practices on production of these ecosystem services. We demonstrate the approach in the Beaver River watershed in Rhode Island using a spatially-explicit, process-based hydrological model (SWAT). Our key finding is that choices in land use and land management practices create tradeoffs across multiple ecosystem services and that the extent of these tradeoffs depends considerably on the scenarios and the ecosystem services being compared. Stressors such as urbanization, increased agriculture intensity and climate change make spatially explicit modeling necessary to understand the complex relationships between efficient land use and the complexity in the function of ecosystems.

Keywords: Ecosystem Services, Land Use Change, SWAT, Tradeoff Analysis, Climate Change

I Introduction

Over the past century, human-dominated land uses have spread rapidly across landscapes all over the world (FAO, 2012). In the eastern United States, a major trend is that urbanization is causing both forest and agricultural lands to decline (Y. Zhou et al., 2010). For example, in Rhode Island, urban sprawl has affected landscapes across the state, with residential areas spreading further away from the city of Providence (Rhode Island Division of Planning, 2006). In addition, the remaining working farmlands have become more intensively managed. Combined, these land use and land management changes are leading causes of losses in valuable ecosystem services associated with managed forests and agricultural lands such as provision of clean water, regulating streamflow and supporting wildlife habitat (Hascic & Wu, 2006).

One challenge to enhance ecosystem services in Rhode Island is that about 90% of land is privately owned (National Wilderness Institute, 1995). Owners of agricultural and forest land provide private goods in the form of crops and timber. However, they do not have the incentives to protect ecosystem services which provide public goods, such as water quality and environmental flow, the water flow necessary to maintain aquatic habitat. These issues call for public policy to motivate private owners to provide these types of ecosystem services.

Another challenge for decision makers in designing policies to protect or enhance multiple ecosystem services in a landscape is that they need to make tradeoffs across those services. Conversion of agricultural lands into residential and commercial development may spur regional economic growth and increase a tax base, but at the same time lead to even worse water quality and increased flood risks. To inform decision

makers, it is necessary to make a systematic assessment of the potential tradeoffs across multiple ecosystem services that arise as a result of land use and management decisions. However, policymakers often lack the funding or expertise to develop methods with which to evaluate complex tradeoffs involving land use change, land management practices and their influence on valued ecosystem services. One solution would be to adapt existing models and data for the purpose of characterizing ecosystem services associated with different land uses.

Despite the importance, such quantitative information at the landscape scale that is useful for decision makers is still rare to date. Limited economic research has been done on the ecosystem services related to the water quality, such as nutrient loading and sediment loading (Kling, 2011; Swallow et al., 2009), but few have focused on the ecosystem services related to water quantity such as environmental flow and flood risks. Moreover, previous studies on ecosystem services have focused on one or two hydrological ecosystem services³ (Kling 2011; Swallow et al. 2009) and few studies to date have looked at the tradeoffs among multiple ecosystem services (Lautenbach et al., 2010; Nelson et al., 2009). Lastly, most of the previous economic studies that use a spatially-explicit hydrological model have been in the context of the Chesapeake Bay (Richardson, Bucks, & Sadler, 2008; Tomer & Locke, 2011) and the Upper Mississippi River Basin (Kling, 2011; Wu & Tanaka, 2005). These gaps in the literature are partly due to the conceptual and computational challenge in demonstrating the linkages between the choices in land use and management and their effects on the hydrological regimes,

³ Hydrological ecosystem services are water-related ecosystem services, which include both quantity and quality of water.

and then linking the changes in hydrological outcomes to shifts in multiple ecosystem services that benefit people (Korsgaard & Schou, 2010).

To address these gaps in the literature, this manuscript will focus on hydrological ecosystem services, both water quantity (environmental flow and flood risks) and quality (nitrogen and phosphorous). In some areas, freshwater rivers and streams are stressed by over withdrawal of water (Watershed Counts, 2014). As humans withdraw a growing share of the available freshwater, less is available to maintain vital ecosystems. Already, freshwater fish species in Rhode Island are threatened and declining (NOAA National Marine Fisheries Service, 2009). Resiliency towards flood risks is a critical ecosystem service in RI and other New England regions, especially in light of increased impervious cover from urbanization, which can increase flash flooding, along with the potential increase in the magnitude of precipitation events due to climate change. Water quality of lakes for recreation and health risks associated with drinking water are growing concerns in RI (RIDEM, 2012). Another contribution of this research is that we examine the spatial heterogeneity and tradeoffs in provision of multiple ecosystem services within a watershed, which can be informative for stakeholders in targeting conservation efforts. Additionally, this research is one of the first studies which examines tradeoffs among hydrological and other ecosystem services in the Northeast US. In addition to the impact of BMPs (which has been the focus of other studies), we also examine the impact of land use change from agricultural/forest land to residential development, which has become one of the key stressors to ecosystem services in the region.

The overall goal of this study is to demonstrate a method for spatially quantifying multiple ecosystem services and the potential tradeoffs at the watershed scale. We

examine the changes in ecosystem services of alternative scenarios based on the key stressors and factors: land use change, land management practices and climate change, using an existing hydrological model and data. First, we will quantify key hydrological ecosystem services under the current land cover, land management, and climatic conditions. Second, we will develop seven alternative scenarios based on the key stressors (land use change, climate change and changes in land management practices). We will simulate their effects on the hydrological ecosystem services and crop production. Third, we will illustrate how tradeoffs could be examined across ecosystem services that arise from the alternative scenarios, if given sufficient data with which to characterize those ecosystem services deemed relevant to land use policy. We also show how such an analysis could be used to identify particular areas within the watershed that have important combinations of services for the watershed as a whole.

One of the challenges in measuring the tradeoffs among different ecosystem services is to ensure that ecological and hydrological models reflect the complexities, nonlinearities and dynamic nature of the ecosystem (National Research Council, 2004). In our research, in order to make inferences of the effect of land use and management choices with useful spatial detail for decision makers, we use the Soil Water Assessment Tool (SWAT), a process-based, spatially-explicit hydrological model. Since each piece of land plays an intricate function in the watershed, these stressors have heterogeneous effects on the function of the ecosystem depending on where these changes take place in the watershed. One caveat is our analysis only includes relevant ecosystem services such as environmental flow, flood risks and water quality and does not provide a complete accounting of all private and public benefits and costs associated with land uses in the

watershed. However, we show how tradeoffs across selected ecosystem services could be evaluated qualitatively using graphing and mapping methods.

II Methodology

We demonstrate our approach using the Beaver River watershed as a case study⁴ (Figure 1). Covering about eight square miles in southern Rhode Island, the watershed is lightly developed with only 2.3% of land having been converted to residential and commercial development, and more than 90% is deciduous forest, softwood forest and mixed forest (RIGIS, 2012). Agricultural land uses only comprise about 0.9% of the total area. During the past three decades, agricultural land declined by 1% and deciduous forests declined by 5%, while conifers and mixed forests increased by about 2% and 3%, respectively.

The Beaver River watershed is exemplary of a watershed that is important for hydrological ecosystem services such as environmental flow and water quality.⁵ It is one of the major tributaries to Pawcatuck River, beneath which lies a supply of groundwater which serves as the sole source of drinking water for more than 60,000 local residents (The Nature Conservancy, 2012a). Additionally, it supports roughly 70% of RI's

⁴The Beaver River streamflow monitoring gauge is located at the outlet of the Beaver River watershed in Washington County (Hydrologic Unit 01090005, USGS Water Resource).

⁵ The Beaver River watershed is comprised of first through third order streams that represent headwater tributaries of a larger watershed. These low order streams account for approximately 60 to 80% of total stream length within most watersheds (Leopold, Wolman, & Miller, 1995; Shreve, 1969), and typically drain 70 to 80% of the total watershed area (Meyer et al., 2001; Sedell et al. 1990). Given their location and abundance within the stream network, headwater streams significantly contribute to the hydrological, physical, chemical, and biological integrity of downstream waters (Meyer et al., 2001; Nadeau & Rains, 2007; Vannote et al. 1980). In New England, it is these headwater streams that provide the spawning and nursery grounds for cold-water fisheries and anadromous fish. Further downstream, riverine functions and values are frequently dominated by the effects of dams, reservoirs and point sources of pollution. The ecosystem functions of headwater streams such as those found within the Beaver River watershed are most influenced by land use and non-point pollution that is simulated by models such as SWAT.

globally imperiled species such as Ringed Boghaunter dragonfly (*Williamsonia lintneri*) (The Nature Conservancy, 2012b). However, we acknowledge that a limitation of focusing on a small watershed such as the Beaver River is that we are not capturing the effects of different scenarios on ecosystem services in areas further downstream. Any externalities may occur not only at a different location downstream but also at a different point in time.

SWAT model

We utilize a spatially-explicit hydrologic model called Soil and Water Assessment Tool (SWAT) to quantify the effect of the key stressors on hydrological ecosystem services in the Beaver River watershed. Developed by the USDA Agriculture Research Service, SWAT is a process-based, watershed-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. Compared to other hydrological models, SWAT has proven to be an effective tool for assessing water resource and non-point source pollution problems for a wide range of scales and environmental conditions across the globe (Gassman, Reyes, Green, & Arnold, 2007). Moreover, it has been widely used to simulate the impacts of land use, land management practices and climate change on the quality and quantity of surface and ground water. Importantly, in a recent study, Rabotyagov *et al.* (Rabotyagov et al., 2010) found that using SWAT results in a more cost-effective site selection for a reverse auction compared to USLE and MUSLE. One advantage of SWAT is that the model can be calibrated and validated to actual observations. This process allows SWAT to better reflect the physical process of water and pollutant flux in a watershed, which is an advantage in simulating the environmental

impacts of land use change, land management and climate change. SWAT also has the advantage over other models in that it uses readily available data, can operate in large-scale basins, has the possibility of simulation for long periods of time, and has a history of successful usage (Arnold & Fohrer, 2005). The Beaver River watershed is at the lower bound of the range of watershed size for which SWAT is suitable (Srinivasan, 2009).

Data

We compiled data from multiple sources to derive parameters that control the hydrologic process in SWAT. We use the 12-digit USGS hydrologic unit codes, National Hydrography Dataset and a 30 meter digital elevation model from NASA ASTER Global Digital Elevation Map in order to provide watershed configuration and topographic parameter estimation. For land use/land cover data, we use the RIGIS land use/land cover 2003/2004 data. The soil map from Soil Survey Geographical Database, slope and other attributes were obtained from the USDA Natural Resource Conservancy Services (NRCS, 2009).⁶ Daily precipitation data and maximum and minimum daily temperature data from 1961 to 2010 were collected at the Kingston Weather Station⁷ in RI.

HRU (Hydrologic Response Units) definition

The land use/cover, topographic, and soil data were compiled using ArcGIS and ArcSWAT.⁸ A total of 31 subbasins were delineated (Appendix Figure 4).⁹ Each subbasin was further subdivided into hydrologic response units (HRU), which represent portions of

⁶ The land use/land cover data set is based on true color digital orthophotography captured in 2003-2004 at 2 feet pixel resolution. The minimum mapping unit is 0.1 hectare for Soil Survey Geographic (SSURGO) soil polygons, 20 meters for the National Hydrography Dataset (NHD), and 5 feet for the lakes and ponds dataset.

⁷ Kingston weather station (374266) is located at latitude 41.4906 and longitude -71.5414 (United States Historical Climatology Network, 2012).

⁸ ArcSWAT is an ArcGIS extension and graphical user input interface for SWAT developed by the USDA-ARS.

⁹ The watershed outlet (sampling site) is located on the right bank 10 feet downstream from Beaver River Bridge on State Highway 138 in Richmond (USGS).

a subbasin that possess unique combination of land use, soil type and slope. To define HRUs, we adopted a land use threshold of 10%, which limited the land use to categories that covered at least 10% of the sub watershed. Since agricultural land in this watershed is below this threshold but is an important part of this study, we kept HRUs with agricultural land. In addition, we also created new HRUs for septic systems (no sewage treatment) based on the population density (medium density residential area: 2 dwellings per acre; medium low density residential area: 0.5 dwellings per acre). This resulted in a total of 372 HRUs, which were comprised of forests, agricultural, residential, septic systems and other land use types.

SWAT Calibration and Validation

Calibration and validation for the SWAT model were performed following an automated method developed by Arnold and Allen (1999) using land use/land cover from year 2003 and 2004. Each SWAT simulation was executed for 1987-2010. This period includes a three-year “warm up” period (1987-1989), a calibration period (1990-1999) and a validation period (2000-2010). The modeled streamflow for 1990-1999 was then compared to the observed, historical water discharge data from the USGS gauge located at the outlet of the watershed.¹⁰ The details of the sensitivity analysis are described in the Appendix.

Graphical comparison of the simulated versus the observed monthly flows for the calibration period (1990-1999) shows that the model predicts the average monthly flow reasonably well (Appendix Figure 1). Moreover, the statistics for overall fit indicate that the model tracked the average monthly flow trends during the validation period

¹⁰ USGS 01117468 Beaver River near Usquepaug, RI

satisfactorily. The R^2 of simulated versus measured monthly average streamflow was 0.78 and the Nash-Sutcliffe coefficient was 0.77.

In addition to calibrating the overall flow, which is the standard calibration approach, we also calibrate both tails of the distribution (lowest 5%, 10% and highest 5% and 10% of streamflow) to the observed data using seven-day moving average (Appendix Table 1). Based on the benchmarks set by Moriasi *et al* (2007), the results show that overall the simulation of the extreme events are satisfactory. For example, based on PBIAS (percent bias), which measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta, Sorooshian, & Yapo, 1999), our calibration of the seven-day moving average for tails of the distribution is categorized as “very good” for both the lowest 5% and 10% of the streamflow distribution. The calibration for peak flow is “good” for the highest 10% and “satisfactory” for the highest 5% of the streamflow.

Ecosystem Services and their Indicators

For any study on ecosystem services, it is important to choose an appropriate set of indicators which can represent the services which are critical to maintain human welfare and ecological integrity. In our research, the simulated water discharge and nutrient loading from the SWAT simulations were used to calculate alternative indicators of the following ecosystem services: environmental flow, flood risk, and water quality. Here we describe the indicators for each ecosystem service.

Environmental flow is the volume of streamflow needed to sustain downstream receiving wetland ecosystems, aquatic organisms, and the overall health and vitality of a river system (USGS, 2012). Alterations in the land use, different management practices

and climate change may change the hydrology and hence the aquatic ecosystem by changing the physical habitats and disrupting the natural connectivity of habitats (James et al., 2012). Many species may be influenced by the altered flow regimes. In particular they are sensitive to timing of the low flow and extreme events. The issue of low environmental flow has become more and more critical in Rhode Island and elsewhere due to large uptake of water to meet increasing water demands (RIDEM, 2012).

Since there is no single indicator for environmental flow, we follow the hydrology literature and measure environmental flow using four different indicators which are complementary (Armstrong et al., 2024; James et al., 2012; Richardson, 2005). Two widely-used indicators include 7Q10 (seven-day consecutive of low flow with a ten-year return frequency) and 30Q1 (thirty-day consecutive of low flow with one-year return frequency). In comparing the scenarios using these two indicators, we will use *Scenario 1 (baseline)* as the benchmark, which is a reasonable proxy for a fully-forested watershed.

Although these two indicators describe the magnitude of the changes in the extreme (in the sense of low probability, but high impact) events, they do not inform how frequently these may occur, which is correlated with how damaging these changes may potentially be for aquatic habitat. Hence we follow an approach by the (US Fish and Wildlife Services, 2012) and use two additional indicators developed by the USGS and RI DEM that have thresholds below which the aquatic ecosystem might be threatened: the Rhode Island Aquatic-Base-Flow Method (RI ABF) and the New England Aquatic-Base-Flow Method (Armstrong et al., 2004.; Richardson, 2005). We counted the days in each month of the 20 years (1990-2010) that the watershed's median streamflow is below the threshold and then calculate the percentage of days below the threshold for each

month of the 20 years (Table 3 and Appendix Table 3). Percentage of days below the threshold of New England Aquatic-Base-Flow Method (Appendix Table 6) is also calculated.

We also employ several indicators to measure flood risks: 1-year flood, 2-year flood and 10-year flood as the indicators (Table 2). These indicators represent the largest streamflow in one year or every two years or every 10 years on average, respectively.

The water quality is measured by the total annual loadings of nitrogen (N) and phosphorus (P). SWAT allows users to quantify nutrient loadings at the subbasin level as well as at the outlet of the watershed. We utilize both in the tradeoff analysis. As an extension, we also use a benefit transfer method to value the impacts of the changes in land use and management practices in monetary terms to reflect people's preferences across different ecosystem services.

III Land use change and climate change scenarios

With the calibrated hydrological model, we investigate seven alternative scenarios which reflect the potential stressors to the ecosystem services from this watershed (Table 1) and then run SWAT from year 1987 to year 2010 including a 3 year warming up period. Daily streamflow and nutrient loadings are simulated at the outlet of the watershed.¹¹ To do so, we create three new digital maps of projected land uses (*Scenarios 2-6*) and apply changes to the weather input to simulate climate change impacts (*Scenario 7*). The alternative scenarios are intended to illustrate in which direction and to what extent the ecosystem services would change. By using scenarios with drastic land use/management changes, we are illustrating the upper bounds and the likely direction of

¹¹ Please refer endnote 6.

the potential changes in ecosystem services. The percentage of area in the watershed in each land use category under each scenario is shown in Appendix Table 2.

Scenario 1 (Baseline): This scenario uses the status quo land cover (land use 2003/2004), land management, and climatic data. More than 97% of the watershed is covered by forests (Appendix Table 2).¹²

Scenario 2 (Conventional Agriculture): Under this scenario, all the forest land which has soil attributes suitable for cultivation is converted to agricultural land. As a result, 16% of the forests are converted to agricultural land. We assume that corn silage is planted on the new agricultural land.

Scenario 3 (BMP Agriculture): This scenario assumes the same land use conversion as *Scenario 2*, but in addition we impose a set of Best Management Practices (BMPs). Based on literature and an expert opinion from an agricultural extension specialist in RI, the BMPs include reduced fertilizer application and a rye cover crop in winter (Arabi et al. 2008; Burdett, 2010). Corn silage is assumed to be planted on the farmland.

Scenario 4 (Biofuel): We assume the same land use conversion as *Scenario 2*, but corn suitable for biofuel is planted instead of corn silage. This scenario is relevant because following the trend in the rest of the US; farms in RI have also started to produce corn for ethanol fuel.¹³ There are two major differences between these two types of corn which could affect water quantity and quality. Only half of the aboveground plant

¹² Crop growth is simulated in SWAT using the modeling approach used in the Erosion Productivity Impact Calculator (EPIC) (Williams, Jones, & Dyke, 1984.). EPIC allows for the variation in growth for different plant species, and variation due to climate and growth conditions (Neppel, et al. 2002). Crop types and their biomass (such as the canopy and its maximum leaf index) will influence the evapotranspiration and the surface runoff and its speed.

¹³ For example, Sodco, Inc. in southern Rhode Island has started to grow corn fuel since 2009.

biomass is harvested in corn production, whereas 90% is harvested for corn silage. In addition, corn will provide more leaf cover at certain times than corn silage.

*Scenario 5 (Suburban Medium Density):*¹⁴ Under this scenario, we convert all the forest land that has the soil properties suitable to be developed into residential land use (about 54% of the watershed) into medium density residential area (2 dwellings per acre).

Scenario 6 (Suburban Medium Low Density): This scenario assumes the same land use conversion as *Scenario 5*, but forest land is now converted to medium-low density residential development (0.5 dwellings per acre).

Scenario 7 (Climate change): We examine the impact of climate change assuming the baseline land use in 2003/2004 (same as *Scenario 1*, Appendix Table 2). Among the many alternative climate change models, we choose to use the downscaled and bias corrected model runs of a general circulation model (CGCM3.1/T47) because its fine resolution of $1/8^\circ$ is more appropriate given the small size of our watershed as opposed to the 2° raw output from the GCM. These model runs were conducted under the SRES A2 Emission scenario, implying a doubling of CO₂ concentrations by 2038 (Mearns et al., 2005; Pachauri, 2007).¹⁵ The downscaled data was made available by the Bias Corrected and Downscaled WCRP CMIP3 Climate Projections Archive (Maurer et al. 2010).

To reflect the simulated changes in the temperature and precipitation, we follow the delta method suggested by Stone (2003) and the IPCC (2012). To do so, we extract the monthly differences in degrees Celsius and the ratios for precipitation between the modeled past data (1980-2000) and the predicted future data (2045-2065). These

¹⁴ During the past couple of decades, there has been a 78% increase in the residential development in Rhode Island with a decline in both the agricultural and forest land (Archetto & Wang, 2012). Though some of the scenarios we created are drastic, it simulates what could happen if current trends continue.

¹⁵ The model runs were conducted as part of the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset.

simulated changes imply an increasing average maximum and minimum temperature for all months (with a range of 2-4 C°) and a decrease in summer rainfall (with a range of 7-33% decrease, Table 4). We apply these differences to the observed monthly data, which we then use as inputs to the calibrated SWAT model to estimate the hydrological outputs and crop yield. Then two twenty-year SWAT runs are used to compare the differences in the relevant hydrological indicators from both periods.

IV Results of Scenario Simulations

The scenarios demonstrate the effects of land use/management choices clearly and verify the theoretical relationships that would be expected (Table 2). More impervious surface will lead to increasing surface runoffs resulting in larger floods and increased environmental flow (Allan, 2007). The reduction in the fertilizer application rate (kg/ha) or adopting other BMPs (Meals, Dressing, & Davenport, 2010; Park, Mostaghimi, Cooke, & McClellan, 1994) will induce less nutrient loading. The conversion of forested land to agricultural land (*Scenarios 2-4*) resulted in a reduction of the environmental flow indicators. For example, converting 16% of the watershed from forests to corn silage fields (*Scenario 2*) decreased 7Q10 from 0.025 cubic meter per second (cms) to 0.021 cms, which is a 16% reduction in the environmental flow. Similarly, this land use change decreased 30Q1 from 0.043 cms to 0.037 cms, a 14% reduction. Changes in environmental flow indicators such as 7Q10 and 30Q1 reflect a drier extreme (lower low flow) with potentially detrimental effects for aquatic habitat (Richardson, 2005).

We find that a conversion from forested land to cropland results in not only increased magnitude but also a higher frequency of these extreme dry events (Table 3).

This effect is larger especially in the drier months of summer in May, June and July. For example, in June, 16% conversion of the watershed from forested land to corn silage farmland results in an average of 4.5% more days that do not meet the minimum threshold required to maintain the aquatic habitat. In contrast to the environmental flow indicators, the flood risk indicators only showed a minor effect under these scenarios, decreasing slightly in magnitude by 1% or remaining the same (Table 2, Flood).

Conversion from forested land to cropland has more drastic implications for water quality than water quantity (Table 2). Increased nitrogen and phosphorous is a result of nutrient runoff from agricultural land. Not surprisingly, converting large areas of forested land to agriculture results in increasing concentrations in both nitrogen and phosphorous. Also enlightening is that in contrast to conventional agricultural practices (*Scenario 2*), implementing BMPs (*Scenario 3*) contributes reduction of these loadings by almost half. For example, the total nitrogen loading is reduced from 157 kg/ha down to 70 kg/ha; total phosphorous loading is reduced from 1 kg/ha down to 0.68 kg/ha.

Interestingly, growing corn instead of corn silage (*Scenario 4*) results in a significant reduction in the total nutrient loading (Table 2). For example, compared to the previous scenario with BMPs (*Scenario 3*), the total nitrogen loading is reduced from 70 kg/ha down to 42 kg/ha; and the total phosphorous loading is reduced from 0.68 kg/ha down to 0.46 kg/ha. This result may be reflecting the difference in how much fertilizer has been applied (less is used to grow corn than corn silage)¹⁶ and how much biomass is left on the ground after harvest. Only half of the aboveground plant biomass is harvested in corn production, whereas 90% is harvested for corn silage.

¹⁶ In *Scenario 3* (BMP Agriculture), we apply manure at 150 lbs N/ per acre and 60 lbs P/ per acre. This amount is significantly more than the amount applied in *Scenario 4* (Bio fuel), which uses the default value of N and P applied as 31.19 lbs. /acre and 0 lb/acre, respectively.

Next, the results of the suburban scenarios (*Scenarios 5 and 6*) show that the urbanization trend could have important effects on our ecosystem services of interest (Table 2). The increase of impervious surfaces and the conversion of forest cover lead to increases in base flow as measured by the environmental flow indicators. This comes at the expense of an increase in the flood risks. For example, the 7Q10 is 2.5 times larger while the 2-year flood is more than twice as large when forested land is developed into the medium density residential area. While an increase in environmental flow may be beneficial, development comes at the cost of water quality as well. Nitrogen and phosphorous loading increases greatly with development and increases with density without sewage system (*Scenario 6*).

Finally, applying the projected changes in future climate (Table 4) to create the climate change scenario (*Scenario 7*), we find that the environmental flows are projected to decrease during the summer months and the flood risks are higher in the winter months (Table 2). Modeled changes in average daily flow by month are shown in Appendix Figure 2. Due to both decreased summer rainfall and additional evapotranspiration stemming from higher daily temperatures, environmental flows as measured by 7Q10 are projected to decrease by around 12%. The higher temperatures combined with possibly decreasing average summer rainfall means that the flow in historically low flow summer months may become drier, leading to even lower environmental flow. Winter precipitation is predicted to increase up to 33% in some months. Flood events measured by high daily flow events are also predicted to increase. For example, a current 10-year flood event may happen every 7 years, a 2-year flood every 1.6 years, and a 1-year flood every 0.6 years under the climate change scenario. These general results are consistent

with other studies of climate change for the Northeast using an ensemble of climate models (Hayhoe et al., 2008).

It is worth noting that the climate model's ability to reproduce observed magnitude, timing and duration of precipitation events have been well documented to be susceptible to the high interannual variability of precipitation. For instance, any trends calculated beginning or ending during multi-year drought events would change the results substantially (Hayhoe et al., 2006). The results should be interpreted as the effects of a plausible series of precipitation events under a climate change scenario. Since changes were based on deviations between modeled past and future monthly means, the changes in our indicators are reflective only of a mean shift of the observed precipitation distribution.

Valuation of Ecosystem Services

We next evaluate the impacts of the stressors and land management practices in monetary terms to reflect people's preferences for different ecosystem services. A common metric of value makes the tradeoff analysis between varying goods and services easy to compare and aggregate (Kumar et al., 2010). We resort to the existing valuation literature and use a simple benefit transfer method. Although benefit transfer may not be an accurate approach of valuation, it has the advantage of a less costly way to at least capture the relative importance of the ecosystem services using a common scale and is often used as a screening technique at an early stage of policy analysis (King & Mazzotta, 2000). Although we will refrain from computing the total net value from each scenario as we are not capturing the values of all ecosystem services, the results from our study can

be used to compare the tradeoffs among different alternative scenarios and serve as a pre-assessment of the future policy scenarios.

Values for each ecosystem service in this study were obtained as follows:

Corn: Following an approach taken by (US Fish and Wildlife Services, 2012), we assume a constant of \$6.25 per bushel based on 2012 prices (USDA, 2012). Following Snyder (2011), corn silage is priced at \$1.46 per bushel. We assume that the profitability for both corn and corn silage is 22% (Ibendahl, 2012).

Environmental flow: Karanja *et al.* (2008) estimated that WTP to maintain the environmental flow was \$13 per year per person. Based on their study, we assume that all Washington County, RI residents are willing to pay \$0.03 per day to maintain the environmental flow in order to protect the rare wildlife species in the watershed.

According to the RI ABF (Appendix Table 3), we can calculate people's WTP for the 20 years to maintain the environmental flow by multiplying \$0.03 by the number of days below the RI ABF threshold. Then multiply this by the number of residents living in the Washington County based on US Census Data (126,563) and divide by 20 years. In this way we can get an approximate estimate of the benefit of the environmental flow per year.

Flood risks: Based on the historical peak flow data, we assume that a streamflow of 250 cubic feet per second is the threshold for a flood event. To estimate the damage cost from a flood event at the outlet of Beaver River watershed, we start with the average flood insurance premium in Richmond, RI, which is \$1717 per year for both building and contents in 2012 dollars (National Flood Insurance Program, 2012). Divided by a 10% probability of a flood event (based on historic streamflow observations), the expected

damage of the flood for each household is \$17,170. Based on the number of households in a two-mile radius at the watershed outlet, we assume for simplicity that 4000 residents (1300 households) would be affected by any flood event. We then multiply the total damage cost per flood event by the number of predicted flood events under each scenario.

Water quality: We take into account of the effects of N and P on drinking water and recreation. Van Grinsven *et al.* (2010) estimated that the health costs of nitrate in drinking water as \$3.38 per kg. Birch *et al.* (2011) estimated the damage cost in the recreational use of an estuary due to eutrophication is \$6.38 per kg. Thus for the total damage cost of the nitrogen, we use \$10.14 per kg in 2012 US dollars. For the damage cost from phosphorus, we used the estimated damage cost function¹⁷ for both drinking water treatment and estimated cost of recreation losses (Ancev *et al.*, 2006) .

Residential development: We use the per acre vacant land price (without building) and the annual interest earned from selling the land as a proxy for the return from residential development by modifying the approach by Lubowski *et al.* (2002, 2008) . The per acre vacant land price is calculated by dividing the lands' assessed tax value by number of acres in a lot. The median vacant land for medium density residential development was \$143,800 per acre and \$71,500 per acre for medium low density and in 2010 in Richmond, RI. Based on the land use change assumptions in suburban residential development, \$366,977,600 and \$182,468,000 will be instantaneous benefits.¹⁸

Combined with the real interest rate data (The World Bank, 2012), the annual return as a

¹⁷ For the damage cost from phosphorus, we used the estimated damage cost function for both drinking water treatment and estimated cost of recreation losses (Ancev *et al.*,2006). Total cost is estimated by the damage cost function $D\{Z\} = 585,446.9 - 59.93Z + 0.0015Z^2$ (Z denotes the average phosphorus concentration).

¹⁸ In the Scenario 5 (medium residential development) and Scenario 6 (medium low residential development), we assume there will be 2552 acres of increase in residential development.

result of residential development is estimated as \$35,156,454 for the medium density and \$17,480,434 for the medium low density residential development.

Comparison of ecosystem service values across scenarios

In contrast to the changes in indicators of ecosystem services examined earlier, the valuation exercise reveals the relative magnitude of the changes and their tradeoffs across scenarios (Tables 5). Our results suggest that in the agricultural scenarios, the increases in profits from growing corn dominates the losses from lower environmental flow and worse water quality (rows 2 to 4). For example, in the conventional agricultural scenario (*Scenario 2*), the conversion to corn silage creates an additional profit of \$65 million from crops compared to the baseline. This far outweighs the losses in environmental flow (\$253,479) and the larger losses from additional N (\$2.7 million) and P (\$0.063 million) compared to the baseline. By imposing BMPs (*Scenario 3*) as well as growing corn instead of corn silage for biofuel (*Scenario 4*), the results show a much smaller loss from nutrient loading.

Our results also indicate that the increase in damage costs from floods is expected to be much larger under the suburban scenarios and far outweighs the benefits from environmental flow (Table 5, rows 5 and 6). With the conversion to agricultural land, the probability of flood is 5% each year. However, this increases to 10% in the medium low density scenario and 75% in the medium residential development. For the suburban scenarios, the damage costs from floods are large as the damages from the increase in the amount of nutrients. However, given our assumptions, the benefit from residential development outweighs those benefit lost in ecosystem services.

V Tradeoff Analysis

In application, it would be important for policymakers to understand to what extent tradeoffs and heterogeneity exist in providing ecosystem services within the watershed. Understanding heterogeneity in ecosystem services across different parts of a study area is important for government agencies or conservation groups whose goal is to enhance multiple ecosystem services under a fixed budget. Although we lack sufficient data to provide a complete accounting of tradeoffs among all policy-relevant ecosystem services in the watershed that are potentially influenced by the different scenarios, we can illustrate how tradeoffs could be evaluated if given sufficient data with which to do so.

We take two approaches in assessing the tradeoffs. First, we examine the heterogeneity and tradeoffs within a watershed by measuring the ecosystem service indicators for each of the 31 subbasins, and graphing the distribution of two ecosystem services at a time and compare them across six scenarios. Then, we focus on the conventional agricultural scenario (*Scenario 2*) and extend a mapping approach by Swallow *et al.* (Swallow et al., 2012) to visually examine the heterogeneity and tradeoffs within the watershed. We characterize the level of ecosystem service in each subbasin as “high” (or “low”) depending on whether the value is above (or below) the median value of the 31 subbasins.

Results: Tradeoffs across different scenarios

The tradeoffs among different ecosystem services considered in our analysis across different scenarios at the watershed level are shown from Figure 2 to 4, Appendix Figure 3. Each point represents a unique subbasin with a combination of crop yield

(vertical axes) against 7Q10 (horizontal axes, Figure 2); against 2 year floods (Appendix Figure 3); and against total nitrogen and phosphorous loading (Figures 3 and 4).

Our results indicate several interesting findings. First, we find that the extent of heterogeneity differs depending on the ecosystem service. For example, under the baseline scenario (*Scenario 1*), the subbasins have small variability between crop yield and environmental flow (Figure 2, panel 1) or flood risks (Appendix Figure 3, panel 1). However, we observe relatively larger variability in total annual nitrogen loading; there are subwatersheds with a similar level of crop yield but having low nitrogen loading whereas others have high nitrogen loading (Figure 3, panel 1). These findings imply that even without the stressors or changes in land management practice, subbasins have inherently different characteristics in generating some types of ecosystem (dis)services such as total nitrogen loading. As an example in the baseline scenario, subbasin 17 and subbasin 18 have about the same agricultural land use (Appendix Figures 5 and 6), but there is a big difference in their nitrogen loading and this implies that there are factors such as soil types, slopes and other intrinsic characteristics that influence the nutrient loading. These findings are consistent with tradeoff analysis under different policy scenarios (Lautenbach et al., 2010).

Moreover, the extent of the tradeoffs among the subset of ecosystem services considered in our analysis depends on which ecosystem services are being compared and also on the stressor and the land management practices. We find little tradeoffs between crop yield vs. environmental flow or flood risk (Figure 2 and Appendix Figure 3), but there is a clearer tradeoff between crop yield and total nutrient loading (Figures 3 and 4) especially under the agricultural scenarios (*Scenarios 2-4*).

These tradeoffs are driven not only by differences in the area converted to agriculture or suburban area (which was decided based on soil type suitability) but also by yield as well as subbasin characteristics which make some subbasins generate more nitrogen and phosphorus than others. As an illustrative example, we compare subbasins 5 and 22, both of which get about 21% converted to cropland under the agricultural scenarios (Figure 3). However, even with the same proportion of the subbasin in cropland, subbasin 22 generates significantly more phosphorous loading compared to subbasin 5 while at the same time generating higher crop yield under agricultural scenarios. The reason for this big difference in the nutrient loading and crop yield is not due to the size of the agricultural land since they have the same percentage of the agricultural land and adopt the same management practices (fertilizer applied, timing of planting and harvesting etc.) but is due to other subbasin characteristics which makes subbasin 22 more prone to phosphorus loading (Figure 4, *Scenario 2-4*). For nitrogen, subbasin 5 and 22 are not very good examples, since the nitrogen loadings between the two are noticeably different even in the baseline. One possible reason for this may be that subbasin 22 has septic systems in the baseline scenario, which contribute to higher nitrogen loading. However, by carefully examining the change of nitrogen loading under traditional agricultural scenario, we find that subbasin 22 is also more prone to nitrogen loading despite the difference in Figure 3 (*Scenario 1-2*).

Likewise, in the suburban scenarios (*Scenario 5*), subbasin 3 and subbasin 28 respond very differently in both nitrogen and phosphorus loadings after converting almost the same amount of land to medium density residential land use (Appendix Figures 8 and 9). This difference in the simulated impact is largely due to the differences

in inherent characteristics of each subbasin, such as distance to the river of the septic systems and soil types instead of simply the differences in the amount of land converted to suburban development.

These plots also confirm the general tradeoffs found in reviewing the scenarios with our raw indicators in Table 2. For instance, land use changes from forest to agricultural land (*Scenario 2 and 3*) will increase the crop yield significantly while decrease the environmental flow for most of the subbasins. Implementing BMPs will decrease the crop yield but increase the environmental flow compared to the conventional practice scenario.

This observed differing influence of the long term drivers (land use change, land management) on ecosystem services in two relative close subbasins such as subbasin 5 and 22 leads us to conclude that there is important heterogeneity among subbasins within the watershed. We can explore this further by modeling ecosystem services tradeoff measured over the whole watershed under one scenario. Next, we are going to investigate the heterogeneity of the subbasins' provision of ecosystem services under the conventional agricultural scenario as an important first step to target the most important pieces of our watershed for supplying particular ecosystem services.

Tradeoffs in conventional agriculture scenario

The mapping exercise further clarifies geographically that there will be tradeoffs involved in deciding where to prioritize conservation investments (Figure 5). We illustrate this point using the conventional agriculture scenario (*Scenario 2*). To get the “biggest bang for the buck”, one strategy for agencies is to target subbasins that currently have low environmental flow, high flood risk, and high N and P concentrations, while at the same time are capable of generating a high crop yield. For illustration purposes,

Figure 5 gives four different combinations of ecosystem services.¹⁹ For example, agencies may prioritize on subbasins with high crop yield-low environmental flow (Panel (a)). However, subbasins with relatively low environmental flows are not the ones that have high flood risks (Panel (b)). Hence, decision makers would face a tradeoff between protecting environmental flow and mitigating flood risk. As another example, agencies may target subbasins that have high crop yield and high N concentration. Although many of these subbasins also have high P concentration, some basins with high crop yield-high P concentration (Panel (d)) actually have low N concentration (Panel (c)). This implies that some intrinsic site variables (such as soil attributes and slope) cause the difference of these two forms of nutrient loading. This finding is potentially useful for stakeholders in deciding where and how to target conservation efforts depends on their interested ecosystem services.

VI Discussion and Conclusions

This research examined a watershed which sits on an increasingly valuable and vulnerable rural-urban fringe. With pressures for local food production, the values of the land for agricultural production will be increasingly weighed against suburban residential development. Both of these possible land uses will result in changes in ecosystem services such as flood resilience and habitat base flow, which are the primary subject of this research. The scenarios were chosen to demonstrate the effects of land use, management practices and climate change on multiple ecosystem services.

¹⁹ This case study demonstrated five ecosystem services, resulting in 26 unique combinations of ecosystem services.

We illustrated one way to simulate the impact of the stressors and BMPs on ecosystem services using an existing process-based hydrological model and data. The temporal and spatial details in the stressors, land management practices, climate, and the hydrological outputs are important in studies of hydrological ecosystem services because where and when things happen influences the effect on the ecosystem services. However, we have made several simplifying assumptions in hydrological modeling. For example, there may be more irrigation with expansion of agricultural land and more wells may be drilled for drinking water with residential development. The hydrological modeling can be improved by incorporating these factors.

The climate change scenario highlighted an additional potential stressor on the hydrological ecosystem services. Due to uncertainty in the modeling of precipitation in climate models, additional research is needed to properly account for possible changes in the variability of future precipitation events. However, we can start to explore what effect land use choices will have when occurring in a plausible future climate scenario. By combining crop silage scenario (*Scenario 2*) with the climate change (*Scenario 7*), what is evident is that there is no simple linear interpretation of the effects of land use and climate change taken together. For instance, although environmental flow is predicted to decrease both under *Scenario 2* (-40%) as well as under the climate change *Scenario 7* (-10%), the combined effect is not additive (-17%). Additional work needs to be done to fully understand the implications of land use change on the resilience of a watershed to scenarios of future climate conditions. Similarly, when combining the medium density (*Scenario 6*) with the climate change (*Scenario 7*) we see a doubling of the magnitude of

a ten year flood, while *Scenario 6* saw only a 60% increase in the same flood measure from the baseline scenario when considered alone.

Although we only provided a crude measure of values, employing a valuation method revealed some important relationships that put the tradeoffs between the services in perspective. Among the three agricultural scenarios, the conventional practices will generate the highest crop yield and thus the highest benefits taking into account the damage costs of decreased environmental flow and increased nutrient loading. In the suburban scenarios, the flood damage cost will far exceed the benefits gained from environmental flow even without taking into account of the damage costs from the nutrient loading. By valuation of multiple ecosystem services under different scenarios using a benefit transfer method; policymakers can compare the monetary tradeoffs among different choices and target the critical ecosystem services that they care about. However, due to the large set of possible ecosystem service values, we can only obtain gross estimates for the values from multiple ecosystem services.

Our analysis has been conducted to illustrate a method to characterize the influence of changes in land use and management on ecosystem services using existing hydrological models. We acknowledge that our analysis only includes relevant ecosystem services and does not provide a complete accounting of all private and public benefits and costs associated with land uses in the watershed examined such as timber production, biodiversity, carbon sequestration and crop pollination. Any application of our method would need to include those ecosystem services deemed relevant to the land uses and policy context of interest.

Despite these caveats, our case study may provide a starting point for stakeholders to take into account of both the physical and monetary terms of multiple ecosystem services into the decision making process. The graphical and mapping approaches may assist in making choices among many competing land use and land management options.

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Table 1: Seven Scenarios

Names of Scenarios	Land Use Changes	Crop	Practices	Climate Change
Scenario 1: Baseline	Status Quo			
Scenario 2: Conventional Agriculture	Forest→Agricultural ¹	Corn Silage	Conventional Management	
Scenario 3: BMP Agriculture			Best Management Practice (BMPs) including reduction in fertilizer and a winter cover crop (rye)	
Scenario 4: Biofuel	Forest→ Agricultural ¹	Corn	Conventional Management	
Scenario 5: Suburban Medium Density	Forest→ Residential ² (Medium)			
Scenario 6: Suburban Medium Low Density	Forest----> Residential ² (Medium Low)			
Scenario 7: Climate Change	Status Quo			Coupled General Circulation Model 3.1/T47

Note: ¹. We change the forest land which the soil type is suitable for agricultural land use.

². We change the forest land which the soil type is suitable for residential development

Table 2: Water Quantity and Quality Statistics from Seven Scenarios

	Environmental Flow (cms)		Flood (cms)			Nutrient Loading (kg/ha)	
	7Q10	30Q1	1 Year Flood	2 Year Flood	10 Year Flood	Total N	Total P
Scenario 1: Baseline	0.025	0.043	2.114	2.803	5.838	24.626	0.483
Scenario 2: Conventional Agriculture	0.021	0.037	2.081	2.839	5.718	157.142	1.037
Scenario 3: BMP Agriculture	0.022	0.037	2.097	2.789	5.757	70.411	0.676
Scenario 4: Biofuel	0.022	0.038	2.101	2.794	5.74	42.656	0.464
Scenario 5: Suburban Medium Density	0.087	0.124	6.752	8.674	12.62	197.515	2.765
Scenario 6: Suburban Medium Low Density	0.041	0.068	3.805	5.294	8.557	205.666	1.169
Climate Change Baseline*	0.026	0.039	6.61	8.45	15.24		
Scenario 7: Climate Change Scenario*	0.022	0.037	7.42	8.98	22.58		

Note: cms stands for cubic meter per second.

*Climate Change Scenarios were created using monthly averages and SWAT's WXGEN weather generator to create daily runs for SWAT input.

Table 3: Average Percent of Days each Month below the Requirement of RI ABF

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Scenario 1: Baseline	22.1%	42.7%	25.2%	25.5%	46.1%	65.2%	42.3%	37.1%	22.0%	10.0%	10.5%	11.1%
Scenario 2: Conventional Agriculture	22.4%	43.2%	27.9%	26.8%	48.5%	69.7%	44.0%	38.5%	25.7%	11.6%	11.5%	12.9%
Scenario 3: BMP Agriculture	24.0%	43.4%	28.2%	27.3%	51.6%	68.2%	43.1%	37.7%	25.5%	11.0%	11.7%	13.4%
Scenario 4: Bio fuel	22.1%	43.4%	27.3%	26.8%	47.7%	67.0%	42.6%	37.6%	25.2%	11.8%	11.5%	12.9%
Scenario 5: Suburban Medium Density	26.1%	42.7%	23.9%	20.5%	34.5%	46.0%	28.5%	17.3%	12.0%	5.8%	8.2%	13.1%
Scenario 6: Suburban Medium Low Density	20.3%	38.2%	19.8%	19.7%	32.4%	49.3%	33.5%	28.4%	19.2%	8.7%	10.7%	12.3%

Notes: The percentage of days below the threshold is averaged over 20 years. Results for *Scenario 7* (Climate Change) are not reported since these values are calculated based on simulated daily flows. The climate change effects are simulated by imposing monthly changes to the weather, and hence the simulated daily flows are not reliable.

Table 4: Modeled Average Monthly Changes in Climate (1980-2000 v. 2045-2065)*

	Precipitation	Maximum Temperature	Minimum Temperature
Month	% Δ mm	Δ °C	Δ °C
January	6.9%	2.1	2.5
February	-4.0%	0.7	1.3
March	35.7%	4.2	4.2
April	10.4%	3.0	3.3
May	0.5%	2.4	2.4
June	8.5%	2.6	2.3
July	-33.7%	2.3	2.6
August	-7.9%	2.0	2.3
September	-9.9%	2.4	2.5
October	0.4%	3.2	3.0
November	33.8%	2.4	2.8
December	19.0%	2.4	2.1

* These changes were calculated from two 20 year runs of the CGCM3.1/T47 model. These are then applied to the observed monthly average precipitation and temperatures.

Table 5: Comparative Annual Benefit of Ecosystem Services from Alternative Scenarios with Baseline (per Year)

Unit: US Dollars(2012)

	Crop Profits	Environmental Flow	Flood Damage	Nutrient Loading		Housing Value
				Damage from N	Damage from P	
Scenario 1: Baseline	\$0	\$0	\$0	\$0	\$0	\$0
Scenario 2: Conventional Agriculture	\$65,400,754	-\$253,479	\$0	-\$2,744,532	\$62,544	\$0
Scenario 3: BMP Agriculture	\$26,958,467	-\$278,648	\$0	-\$948,251	\$22,225	\$0
Scenario 4: Biofuel	\$13,137,433	-\$176,177	\$0	-\$373,418	-\$2,213	\$0
Scenario 5: Suburban Medium Density	\$163,211	\$891,672	-\$14,422,800	-\$3,580,695	\$232,951	\$35,156,454
Scenario 6: Suburban Medium Low Density	\$22,703	\$735,270	-\$1,030,200	-\$3,749,510	\$76,880	\$17,480,434

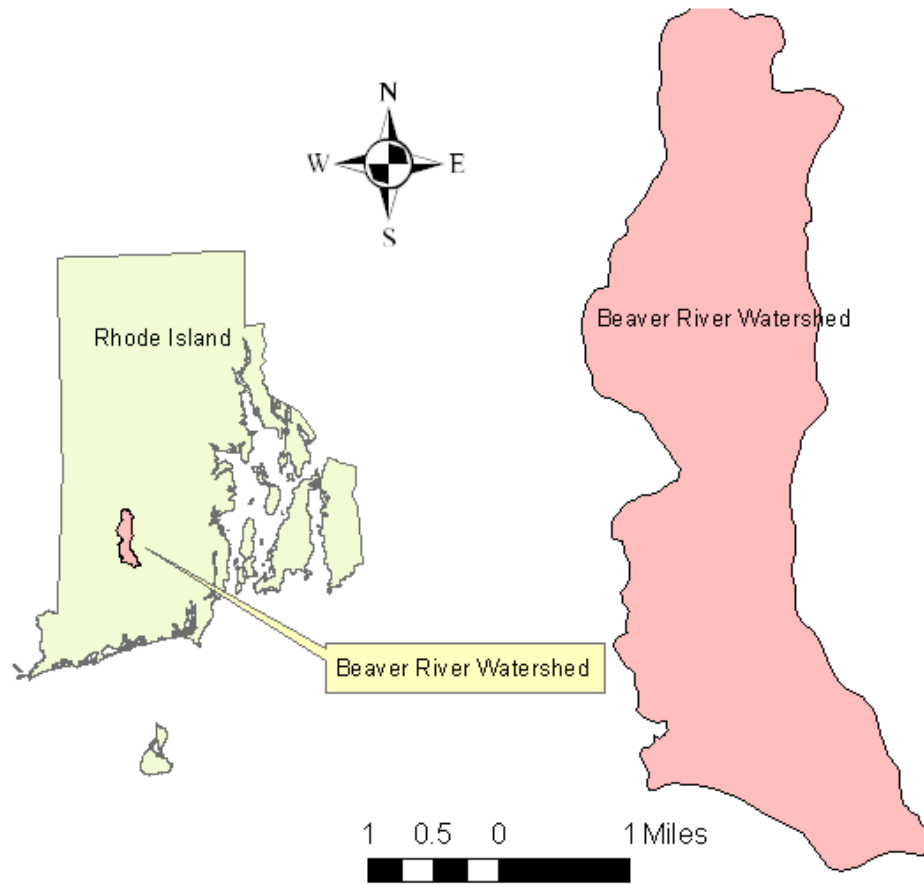


Figure 1. Location Map of the Study Area (Source: RIGIS)



Figure 2. Tradeoff between Crop Yield (vertical axis, annual yield of crop, unit Tons/ha) and Environment Flow (horizontal axis, 7Q10, unit Cubic meter per second) in Different Scenarios; Scenario 1 to 6 represents: Baseline, Conventional Agriculture, BMP Agriculture, Bio fuel, Suburban Medium Density and Suburban Medium Low Density respectively.

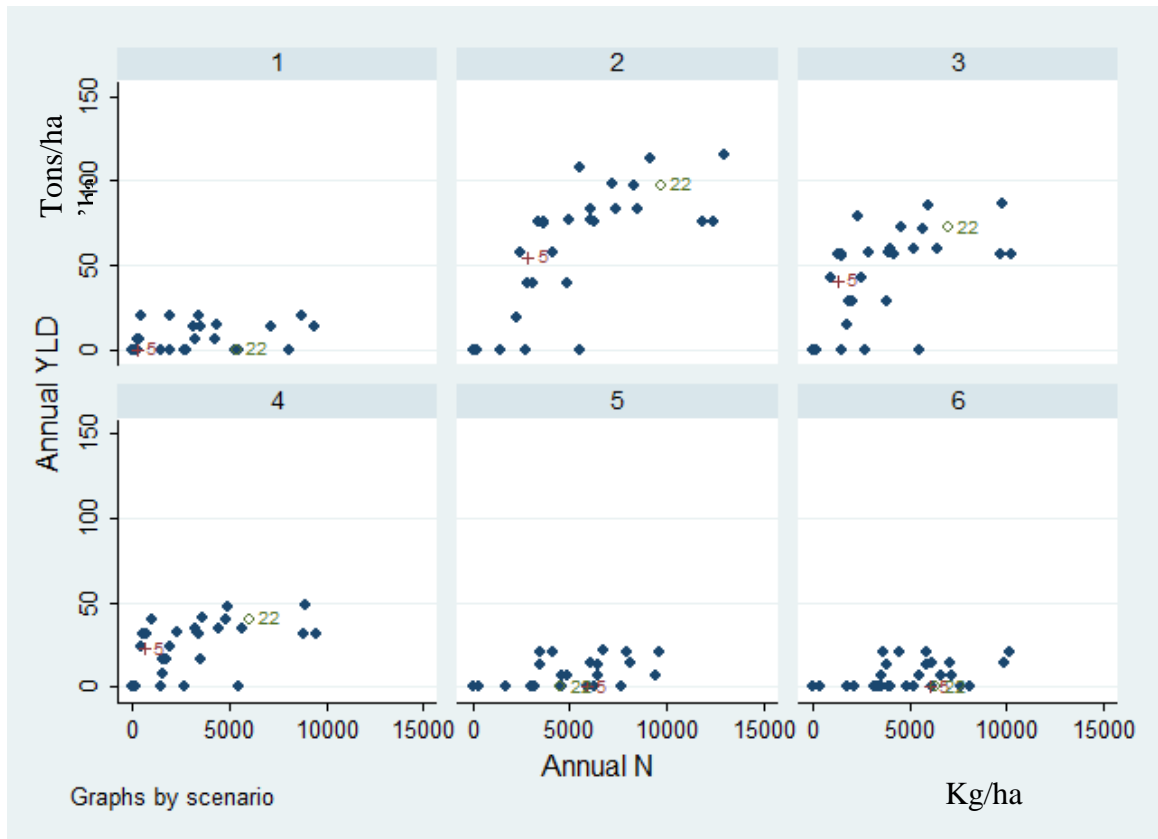


Figure 3. Tradeoff between Crop Yield (vertical axis, annual yield of crop, unit Tons/ha) and Annual N Loading (horizontal axis, annual N, unit Kg/ha) in Different Scenarios; *Scenario 1 to 6* represents: Baseline, Conventional Agriculture, BMP Agriculture, Bio fuel, Suburban Medium Density and Suburban Medium Low Density respectively.

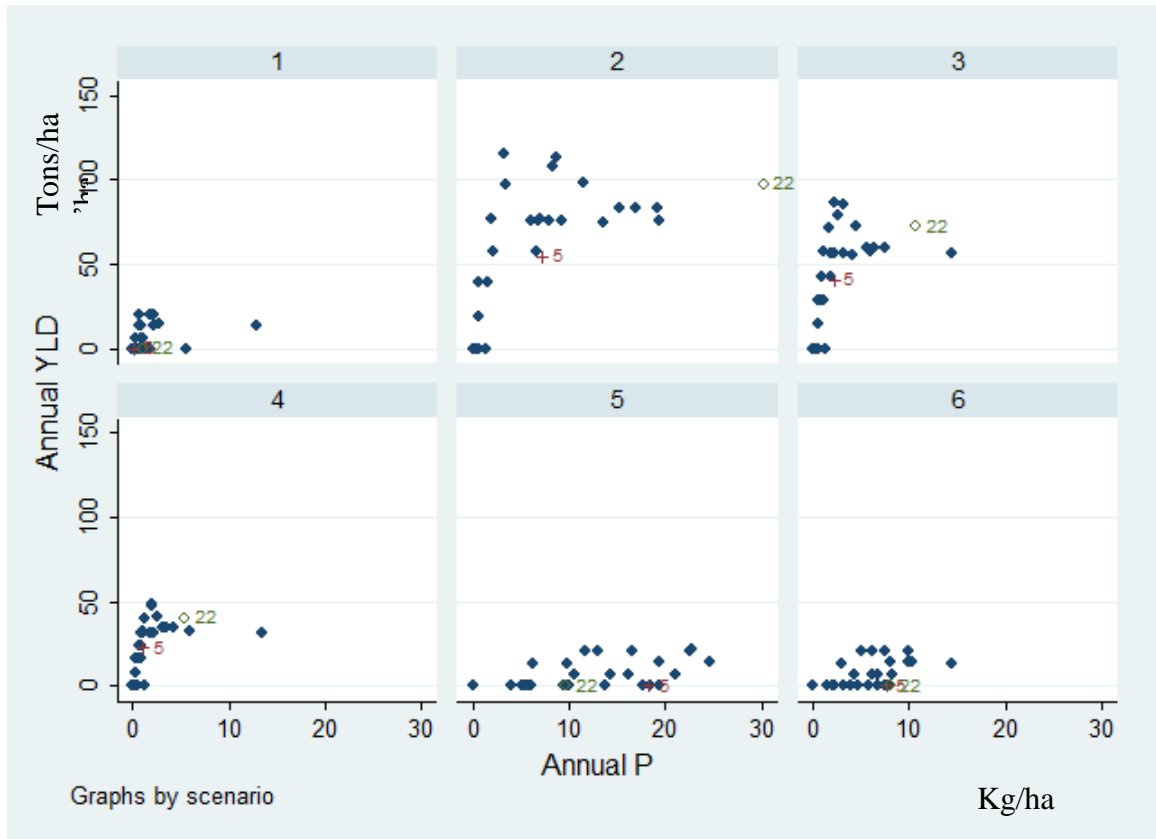


Figure 4. Tradeoff between Crop Yield (vertical axis, annual yield of crop, unit Tons/ha) and Annual P Loading (horizontal axis, annual P, unit Kg/ha) in Different Scenarios; *Scenario 1 to 6* represents: Baseline, Conventional Agriculture, BMP Agriculture, Bio fuel, Suburban Medium Density and Suburban Medium Low Density respectively.

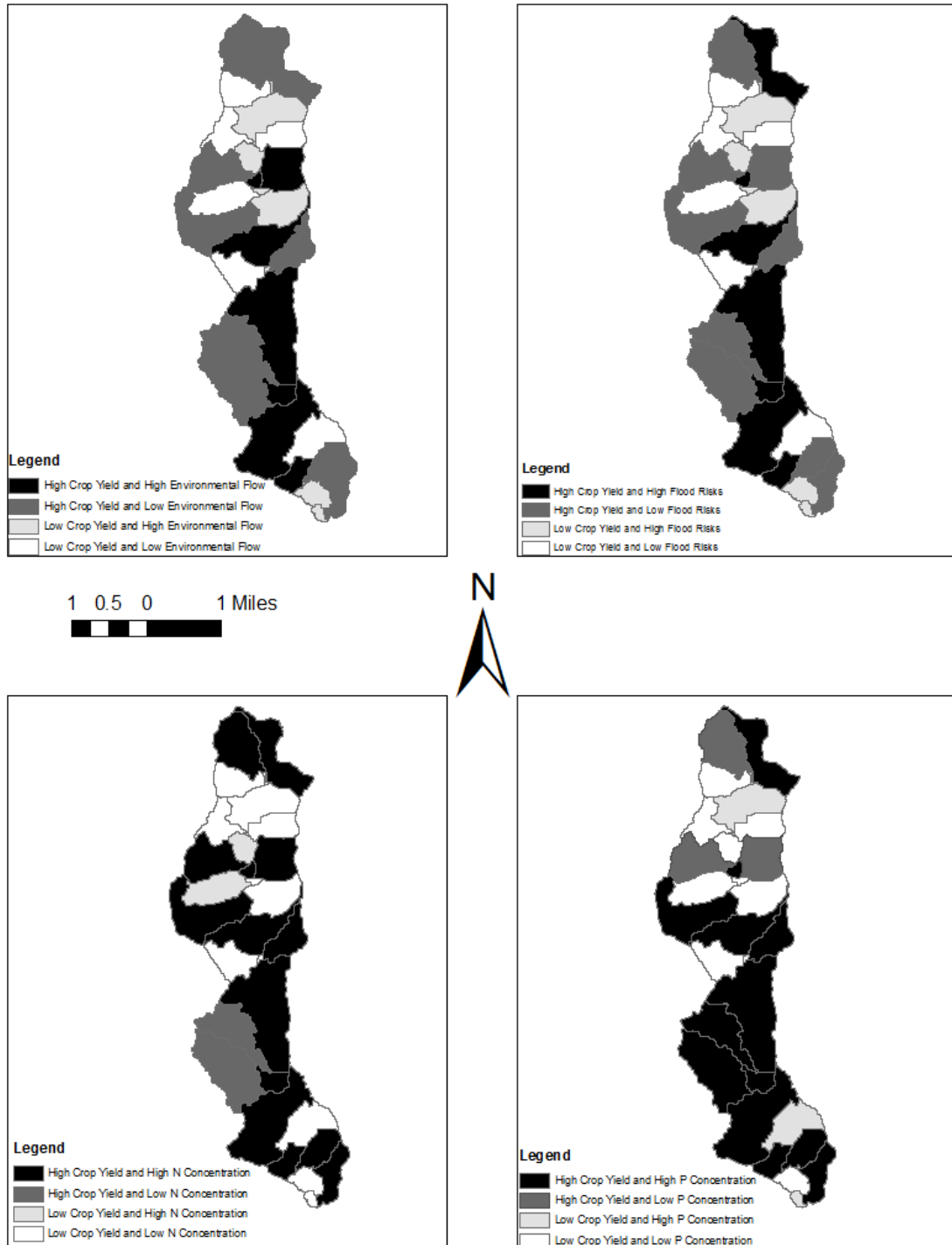


Figure 5. Tradeoffs in Ecosystem Services in Beaver River watershed (a): Tradeoffs between the Crop Yield and Environmental Flow; (b): Tradeoffs between Crop Yield and Flood Risks; (c): Tradeoffs between the Crop Yield and the Nitrogen Concentration; (d): Tradeoffs between the Crop Yield and the Phosphorous Concentration.

Appendix: Modeling the production of multiple ecosystems services from agricultural and forest landscape in Rhode Island

Calibration and Validation of the SWAT Model

Sensitivity Analysis

Since different watersheds have different hydrologic attributes, a sensitivity analysis is necessary to reduce the uncertainty and also provide overall coarse guidance for the calibration and validation. Based on the ranking of sensitivity analysis, we found the top five parameters which the SWAT output were particularly sensitive to were: soil evaporation coefficient (ESCO), canopy evaporation coefficient (CANMX), the curve number (CN2), evaporation coefficient (threshold watershed depth in the shallow aquifer for “evaporation”, REVAPMN), and base flow alpha factor (ALPHA_BF). Similar sensitivity analysis have been found in (Reungsang *et al.* 2007). The soil evaporation coefficient values adjust the depth distribution for evaporation from the soil to account for the effect of capillary action, crusting, and cracking (Neitsch *et al.* 2005). The curve number determines the partitioning of precipitation between surface runoff and infiltration as a function of soil hydrologic group, land use, and antecedent moisture condition (Kaur *et al.* 2003).

Several simulations were conducted for each input parameter while holding the other parameter constant. Based on the result, we adjusted the range of the parameters to account for the uncertainty of the soil and land use conditions of that watershed. For example, the soil evaporation coefficient (ESCO), which has a range between 0.0 and 1.0, was changed from default 0.95 to 0.98 in our research. The initial and final values of the selected calibration parameters, as well as ranges for each parameter based on SWAT

auto-calibration and the default ranges were given by (Neitsch *et al.* 2005) was listed in Appendix Table 4, such as soil evaporation coefficient (ESCO), canopy holding waters capacity (CANMX), curve number (CN2), threshold depth of water in the shallow aquifer for “revap” or percolation to the deep aquifer to occur (REVAPMIN), and base-flow factor (ALPHA_BF). These parameters were chosen on the basis of the results of the sensitive analysis and they are consistent with previous studies (Reungsang *et al.* 2007) .

Calibration and Validation

Each SWAT simulation was executed for the 1987-2010 to encompass a complete cycle and also a three-year “warm up” period (1987-1989) is included. Calibration of SWAT was performed for the years 1990-2000, while the years 2000-2010 were used as validation. The 1990-2010 annual average streamflow was simulated using historical precipitation and temperature records at the Kingston weather station. Average annual streamflow of the calibration period (1990-1999) is $0.540 \text{ m}^3/\text{s}$ and it is lower than the observation $0.571 \text{ m}^3/\text{s}$ by 5.44%. Average streamflow in validation period (2000-2010) is $0.616 \text{ m}^3/\text{s}$ and it is slightly higher than the observed $0.613 \text{ m}^3/\text{s}$ by 0.49%, almost identical (Appendix Figure 5). The following steps were then taken to complete the calibration and validation process of this study based on comparisons between the simulated and measured data at the watershed outlet: (1) calibrate the long-term average annual streamflow; (2) calibrate the monthly streamflows; (3) validate monthly streamflow; (4) calibrate the seven day moving average for summer months (from June to August); (5) validate the seven day moving average for summer months. For the first step, the annual streamflow was calibrated against measured streamflow at the outlet of the watershed from year 1990 to 2000. This step was performed to check if the simulated

water yield from SWAT output is realistic. Once the simulated annual streamflow was within 10% of measured streamflow, the validation from year 2000 to year 2010 was estimated using input parameters determined during the validation step. Then monthly streamflow was calibrated from year 1990 to year 2000. The same validation step followed after monthly calibration.

Appendix Tables

Appendix Table 1: Comparison of the Performance of the Simulated vs. Observed 7 Day Moving Average, Lowest and Highest 5% and 10% (1990-2010)

	R²	NSE	PBIAS	RSR
7 day moving average lowest 5%	0.99	0.72	5.79	0.53
7 day moving average lowest 10%	0.99	0.80	-3.70	0.44
7 day moving average highest 5%	0.79	-0.10	16.8	1.04
7 day moving average highest 10%	0.88	0.32	14.9	0.83

Note: 1. The daily simulation from SWAT model was used to calculate the 7 day moving average.

2. Nash-Sutcliffe efficiency (NSE), Percent Bias (PBIAS), Deviation of Measured Data (RSR), Source: Moriasi et al. (2007)

Appendix Table 2: Percentage of Land Use across Different Scenarios after HRU Definition**Unit: %**

Land Use	Scenario 1: Baseline	Scenario 2: Conventional Agriculture	Scenario 3: BMP Agriculture	Scenario 4: Biofuel	Scenario 5: Suburban Medium Density	Scenario 6: Suburban Medium Low Density
Medium Density Residential (1 to 1/4 acre lots)	0.43	0.55	0.55	0.55	54.41	0.43
Medium Low Density Residential(1 to 2 acre lots)	0	0	0	0	0	57.64
Developed Recreation	0.01	0.01	0.01	0.01	0.01	0.01
Cropland (tillable)	0.87	16.62	16.62	16.62	0.87	0.87
Deciduous Forest (>80% hardwood)	69.27	63.44	63.44	63.44	31.11	31.65
Softwood Forest (>80% softwood)	8.75	4.94	4.94	4.94	2.82	2.82
Mixed Forest	19.18	12.94	12.94	12.94	3.37	3.5
Wetland	1.05	1.05	1.05	1.05	1.07	1.06
Septic Systems*	0.46	0.45	0.45	0.45	6.34	2.02

Note: Land use maps were created based on 2003/2004 land use and land cover data (RIGIS). The percentage of land uses were calculated after the HRUs were defined using a 10% minimum threshold and thus there are a subtle difference in the percentage of area because of this threshold. A GIS layer for septic systems was created as a new land use type in our study.

Appendix Table 3: Days below the Requirement of RI ABF in Each Month from 1990 to 2010 (20 years)
Days

Unit:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Scenario 1: Baseline	137	241	156	153	286	391	262	230	132	62	63	69
Scenario 2: Conventional Agriculture	139	244	173	161	301	418	273	239	154	72	69	80
Scenario 3: BMP Agriculture	149	245	175	164	320	409	267	234	153	68	70	83
Scenario 4: Biofuel	137	245	169	161	296	402	264	233	151	73	69	80
Scenario 5: Suburban Medium Density	162	241	148	123	214	276	177	107	72	36	49	81
Scenario 6: Suburban Medium Low Density	126	216	123	118	201	296	208	176	115	54	64	76

Note: Days below RI ABF threshold in each month of the 20-year-period. E.g. In January, there is 137 days below RI ABF threshold in the 620 days of 20 January from 1990 to 2010(31*20=620).

Appendix Table 4: Initial and Final Values of the Calibration Parameters and Possible Ranges

Parameters	Range	Initial Value	Final Calibrated Value
1. Soil evaporation coefficient (ESCO)	0.1-1.0	0.95	0.98
2. Maximum Canopy Storage (CANMX)	0-6	0	1.89
3. Initial SCS runoff curve number for moisture condition (CN2)	25/35-98	-	Multiply by 0.4
4. Threshold depth of water in the shallow aquifer for “revap” or percolation to the deep aquifer to occur (REVAPMIN)	0-500	1	85.59
5. Baseflow alpha factor, days (ALPHA_BF)	0.1-1.0	0.025	0.0224

Note: 1. The ranges are based on recommendations given in the *SWAT User's Manual* (Neitsch *et al.* 2005); the curve number range was selected arbitrarily.

2. The base flow separation analysis yielded a subsurface contribution of 64%, based on values of 0.0224 and 102.46 days for the base-flow alpha factor. The base-flow alpha factor was one of the parameters selected for calibrating SWAT.

Appendix Table 5: Days below the Requirement of New England ABF **Unit: Days**

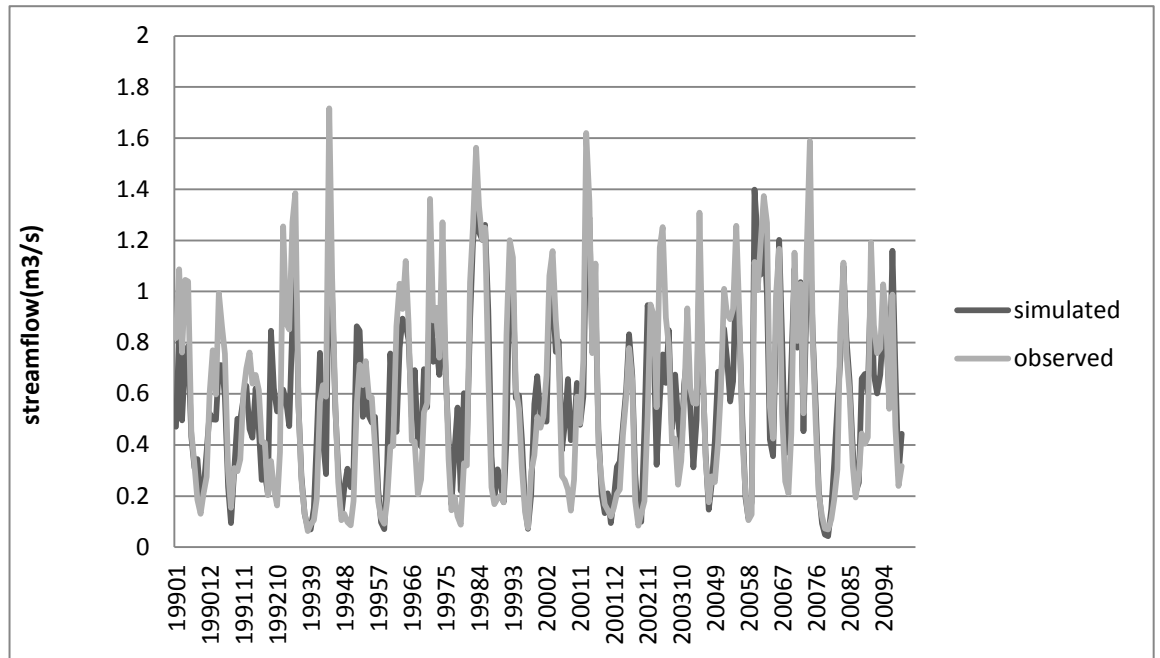
	Summer	Fall/Winter	Spring
Scenario 1: Baseline	194	17	0
Scenario 2: Conventional Agriculture	211	15	0
Scenario 3: BMP Agriculture	205	16	0
Scenario 4: Biofuel	202	15	0
Scenario 5: Suburban Medium Density	13	9	0
Scenario 6: Suburban Medium Low Density	116	11	0

Note: Based on the New England ABF method, the streamflow for August is assumed to represent the month of greatest stress for aquatic organisms in the summer. The streamflow for fall and winter seasons was determined by averaging the medians of the monthly mean flows for twenty February months. The streamflow for spring was determined from an average of the April and May for the medians of the monthly mean flows for 20 years (Armstrong *et al.* 2004). The number of days below the threshold during different seasons was then calculated.

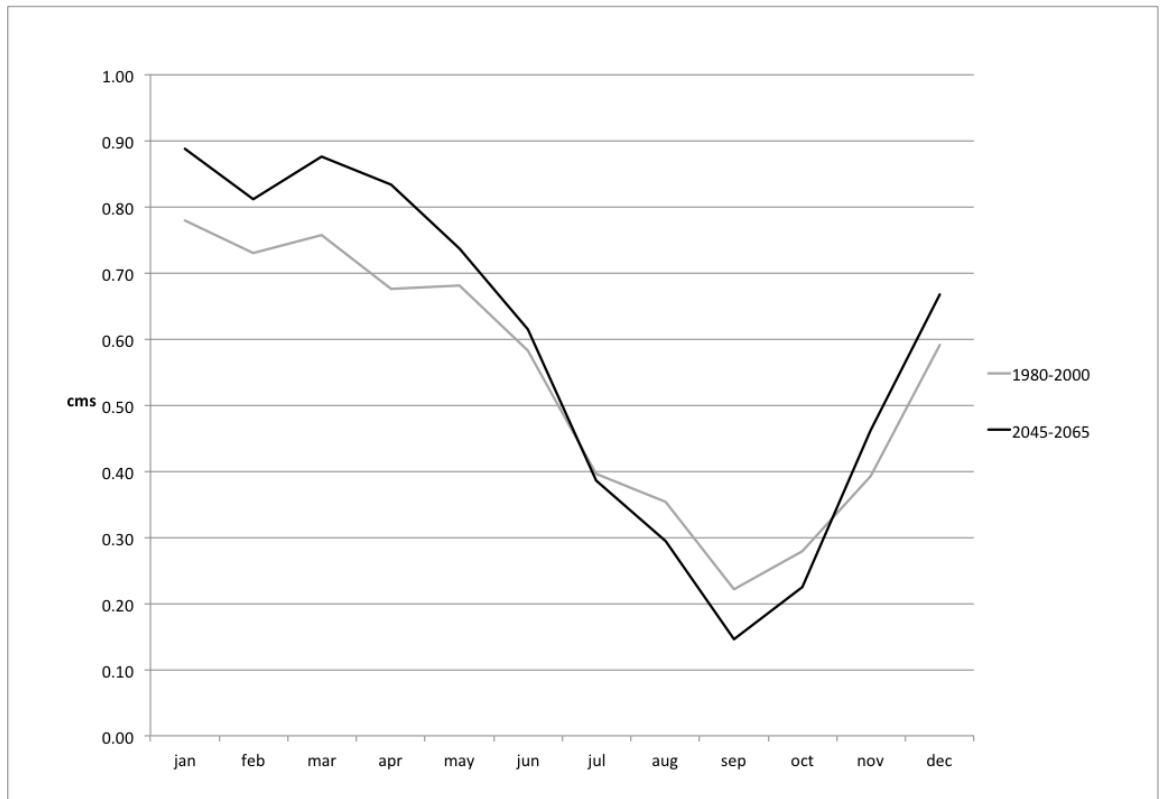
Appendix Table 6: Percent below the Requirement of New England ABF **Unit: %**

	Summer	Fall/Winter	Spring
Scenario 1: Baseline	31.3%	3.0%	0.0%
Scenario 2: Conventional Agriculture	34.0%	2.7%	0.0%
Scenario 3: BMP Agriculture	33.1%	2.9%	0.0%
Scenario 4: Biofuel	32.6%	2.7%	0.0%
Scenario 5: Suburban Medium Density	2.1%	1.6%	0.0%
Scenario 6: Suburban Medium Low Density	18.7%	2.0%	0.0%

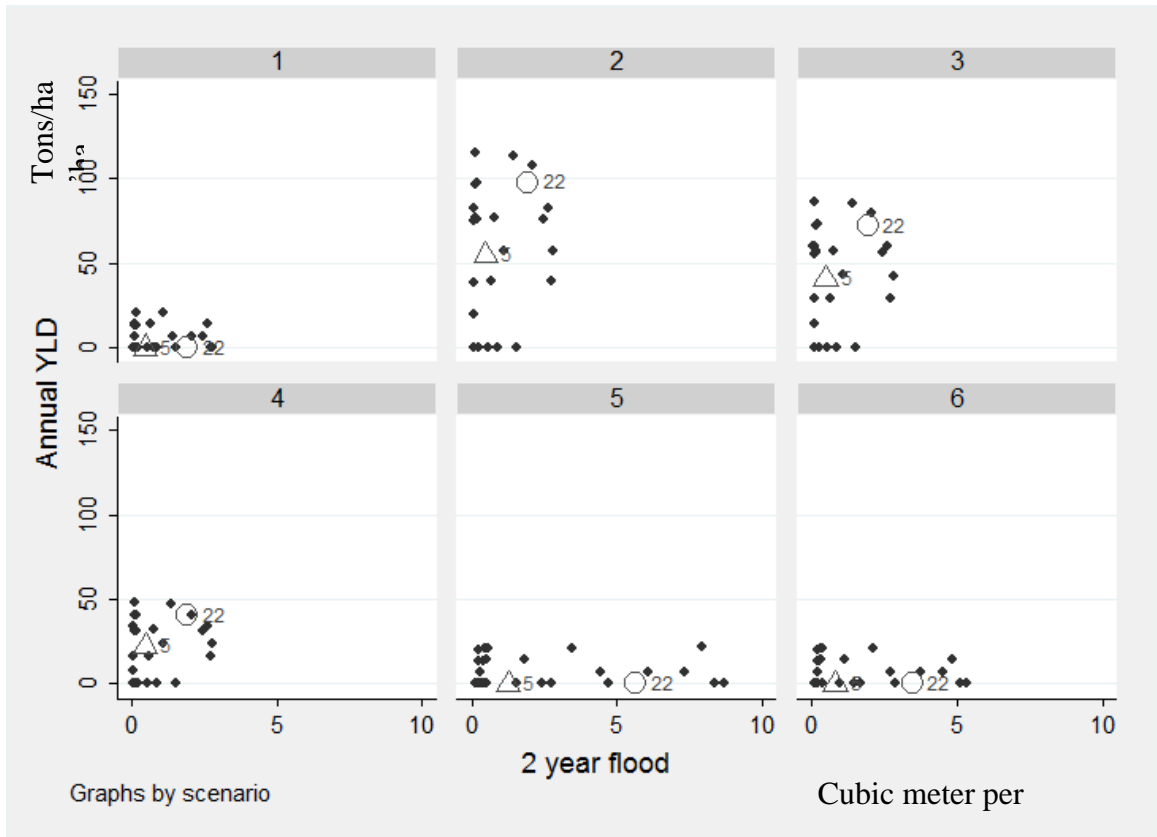
Note: Based on the New England ABF method, the streamflow for August is assumed to represent the month of greatest stress for aquatic organisms in the summer. The streamflow for fall and winter seasons was determined by averaging the medians of the monthly mean flows for twenty February months.; The streamflow for spring was determined from an average of the April and May for the medians of the monthly mean flows for 20 years(Armstrong *et al.* 2004). The percent of days below the threshold during different seasons was then calculated.



Appendix Figure 1. Annual Simulated vs. Observed Streamflow during the Calibration Period (1990-2000) and Validation Period (2001-2010)

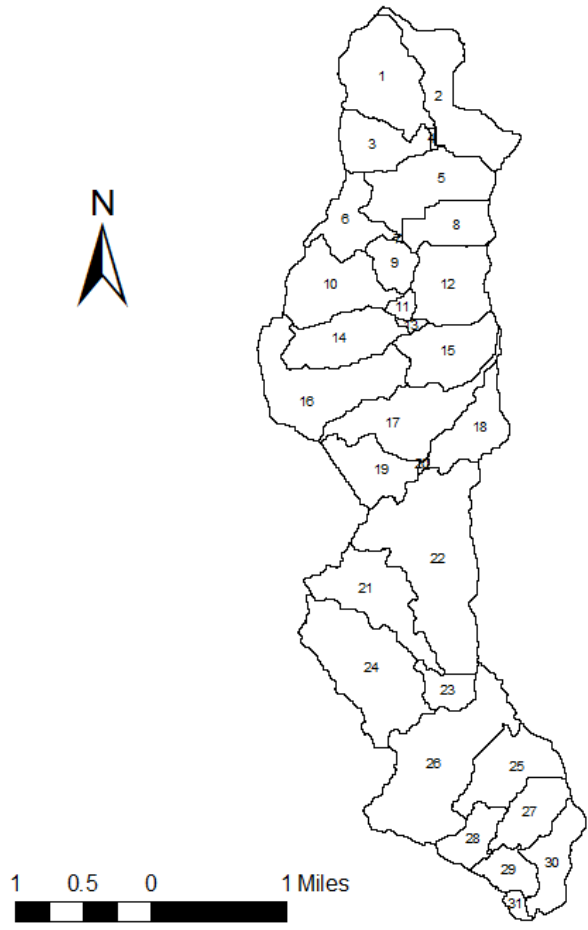


Appendix Figure 2: Median Monthly Average Daily Flow (20 Years), Baseline Flow vs. Climate Change, *Scenario 7*.

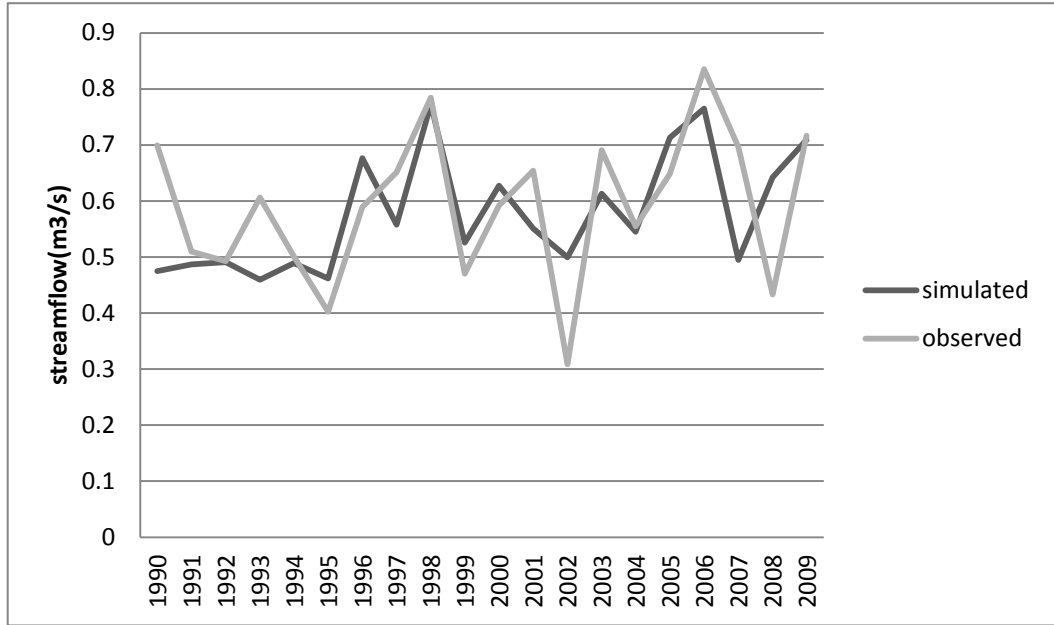


Appendix Figure 3. Tradeoff between Crop Yield (vertical axis, annual yield of crop, unit Tons/ha) and Flood Risk (horizontal axis, 2 year flood, unit Cubic meter per second) in Different Scenarios; Scenario 1 to 6 represents: Baseline, Conventional Agriculture, BMP Agriculture, Biofuel, Suburban Medium Density and Suburban Medium Low Density respectively.

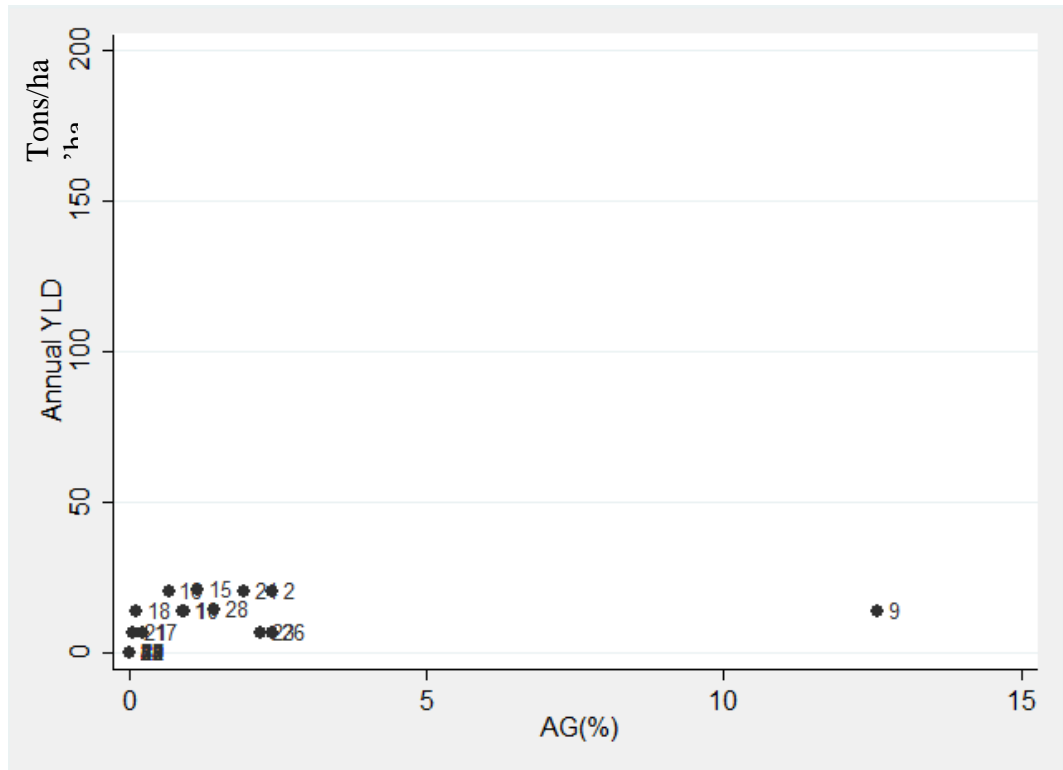
Note: Each point represents a unique subbasin.



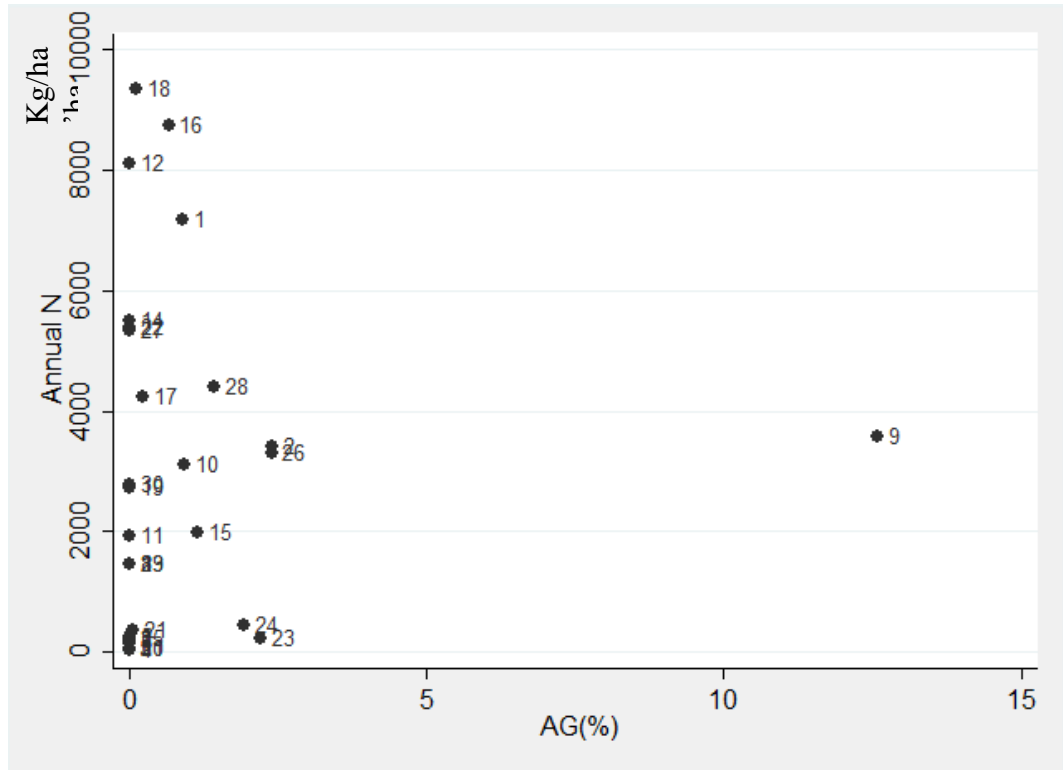
Appendix Figure 4. Subbasin Map of the Beaver River Watershed, RI



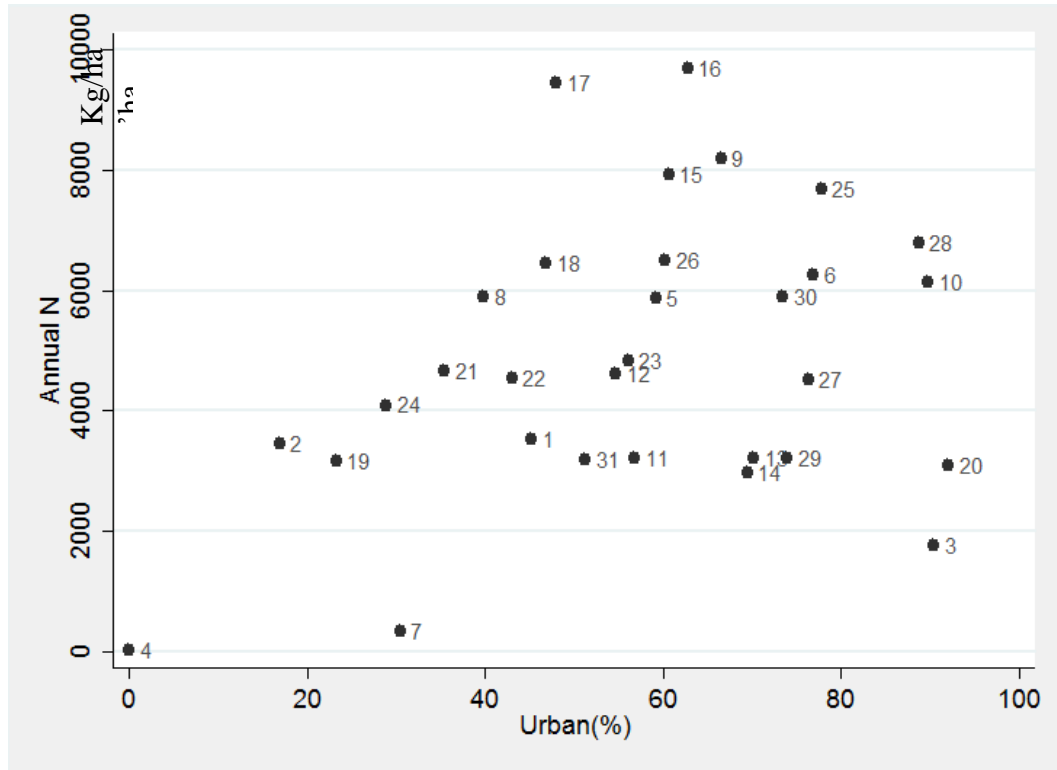
Appendix Figure 5. Annual Simulated vs. Observed Streamflow during the Calibration Period (1990-1999)



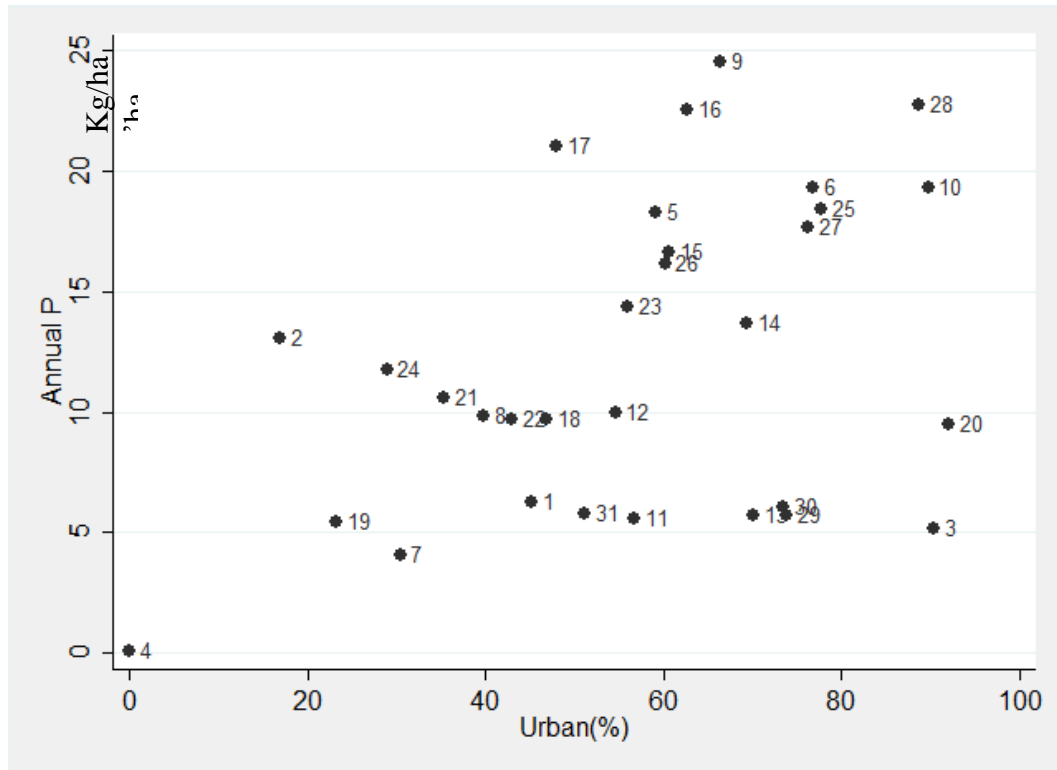
Appendix Figure 6. Annual Crop Yield (vertical axis, annual yield of crop, unit Tons/ha) vs. Percentage of Agricultural Land under Baseline (*Scenario 1*)



Appendix Figure 7. Annual Nitrogen Loading (vertical axis, annual N, unit Kg/ha) vs. Percentage of Agricultural Land under Agricultural Scenarios (Scenario 2-4: Conventional Agriculture, BMP Agriculture, and Biofuel respectively)



Appendix Figure 8. Annual N Loading (vertical axis, annual N, unit Kg/ha) vs. Percentage of Urban under Suburban Medium Density Residential Scenario (*Scenario 5*).



Appendix Figure 9. Annual P Loading (vertical axis, Annual P, unit kg/ha) vs. Percentage of Urban under Suburban Medium Density Residential Scenario (*Scenario 5*).

The direct and spillover effects of residential zoning policy on land development

Prepared for submission to Land Economics

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The direct and spillover effects of residential zoning policy on land development

Abstract: Zoning has been widely used as a tool to manage residential development. Residential zoning policy regulation, particularly minimum lot size zoning restrictions in one area may affect the land development of the area itself as well as in the adjacent areas. Accounting for both the direct and the potential spillover effects of minimum lot size zoning restrictions is important for land use planning. However, limited research has been done to examine the spillover effect of minimum lot size zoning restrictions on nearby land development. In this study, we estimate the direct and spillover effect of minimum lot size zoning restrictions in Rhode Island. To address the non-random placement of residential zoning, we use propensity score matching and nearest neighborhood matching to preprocess the data. Additionally, to address simultaneity and the presence of spatially correlated unobserved characteristics, we use the soil construction constraint index as an instrumental variable for minimum lot size restrictions. Our results suggest that minimum lot size restrictions in the neighborhood significantly decrease the probability of urban development outside of the zoned area, up to 2000 meters radius buffers.

Key words: minimum lot size restrictions, land use, spillover effect, endogenous, matching, instrumental variable

I Introduction

Over the past century, human-dominated land uses have spread rapidly across landscapes worldwide (Food and Agriculture Organization, 2012). This is commonly referred to as urban sprawl. In the eastern United States, this transition is causing both forest and agricultural lands to decline (Yuyu Zhou, Wang, Gold, & August, 2010). For example, in Rhode Island, one of the most densely populated states, while urban area has increased by 74%, agricultural land and forests have decreased by 24% and 18% from 1972 to 2010. All these changes on land use may have substantial influence on the environment and ecosystem services, including poor air quality, water quality deterioration, and the loss of the wildlife habitat (Hascic and Wu, 2006).

Local municipalities across the nation have enacted a number of policies to preserve undeveloped land, including property tax reform, zoning regulations and ordinances, smart growth policy, and investments in land conservation (Juergensmeyer and Roberts 1003; Gardner, 1977; Daniels and Lapping, 2005; Hollingshead, 1996). Among these tools, zoning has been used as a common tool to manage residential development undertaken by local government (Fischel, 2002). Compared to other land use management tools, zoning is widespread strategy in urban growth management nationwide, however it is also one of the most widely denounced (Berry, 2001). In addition, local zoning ordinances and other forms of land use regulations are believed to contribute to increased housing prices by reducing supply and increasing the size and quality of new housing (Jud 1980; Quigley and Rosenthal 2004; Ihlanfeldt, 2007; Cho et al. 2010).

The objective of this research is to examine the direct and spillover effects of residential zoning on land use change. Although zoning is in widespread use, little is known of its overall effectiveness and particularly with regards to how it affects neighborhood's development, the spillover effect on the adjacent land. Residential zoning may be effective in terms of controlling development of the zoned area itself (Ihlanfeldt, 2007).²³ However, at the same time, it may push development to nearby areas outside of the zoning areas due to the spillover effect. It may stimulate, instead of discourage, neighborhood land use change if the residential zoning in the neighborhood is less restricted compared to the pixel itself, resulting in a negative spillover effect.²⁴ Stringent zoning may also retrain residential development of the surrounding areas, having a positive spillover effect. The net spillover effect is ambiguous and is subject to empirical testing.

Limited research has been done on the effectiveness of residential zoning on development, especially concerning residential zoning's potential spillover effect. Hsieh, Irwin, & Forster, (2000) studied the effect of rural zoning at the county level. They found that rural zoning did not have a significant impact on land development within the county but in some case generates a spillover effect in nearby counties that results in a higher amount of land development. Cho et al. (2010) investigated neighborhood spillover effects between rezoning of vacant parcels and housing price in the Knoxville, TN. They found the probability of rezoning vacant land is expected to increase as housing price in a neighboring location increases.

²³ The neighborhood is defined as the areas within a certain distance buffer of the land. We will have a more detailed explanation in the neighborhood definition section.

²⁴ Pixel is the smallest unit of digital aerial photographs, imagery from satellites, digital pictures, or even scanned maps (ESRI, 2014). Each pixel (cell) contains value representing land use information.

On the other hand, the findings of the effects of residential zoning on urban sprawl are mixed. Foley (2004) examined the influence of minimum lot size zoning restrictions on development in Oakland County, Michigan, a suburb of Detroit, and found a quadratic relationship between average minimum lot size and land development. However, most of these analyses failed to account for the endogeneity problem of zoning due to its non-random placement, except a handful of studies in recent literature (Cho, et al.2010; Liu and Lynch, 2010; Towe et al.2011). For instance, Towe et al. (2011) examined spillover effect of residential subdivision in Baltimore County and tackled the problem of endogeneity using propensity score matching method.

The evaluation of how residential zonings influence on development is hindered by two challenges. The first challenge lies in evaluating the impact of residential zoning is its non-random placement, which creates endogeneity problem. The comprehensive federal Planning and Land use Regulation Act in 1988 requires all cities and towns to produce a comprehensive plan to guide development (US Environmental protection Agency, 1992). Residential zoning regulation was enacted based on historical land use, meeting different financial and political priorities as well as addressing environmental protection and resources management (US Environmental protection Agency, 1992). Clearly, land that is zoned for residential uses might be systematically different from other uses in biophysical and socio-economic characteristics such as slope, productivity of the land, distance to the market, and household income.

Furthermore, as zoning regulations are typically set at the municipality level, a consistent digitized data set of zoning information over a large spatial coverage is seldom readily available. In this study, I compiled a unique data set of pixel-level zoning

information from 17 towns and municipalities in Rhode Island. While this data set is limited to cross-sectional information on the most recent digitized zoning ordinances, to our knowledge, it is the first study to use such data in New England.

We conduct this study in the context of Rhode Island, which has the second highest population density in the U.S. Urban sprawl has affected landscapes across the state with residential areas spreading further away from the City of Providence, the state capital (Rhode Island Department of Administration Division of Planning, 2006). According to their most recent findings Rhode Island developed its land at a rate much higher than historic trends.²⁵ During 1970-1995, developed land increased from approximately 143,000 to 205,000 acres, which is about 43% increase. This increase in developed land was disproportional to the change in the state's population, which increased by only 5% during this period. With population continuing to migrate towards the rural parts of the state, land in residential use increased by 55 percent. Moreover, the state's Division of Planning expects that this urban sprawl to continue in the foreseeable future.

The tremendous construction and building boom that come along with urban sprawl has been placing enormous pressure on the environment, including the degradation of surface and ground water quality, degrade and destroy critical resources both inland and also in Narragansett Bay. In 1988, Rhode Island Comprehensive Planning and Land Use Regulation Act was passed (EPA, 1992). Followed by Zoning Enabling Act and Subdivision Enabling legislation, these two acts were passed in 1991 and 1992, requiring municipalities to take into account the effect of existing and projected population, growth and land development pressure on local resources. Each Rhode Island municipality is required to prepare a local comprehensive plan by December 1991 under the guidance of

²⁵ Rhode Island Statewide Planning Program, published in Land Use Trends 1970-1995

these Acts and the Rhode Island Division of Planning. Then they were allowed to have eighteen months to prepare a zoning ordinance and map in conformance with the approved land use plans. These local comprehensive plans are expected to address the declining resources issues from local perspective in order to maintain sustainable development in the future.

This study contributes to the land economics literature in several ways. First, the results are among one of the first attempts to examine both the direct and spillover effect. Numerous literatures have examined the effectiveness of zoning regulation within the same jurisdictions. However, relatively few studies focus spillover effect on adjacent land's development. This study not only examines the effectiveness of minimum lot size zoning restriction within jurisdictions but also in its neighborhood. Second, in comparison to previous research, which uses aggregated zoning information, this study uses pixel level (30 meter by 30 meter) data to examine the spillover effect instead. Thus we are able to capture the spillover effect at a smaller scale comparing to studies at county levels. Third, this study uses a unique setting which allows using an instrumental variable approach to deal with the endogeneity problem stemming from nonrandom placement of residential zoning and the potential simultaneity problem between zoning and land use change. Finally, we provide evidence spillover effect exists despite the changes in neighborhood's definition. Specifically, the spillover effect is examined at different distance radius and it shows a decaying influence when the radius buffer is increased from 100 meters to 2000 meters. The spillover effect is not significant at 5000 meters. Comparing to Hsieh, Irwin, & Forster, (2000)'s studies which found that rural zoning is not effective within counties, we found that the spillover effect is negative and

significant within the town boundary using pixel level data. Furthermore, we find that residential zoning can have a spillover effect in both the neighborhood within and outside of towns and municipalities boundaries.

II Conceptual framework

The land use decision is based on the random utility model (RUM). RUM has been extensively used when analyzing micro-level discrete choices in land use change modeling (e.g., Bockstael 1996, Irwin, 2004; Lewis, 2010). This model assumes that the benefit that parcel i obtains from converting land use from j to k at time t is:

$$\pi_{ijkt} = V_{ijkt} + \varepsilon_{ijkt} \quad (1)$$

V_{ijkt} is determined by the model we choose, and it represents the observable part of the profits or utility. ε_{ijkt} represents the unobservable part of the utility.

If all the parameters of V_{ijkt} is known, then the probability of converting land use from j to k should follow the following form:

$$P_{ijkt} = \frac{\exp(V_{ijkt})}{\sum_{i=1}^k \exp(V_{ij,t})} \quad (2)$$

Each landowner maximizes his or her profit by choosing from alternative land use choices. As a rational landowner, he chooses the one that gives the highest profit. We assume that once the land has been developed into residential land use, it is irreversible; this means that residential land cannot be converted to forest or agricultural purposes again. In contrast to Irwin (2004) and Lewis (2010) whose models assume that parcel is the smallest unit to make land use change decisions, we assume that the land owner can make choices at the pixel level, i.e., at a smaller scale than the parcel level, allowing conversion of a portion of their parcel to another land use. This scale is more suitable for

the study of the rural-urban fringe in Rhode Island given its relatively high population density.²⁶ Allowing land use change at the sub-parcel level is also more realistic.

Following the land use conversion model in Irwin (2001) and Lewis (2010), in each period the land owner of pixel i compares profit across alternative land uses and convert land use from j to k if:

$$R_{ikt} - rC_{ikt} \geq R_{ijt} \quad (3)$$

Where R_{ikt} is the annual net return to land use k in time t ; r is the interest rate; and C_{ikt} is the one-time cost of converting land from the original land use j to use k . In (3), R_{ijt} means the annual net return to land use j in time t if the land use remains the same. Moreover, the profit of the land owner can be expressed as follows:

$$\pi_{ikt} = x_{ikt}\beta_{jk} + \varepsilon_{ikt} \quad (4)$$

We assume that the parameters will be same for all the land owners on the same piece of land and ε_{ikt} is the portion of the profit that is known by the landowners but unknown to the researcher. The probability that a land owner chooses a land use change type, for example, k over l , can be expressed as follows:

$$P_{ijk} = P(x_{ikt}\beta_{jk} + \varepsilon_{ikt}) > P(x_{ilt}\beta_{jk} + \varepsilon_{ilt}) \quad \forall k \neq l \quad (5)$$

To simplify the study, we assume the errors are independent and identically distributed with Type I extreme value distribution. Additionally, we model the unidirectional conversion from forest and agricultural land use to urban. This unidirectional land use conversion is consistent with the trend of Rhode Island's land use change in the past four decades that agricultural and forest land is being converted to

²⁶ Some zoning units is a quarter acre, which is smaller than the size of a pixel in populated cities. However it only accounts for about 2% of the total data.

residential and commercial use (Rhode Island Department of Administration Division of Planning, 2006).

III Data

Land use data

Land use land cover data for Rhode Island are derived from three satellite images 1985, 1999 and 2010 (Novak & Wang, 2004; Archetto & Wang, 2012), which are the best available dataset depicting landscape pattern changes from in Rhode Island with 30-meter spatial resolution. The quality of this remote sensing data will be suitable for detecting and monitoring land cover change as compared to other LULC datasets (e.g., Rhode Island Geographic Information System (RIGIS), NRCS, 2010). The overall classification accuracy for the urban, forest and agriculture are greater than 90%.²⁷ The initial classification of this dataset was coded in twelve categories, including urban (impervious surface), urban grass, agriculture, deciduous forest, coniferous forest, mixed forest, brush land, water, herbaceous wetland, deciduous wetland, coniferous wetland, barren areas (Novak & Wang, 2004). Based on our research interests, we have reclassified the land use categories by aggregating the three types of forests while eliminating other categories since other land use categories have negligibly changed in the past few decades.²⁸ Table 1 shows the land use conversion matrix from year 1985 to year 2010 in the 17 towns and cities of Rhode Island. Urban land use and land over increased by more than 40% with the decrease of forest land use and land cover about 15%.

²⁷ These accuracies met the USGS minimum requirement of 85% for the land use and land-cover classification of remotely sensed data (Anderson, 1976).

²⁸ Other land use types including brushland, wetlands etc. For more information, please contact the author for the detail of land use change.

In contrast to most of the land use change modeling literature (e.g., Irwin & Bockstael, 2007; David J. Lewis, Plantinga, & Wu, 2009), which uses parcel data derived from the National Resources Inventory (NRCS, 2010), we use pixel-level data based on land use and land cover maps interpreted and ground-truth from satellite images.

Modeling using pixel-level data has several advantages. Pixel level (30 meter by 30 meter) is a smaller than parcels in most of Rhode Island's municipalities.²⁹ Furthermore, Rhode Island is smallest state in terms of area, and there are big variations in terms of minimum lot size zoning restrictions across the state.³⁰ Thus, Pixel level information can provide detailed information to investigate the spillover effect of minimum lot size zoning restrictions comparing to aggregated information.

Minimum lot size zoning restrictions

After contacting all towns and municipalities in Rhode Island, we received minimum lot size zoning restrictions data from 17 towns out of 39 towns.³¹ Since each town or municipality makes its local comprehensive plans and maps under the guidance of the state comprehensive planning, there is inconsistency between these zoning ordinances. To make the information from the 17 towns consistent and comparable, we converted minimum lot size zoning restriction from the unit of square feet and acres to hectares.³² However, some towns currently do not have GIS specialists and digitized zoning maps due to their budget constraints.

Other variables

²⁹ Except heavily developed areas in cities, such as some parcels in Providence and Pawtucket.

³⁰ The minimum lot size zoning restrictions vary from 0.01 to 2.02 hectares (equivalent to 1200 to 217800 square feet).

³¹ We contacted each town three times using emails and phone calls to get the latest zoning information.

³² Non-residential developed areas, such as industrial and commercial districts do not have minimum lot size requirement, therefore it is not examined in our analysis.

Based on von Thünen's theory (1966), distance to the central market is an important determinant in the conversion of natural land into developed land uses (Samuelson, 1983). We present statistics such as distance to downtown Providence, distance to the nearest shoreline, distance to the nearest highway exits. We calculated the Euclidian distance (the shortest line) between the centers of the pixel to the above interest destinations.³³

Biophysical characteristics, such as slopes, also influence land use decision-making by impacting the ease of land use conversion and construction. Others factors will directly affect the potential profits or opportunity costs of the land, including the farmland soil productivity index (0=neither prime nor state-wide important, 2=farmland of state or local importance) and conservation status (conserved by the state or non-state). Soil construction constraint index is a soil attribute that determines whether the land is developable (0 to 5, 0=no constraint, 5=significant constraints for construction) for neighborhood's construction constraint index will be used as an instrumental variable for the residential zoning of the neighborhood residential zoning correspondingly. All the biophysical attributes are derived from Rhode Island Geographic Information System (RIGIS).

Socio-economic characteristics of the area also affect the land use decision-making, including the population density and the median household income of the particular census tract where the pixel is located. These variables are derived from block level of US Census dataset of year 1990, 2000, and 2010. Due to the fact that the population growth in RI has been steady since 1990s, we use a linear interpolation method to obtain

³³ We use Kennedy Plaza at downtown Providence as our reference point for GIS calculation. We consulted the GIS expert and in a small state like Rhode Island, the Euclidian distance can be a very good approximate of the actual distance (Personal Communication, August, 2013).

population levels for years 1985 and 1999, discounted by the population grow rate.³⁴

The median household income is calculated and adjusted based on the median income level for the state of Rhode Island.³⁵ All the income is adjusted to 1999 dollars using Consumer Price Index (CPI) inflation calculator (Bureau of Lab Statistics, 2014).

Stratified Sampling

The initial data has about more than 2 million pixels, derived from all 17 towns in Rhode Island, including land use conversion, zoning ordinances, and other attributes which may be spatial dependent and spatial correlated. For example, residential development can be constrained by biophysical such as slope and productivity of the land which tends to be spatial correlated. The correlation may also be driven by a spatial process, whereby decision to develop on one pixel may be driven by development on nearby pixels. If we do not account for spatial dependence and spatial autocorrelation, the coefficient of estimation will be biased since the omitted spatial variables are likely to be correlated with one more of the observed spatial variables (Brady & Irwin, 2011). To reduce this problem, we employ stratified random sampling to get rid of the spatial dependence and autocorrelation. We sampled a total of 9,604 pixels based on stratified sampling method (Fowler, 2014), Since only 534 hectares of agricultural land has been converted to urban during the study period (Table 1) we oversample the pixels that converted from agricultural land to urban land use. For the remaining land use land cover conversions, we performed stratified random sampling for other conversion categories during 1985 to 1999. Using the GIS technique, we obtained conversion information for

³⁴ The population growth rate from 1980-1990 is 5.95 % (Source: Census 2000 analyzed by the Social Science Data Analysis Network (SSDAN)).

³⁵ The average median household income data of RI(1985) is \$24,265 (Source: Southern Regional Education Board, 2013)

the same pixels during period 1999 to 2010 by matching geographic locations. After sampling, the Moran's I index (a measure of global spatial autocorrelation) was reduced from 0.79 to 0.07, indicating a significant reduction in spatial correlation.

Sampled data well represents the full dataset. Table 2 shows the land use land cover area after sampling from 1985 to 2010. From year 1985 to 1999, 59.32 hectares rural land (both forest and agricultural land) has been developed and from year 1999 to 2010, additional 65.34 hectares has been converted to urban area. Appendix Table 1(1.1-1.4) further demonstrates that selected sample data are very similar to the full data.

Defining neighborhood

Different researchers have used various definitions of neighborhoods and neighbors in the literature. Some of them are based on geographic location, such as rook, queen, and adjacency; others are based on political divisions, such as counties and school districts (Robalino & Pfaff, 2010). To estimate the spillover effects we define the neighborhoods using a distance measure. Specifically, based on the size of the seventeen towns and municipalities, we created seven circular buffers with different radius: 200-meter, 250-meter, 500-meter, 750-meter, 1000-meter, 2000-meter and 5000-meter radius. We hypothesize the neighborhood minimum lot size zoning restriction has a negative spillover effect however with increasing of distance radius, this spillover effect attenuates.

Neighborhood characteristics are calculated by taking the average of the characteristics within the distance radius. For instance, mean minimum lot size zoning restrictions in the neighborhood are calculated by taking the average of minimum lot size zoning restrictions within the distance radius. The unit that we use for minimum lot size

is hectares.³⁶ Using the same approach, we also averaged the farmland soil productivity index, slope category, conversation index (conserved by the state or non-state), population density, and median household income in the neighborhood.

Descriptive statistics show that the biophysical and socio-economic characteristics are very similar despite different definition of the neighborhood (Table 4). The variations of the characteristics among neighborhood are smoothed out by increasing of the radius. For example, with the increasing of radius from 100 meters to 5000 meters, the minimum lot size restriction stays 0.75 hectares with a slight increase in 250 meters and 500 meters. Meanwhile, its standard deviation decreases from 0.57 to 0.40. Likewise, the average farmland soil productivity index reduces from 2.11 to 2.06, and the standard deviation of the slope declines from 1.17 to 0.47.

IV Identification Strategy

Any econometric analysis of impact evaluation of zoning faces several challenges. First, the placement of minimum lot size zoning restrictions is non-random, which implies that areas with minimum lot size zoning restrictions maybe systematically different from those without. If not the non-random placement of zoning is not controlled for, it will lead to coefficient bias. To measure the effect of minimum lot size zoning restrictions on land use change, we follow Ho et al. (2006) and preprocess the data based on matching method using both propensity score matching and covariate matching. By dropping unmatched observations during this procedure, we can improve the overall balance of the variables and thus improve the efficiency of the estimators (Ho,

³⁶ We have converted the unit from square feet to hectares to make it consistent with our radius buffers for defining neighborhoods and also the distances to market center and other interested destinations.

Imai, King, & Stuart, 2006). The second challenge is the simultaneous interactions between zoning and land use development. On one hand, local governments enact residential zoning policies based on the current land use in an attempt to either restrict or encourage future development of the land. On the other hand, the zoning regulations will affect the probability of further development of the area itself. If the simultaneity problem is not taken into account of, we may overestimate the effect of the regulation.

Additionally, the impact of zoning on land use change may be affected by unobservable variables leading to omitted variable bias. For example, unobserved variables at the town level reflecting different economic, political conditions such as tax rate, demand for labor, and the formation of members on local planning and zoning boards, which can be important for land use change. If these factors are not captured in the model, it will cause biased estimates of parameters.

The third challenge is dealing with spatial dependence of the data. We already solved this problem through random stratified sampling.

Instrument variables approach

There are three important issues that we need to address in our research: spatially-correlated observable variables (such as soil attributes population density), non-random replacement of residential zoning, and simultaneity between residential zoning and its development.

Since residential zoning and land development decision are simultaneously determined, estimating directly the effect of zoning and neighborhood's zoning on land use development using ordinary least squares will be biased. To check the endogeneity of the variables of interests, we first manually conducted Durbin-Wu-Hausman Test

(DWH). Our results show that the zoning of the pixel itself and its neighborhood's zoning are endogenous.³⁷

To deal with the simultaneity problem, we use the instrumental variables approach. Additionally, we propose to utilize information on whether the soil type is suitable for construction as the instrumental variable. A good instrumental variable must fulfill two conditions (Cameron & Trivedi, 2005). First, the instrumental variable should be correlated with the endogenous variable, in our case which is the minimum lot size restrictions. The placement of zoning policies is highly correlated with whether the soil is suitable for construction. Soil suitability is one of the necessary conditions when applications for residential zoning are reviewed in Rhode Island (Personal Communication with Nancy Hess, 2013). Simple correlations are shown in Table 5, which suggests the minimum lot size zoning restriction of the pixel itself and its instrument are correlated and so are its neighborhood minimum lot size zoning restriction and its instrument. The F statistics for instruments of the minimum lot size zoning restriction of the pixel itself and its neighborhood are 1459.85 and 72.62 respectively.³⁸ Secondly, a good instrumental variable should also satisfy the exclusion restriction, i.e., that it should affect the outcome only through the endogenous variable. We argue that soil suitability for construction affects land development decisions only through zoning, because soil suitability for construction affects land development solely through the decision process for zoning regulation. We therefore use soil suitability index for construction as the instrument variable to essentially pick up the difference between treated (residential zoned area) and control groups (non-residential zoned areas). We use

³⁷ Codes and results can be provided upon request.

³⁸ A rule of thumb is that F statistics should be above 10 (Stock, Wright, and Yogo).

the neighbor's averaged value to instrument for the neighborhood's zoning, and the index value of the pixel as the instrument for its own zoning.

Based on validity tests, we conclude that our instruments also satisfy condition two, that the instrumental variable is uncorrelated with the error term. However, this condition is impossible to test in the just-identified case (Cameron & Trivedi, 2005). In such cases, seeking help from economic theory is necessary. A rational land owner will not spend time and money finding out the soil suitability index for construction, since it has already been captured by zoning regulations. In practice, experienced builders or developers will do the soil testing, however a lay person will not find out if the land is developable or the building is structurally unsound unless they hire professionals (Hans, 2012).

Additionally, we have used multiple tests for the relevance test of the instruments, which are Condition One. We performed weak instruments tests using Shea's Partial R Square and First Stage F statistics. Our results in Table 5 show both instruments have passed all the weak instrument tests, using 100 meter radius buffer neighbors as an example. For more information on weak instrumental variables using other distances for neighborhoods, see Appendix Table 5. Our instrument passed all the weak instrument tests for zoning of the pixel of land itself and its neighborhood.

In contrast to a standard IV model, we are complicated by the fact that we have two endogenous variables in the first stage regressions: minimum lot size zoning restriction of the pixel itself and its neighborhood's minimum lot size zoning restriction.

We estimate the following reduced form models:

$$Zoning_i = \beta_0 + \beta_{1,it}X_{it} + \beta_{2,-it}X_{-it} + \sigma_{it} \quad (6)$$

$$Zoning_{-i} = \beta_0 + \beta_{1,it}X_{it} + \beta_{2,-it}X_{-it} + \sigma_{it} \quad (7)$$

Two separate OLS models are estimated, and two minimum lot size zoning restrictions are predicted by using the same explanatory variables.

In the second stage, we estimate a system of two weighted probit models using the predicted values of minimum lot size zoning restrictions (for pixel itself and its neighborhood's) from the first stage regression. To control for unobserved heterogeneity at different town, different time period, town fixed effects and time fixed effects. Due to the limitation of our data, we are unable to control for time variant unobservables.³⁹ The standard errors are clustered at the town level (Stata, 2014).

$$Prob(D_{int} = 1) = \beta_0 + \beta_{1,i}\widehat{Zoning}_i + \beta_3Time_t + \beta_4Town_n + \varepsilon_{it} \quad (8)$$

$$Prob(D_{int} = 1) = \beta_0 + \beta_{2,-i}\widehat{Zoning}_{-i} + \beta_3Time_t + \beta_4Town_n + \varepsilon_{it} \quad (9)$$

Where \widehat{Zoning}_i is predicted the minimum lot size restriction of the pixel, and \widehat{Zoning}_{-i} is predicted the minimum lot size restriction in the neighborhood (in pixels of certain radius buffers other than pixel i). Additionally, standard errors (using cluster at town level) are adjusted and sample weights are allowed in the second stage. $D_{it} = 1$ if the land has been developed of pixel i at town n in time period t and $D_{it} = 0$ if the land has not been developed of pixel i at town n during time period t .

We hypothesize the minimum lot size restriction of the pixel itself will have a negative impact on the probability of the pixel's development. However, the impact of the neighborhood's minimum lot size restrictions on the pixel's development could go both directions. On one hand, it may have positive impact (on the pixel's development) since the development has been pushed the adjacent area. On the other hand, it may have

³⁹ One unobservable variable which may affect the probability of development and also correlated with zoning is each district's political dynamics. We attempted to use data for political voting statistics; however there was not enough variation among the 17 towns that we examine in this study.

negative impact (on the pixel's development) if the pixel located in a very restricted residential minimum lot size zoning environment and thus the land owner might be just keep up with the neighbors since it is not effective to develop a small piece of due to the effect of economy of scale.

As robustness checks, we estimate probit regressions for agriculture and forest land pixels separately to test for heterogeneity in the spillover effect of the neighborhood's minimum lot size restrictions. Additionally, we carry out the robust tests for different neighborhood's radius buffers, to examine whether the neighbor's minimum lot size zoning restrictions exist with increasing distances of neighborhood and find out the possible reasons for such variances among different neighborhood.

V Preprocessing using matching

Control groups and self-selection of the placement of zoning

In order to examine the impact of residential zoning regulations and detect whether the spillover exists, we separate the zoning ordinances into two groups, the residential zoning group and non-residential zoning group. Since all the zoning regulations are mandatory, the non-residential zoning will serve as a plausible counterfactual for the treatment group, the land that has been designated for only residential uses. A major caveat of previous research investigating the impact of zoning regulations is due to the non-random placement of the regulations by the town planners. Multiple characteristics may still differ between the residential zoning group and non-residential zoning group, and if they are correlated with the decision of zoning placement, it could potentially bias

estimates. In our case, these differences could be driven by other reasons such as historic development, preservation, and conservation.

Our objective is to assess the effect of residential zoning on its neighborhood's development. Mathematically, this is can be expressed as

$$ATT = \frac{1}{N} \sum_{1,i} [Y_{1i}|D_i = 1] - [Y_{0i}|D_i = 1] \quad (10)$$

Where $D_i = 1$ if a pixel i is zoned in the residential category, whereas $D_i = 0$ if the pixel i is zoned in other categories (commercial, industrial, open space, and others). Y_{1i} and Y_{0i} are the observed outcome and potential outcome (if the pixel were not zoned in the residential category), given the fact it is zoning in residential category. Since the same pixel cannot be zoned in both residential and other category at the same time, finding the counterfactual for the treatment (pixels zoned in residential category) is necessary.

Considering the huge variation among residential-zoned areas, we divide residential-zoned areas into five types to make matching process easier : low residential density (minimum lot size >0.93 hectares (100000 square feet)), medium low residential density (<0.93 hectares (100000 square feet) and >0.56 hectares (60000 square feet)), medium residential density (<0.56 hectares (60000 square feet) and >0.23 hectares (25000 square feet)), medium high residential density (<0.23 hectares (25000 square feet) and >0.09 hectares (10000 square feet)), and high residential density (minimum lot size <0.09 hectares (10000 square feet)).⁴⁰ Non-residential zones areas will be matched accordingly to construct as counterfactuals.

To construct a valid control group, we use a hybrid of propensity score matching and covariate matching (nearest neighbor matching) approaches on our stratified random

⁴⁰ They are 0.93 hectares for low residential, 0.56-0.93 hectares for medium low residential, 0.23-0.65 for medium residential, 0.09-0.23 for medium high residential and less than 0.09 for high residential zones.

sample pixels to select the control groups (Appendix Table 3 and 4). The hybrid propensity score matching and covariate matching involves two steps. First, we use ordered logistic regression to estimate the conditional probability of a treatment (i.e., each level of zoning ordinances) being designated to a pixel. Then, we use the predicted propensity score to match one treated observation with three controlled nearest neighbors.

41

We performed multiple diagnostic tests to assess covariate balance. First, we used standardized bias, which is one of the most common numerical balance diagnostics (E. A. Stuart, 2010). The standardized bias measures the difference in means of each covariate first and then divides them by the standard deviation in the full treatment group $\frac{\bar{X}_t - \bar{X}_c}{\sigma_t}$ (Rosenbaum & Rubin, 1985), where \bar{X}_t and \bar{X}_c are the mean of the treated and controlled group respectively; and σ_t is the standard deviation of the treated group. The rule of thumb for a sufficient balance is that the absolute standardized differences of means should be less than 0.25 (Rubin, 2002). Besides the standardized bias diagnostic, we also follow Imai, King, Stuart, King, & Stuart (2008) and computed the ratio of variances for each covariate.⁴² Based on Rubin (2002) the variance ratio should be between 0.5 and 2. As shown in Appendix Table 3 and 4, both standardized bias and ratio of variances tests results show that matching greatly improved the balance in our sample dataset. In addition to numeric diagnostics, we also used QQ plots and histograms for a quick assessment of the distribution of the propensity scores in the original and matched groups

⁴¹ We choose 1:3 matching for two purposes: First, since there is tradeoff among the number of observations being used and how well matched are these observations. Three nearest neighborhood will generate a reasonable matched pool for the empirical analysis later on. Second, it enables we have enough observations to do a covariate matching using the already matched observations.

⁴² Results can be provided upon requests.

(Ho *et al.* (2006) and Stuart (2010)). Graphical diagnostics results (Appendix Figure 1-30) further demonstrate the balance between the treated and controlled group are greatly improved for different residential density zoning area.⁴³

After matching, the difference between both the mean and the standard deviation in the treated and the control are greatly reduced compared to the full sample (Table 3). For instance, the distance to the nearest shoreline is 15.22 kilometers and 10.85 kilometers for the treated and the control in the full sample, with a standard deviation of 10.24 kilometers and 10.25 kilometers respectively. After matching, the distances drop to 10.94 and 10.50 kilometers and the standard deviations are 9.01 and 9.06 kilometers correspondently.

VI RESULTS

The impacts of the minimum lot size zoning restriction of the pixel itself are consistent in their signs and significance across different model specifications with different radius buffers definition for the neighborhood (Table 8). However, the marginal effect estimates of neighborhood's minimum lot size zoning restriction on residential development shows that the impact is decaying with the increasing of the neighborhood radius (Table 9).

First stage results

The estimation of the first stage regression shows that the soil suitability construction index of the pixel itself and its neighborhood both has a positive and significant impact on predicting the minimum lot size restriction residential zoning of the

⁴³ Details of different residential density zoning area are shown in control groups and self-selection of the placement of zoning section.

pixel itself (Model 1) and its neighborhood zoning (Model 2). The results are shown in Table 6. These impacts are also consistent when we enlarge the radius buffers from 100 meters to 250, 500, 750, 1000, 2000, and 5000 meters. The soil suitability construction index increase 1, the minimum lot size requirement of the pixel will increase 0.020 hectares. Take 100 meters radius buffer as an example, when the overall soil suitability construction index in the neighborhood increases 1, the minimum lot size requirement of the pixel will increase 0.028 hectares.

In addition, the association between the soil suitability construction index for the pixel itself and its neighborhoods are as expected. The more significant constraints are for construction of the soil of the pixel itself, the more restricted the minimum lot size residential zoning will be. It also supports the argument that instruments are highly correlated with endogenous variable (minimum lot size restriction of the pixel itself and its neighborhood) respectively. It is also true for the neighborhood that the more constraints for construction of the soil types have in the neighborhood, the greater minimum lot size restriction will be. If overall quality of the neighborhood's soil is not suitable for construction, the policy maker needs to put very restricted minimum lot size in the neighborhood accordingly. In addition, these two instruments are highly correlated with the endogenous minimum lot size restriction of the pixel itself and its neighborhood, thus they satisfy the condition one of "good instrumental variables" (Cameron & Trevisani, 2008).

In Model 1, among all the control variables, the distance to downtown Providence has a positive and significant effect on the pixel's residential zoning at 5% level. It means the further away the pixel is from downtown Providence, the more restricted residential

zoning is. As one of the oldest city in New England, the urban sprawl started from the capital to the rural areas. To prevent overdeveloping and encourage sustainable planning, rural areas have a higher minimum lot size requirement compared to the city. As expected, the farm soil productivity has a positive and significant impact on the residential zoning at 10% level. More intuitively, town planners would encourage people to keep best soil for agricultural or forest use instead of recommending it for residential purposes. Notably, the conservation status (conserved by the state or non-state) of the pixel itself is positive and significant at 10%. Unsurprisingly, population density has a negative and significant influence on the pixel's residential zoning. The more populated the area, the less restricted the zoning will be. For example, in the cities where there are a lot of job opportunities are provided, there will be a lot of people who choose to live nearby to save time and money on commuting. Most part of the cities is less restricted and provides high density residential housing for the young people, students and working class. Moreover, Table 6 Model 2 shows that the higher household median income, the more restricted the residential zoning is. Rich neighborhood they may value more of the nature, more privacy and perhaps even have more political power in the town compared to others, thus it is quite straightforward. All these control variables' estimates hold for the neighborhood (Model 2 vs. Model 1), except the average farmland soil productivity of the neighborhood does not have a significant impact on the neighborhood's minimum lot size zoning.

Second stage results

The Minimum lot size zoning restriction of the pixel itself (hectares) and neighborhood minimum lot size restriction have a negative and significant impact on the

urban development when we control for pixel's characteristics and neighborhood's characteristics (as Table 7 shown). Take the 100 meter radius buffer neighborhood as an example, we find that one hectare increase in the pixel's minimum lot size restriction will decrease the likelihood of development of the pixel by 1.548%. Moreover, one hectare increase in the neighborhood minimum lot size restrictions, the probability of the pixel being converted to the urban area will decrease by 1.671%. It supports our priori hypothesis, that the neighborhood's minimum lot size zoning restrictions will have a negative spillover effect. Particularly, it means that the development of the pixel will be discouraged when the neighborhood are zoned in a higher minimum lot size district and vice versa.

As for the results of the characteristics of the pixel itself and the neighborhood, as expected, distance to downtown Providence affect the probability of urban development. The population density also affects the probability of urban development. It means Rhode Islanders have a preference of living further away from the city center and also prefer less populated areas, which explains well of the urban sprawl trend in the past few decades. In addition, Farmland soil productivity index also has a positive and significant effect but only at 10% level. This result is not surprising either. It means the more productive soils have a higher probability of being developed. Considering that most of the urban development is residential development, land owners prefer to buy a land with a better soil productivity so they can have some gardening, planting, farming activities on their land. Similar to the minimum lot size restrictions, neighborhood's conservation status (100 meter radius buffer) also has a negative and significant impact on the probability of urban development. The results in the neighborhood's minimum lot size

zoning restrictions on the urban development (Model 2) are almost consistent with the results in the pixel's minimum lot size zoning restrictions on the urban development (Model 1) except population density of the pixel does not significant affect the probability of the urban development.

These results can be useful for policy makers to account for the potential wide-ranging effects of zoning policy. Quantitative estimates of the effects of residential zoning on development and spillover effects on its neighborhood development can be pertinent information for the policy makers. These interactions among land use change and residential zoning should be considered in predicting land use change and should be accounted for the potential impacts on the development when local government officials and town planners make changes and adjustments of minimum lot size zoning restrictions.

Robustness tests

Estimates from the minimum lot size restriction of the pixel itself (Table 8) on urban development using instrumental variables are consistent in both magnitude and significance when we control for neighborhood's characteristics based on different radius buffer neighborhood definitions. For example, when neighborhood radius buffer increases from 100 meters to 5000 meters, the marginal effects of minimum lot size restrictions on the neighborhood changes from -1.55 to -1.67 and the level of the significance remain at 1% level. Thus, controlling for the characteristics of neighborhood does not change the estimation of minimum lot size restriction of the pixel on the urban development.

Marginal effect estimates of neighborhood's minimum lot size restriction (Table 9) on the urban development shows a different pattern comparing to that of the minimum lot size zoning restriction of the pixel (Table 8). With the radius buffer to define the neighborhood increasing from 100 meters to 5000 meters, the spillover effect is becoming stronger negative but the significance level decreases from 1% to 5% and until it is no longer significant. The possible explanations for the increasing magnitude but decaying significant level are due to the average size of minimum lot size restriction district and the size of the town. In our study area, the average size of the town is 798.41 hectares and the average size of zoning district is 56.75 hectares. With the increasing of neighborhood buffers, the neighborhood definition area extends the town's boundary and thus the spillover effect of the neighborhood minimum lot size zoning restrictions disappears.⁴⁴ Different towns and municipalities may have different characteristics other than minimum lot size, such as property tax rate, job opportunities, and amenities. These factors may also influence the decision whether to develop the land or not, however we have them controlled for in the town fixed effect.

VII CONCLUSIONS

Using pixel level land use change data, we examine the impact of minimum lot size restriction of the pixel and its neighborhood on the urban development in Rhode Island. Different from other studies which explore the effectiveness of zoning regulations and policies, we contribute to the existing literatures in two ways. First, we have accounted for the non-random placement of zoning by adopting matching method. It allows us to

⁴⁴ When distance band increase from 2000m to 5000m, the neighborhood definition area will increase from 400he to 2500 he accordingly. When the neighborhood area is greater than 798.41 hectares, which is the average size of town, we believe the spillover effect disappears.

examine the impact of zoning, more specifically, the minimum lot size zoning restrictions on the development. Second, we use instrumental variable approach to tackle the simultaneity problem between the minimum lot size restriction of the pixel and its development, neighborhood's minimum lot size restriction and development of the pixel respectively. Our results show that minimum lot size restriction has a consistent effect on the urban development of the pixel when we used different control for the neighborhood's characteristics. More importantly, we found that spillover effect of zoning does exist both within and outside of towns and municipalities. The minimum lot size restriction in the neighborhood has a negative impact on the land owners' decision on whether to develop the land. Additionally, the spillover effect is negative and significant up to 2000 meter radius buffer (within the town boundary). It is not significant in 5000 meter radius buffer.

One caveat of this study is that we do not have a rich panel data for zoning for the entire Rhode Island. However, our study is still valid even though there have been changes in the terms of subdivision for residential zoning. First, residential zoning has been largely stable across time (Personal Communication with Nancy Hess, 2013). Moreover, zoning tends to be "sticky". A comparison of bylaws over time for a sample of jurisdictions reveals that the fundamentals of zoning bylaws – such as the establishment of zoning districts or the uses allowed in those districts – are altered very rarely, perhaps only once every 20 to 30 years (Schuetz, 2007). Future direction of examining the effectiveness of zoning and its spillover effect will take into account of the dynamics between land use land cover change and zoning regulations accordingly.

Despite these caveats, our results suggest local governments should take into account of the spillover effect of minimum lot size restriction when they make their comprehensive plans. For example, to obtain sustainable development, town planners may want to encourage urbanization in some area while conserve other places for amenities or future development. In such cases, accounting for the spillover effect of minimum lot size restriction will be very important when designing comprehensive zoning plans and also make these regulations more effective. Our results also indicate the negative and significant spillover effect of average conservation status in the neighborhood. All these information not only can be utilized for future land use planning and forecasting at state level, but it can also be used to assist protecting ecosystem services in Narragansett Bay watershed through effective minimum lot size zoning restrictions by cities and towns.

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Table 1, land use conversion, 1985-2010 (hectares)

1985 land use land cover	2010 land use land cover				
	Urban	Agriculture	Forest	Others	Total,1985
Urban	19871.73	0.00	1081.53	783.72	21736.98
Agriculture	534.33	4851.00	512.64	575.37	6473.34
Forest	9105.93	1746.99	62218.08	2534.76	75605.76
Others	1209.51	69.75	443.79	1733.40	3456.45
Total,2010	30721.50	6667.74	64256.04	5627.25	107272.53

Table 2: Land use land cover area after sampling, 1985-2010 (hectares)

	1985	1999	2010	Δ change 1999-1985	Δ change 2010-1999
Urban	0	58.32	123.66	58.32	65.34
Rural	864.54	806.22	740.88	-58.32	-65.34

Table 3: Comparison of Land Use Change Descriptive Statistics between matched sampled vs. full sample dataset

Variable	Full sample		Matched sample	
	Mean (Std. Dev.)		Mean (Std. Dev.)	
	treated	control	treated	control
Distance to the nearest shoreline (km)	15.22 (10.24)	10.85 (10.25)	10.94 (9.01)	10.50 (9.06)
Distance to Providence Kennedy Plaza (km)	31.40 (10.67)	31.82 (15.74)	33.03 (12.05)	34.87 (13.71)
Distance to the nearest highway exit (km)	10.57 (5.63)	8.75 (6.70)	9.07 (5.02)	9.05 (5.38)
Mean farmland soil productivity index (0 to 2, Prime = 1, Important = 2, Not = 0)	0.45 (0.73)	0.60 (0.74)	0.52 (0.76)	0.69 (0.80)
Soil suitability construction index ⁴⁵	2.23 (1.49)	2.15 (1.45)	2.11 (1.45)	1.98 (1.39)
Slope category⁴⁶	7.30 (3.34)	6.88 (3.47)	7.22 (3.32)	6.88 (3.42)
Conservation status (conserved by the state or non-state (1= Yes,0=No))	0.16 (0.36)	0.46 (0.50)	0.21 (0.40)	0.32 (0.47)
Population density in 1985 (1000 people per square kilometers)	0.17 (0.39)	0.20 (0.40)	0.20 (0.39)	0.25 (0.59)
Population density in 1999 (1000 people per square kilometers)	0.17 (0.38)	0.26 (1.02)	0.23 (0.53)	0.19 (0.49)
Median household real income in 1985 (\$1000, in 1999 dollars)	50.13 (8.27)	51.53 (12.11)	50.19 (8.90)	49.94 (9.28)
Median household real income in 1999 (\$1000, in 1999 dollars)	58.72 (9.35)	58.41 (14.66)	58.15 (10.74)	56.67 (12.72)
Observations	7581	2025	2807	544

⁴⁵ We use Numeric code from 0 to 5. Restrictions or constraints to residential or commercial development(1= Few restrictions,2= Seasonal high water table from 3.5 to 1.5 feet,3= Steep slopes in excess or 15 percent,4= hydric soils,5= Significant constraints)

⁴⁶ Slope of the land. Number given is the slope group(1: 0-1% slope,2=0-2% slope,3= 0-3% slope,4= 0-8% slope,5= 0-15% slope,6=0-25% slope,7=0-35% slope,8= 0-50% slope,9=3-8% slope,10=3-15% slope,11=8-15% slope,12=15-25% slope,13=15-35% slope, 14=25-65% slope)

Table 4: Neighborhood descriptive statistics

Variable	RADIUS						
	100M	250M	500M	750M	1KM	2KM	5KM
	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)
Mean minimum lot size restriction (hectares)	0.75 (0.57)	0.76 (0.54)	0.76 (0.51)	0.75 (0.49)	0.75 (0.48)	0.75 (0.44)	0.75 (0.40)
Mean soil suitability construction index	2.11 (1.17)	2.13 (0.99)	2.14 (0.82)	2.13 (0.73)	2.12 (0.67)	2.09 (0.56)	2.06 (0.47)
Mean farmland soil productivity index (0 to 2, Prime = 1, Important = 2, Not = 0)	0.53 (0.62)	0.51 (0.52)	0.49 (0.42)	0.48 (0.36)	0.47 (0.32)	0.45 (0.23)	0.43 (0.14)
Mean slope category	7.04 (2.60)	6.87 (2.14)	6.64 (1.79)	6.53 (1.63)	6.47 (1.51)	6.23 (1.25)	6.12 (1.10)
Mean conservation status (conserved by the state or non-state (1= Yes,0=No))	0.22 (0.36)	0.21 (0.31)	0.20 (0.25)	0.20 (0.21)	0.19 (0.19)	0.19 (0.14)	0.18 (0.09)
Mean population density in 1985 (1000 people per square kilometers)	0.21 (0.42)	0.21 (0.40)	0.21 (0.40)	0.21 (0.39)	0.21 (0.38)	0.22 (0.37)	0.22 (0.31)
Mean population density in 1999 (1000 people per square kilometers)	0.23 (0.53)	0.23 (0.49)	0.23 (0.45)	0.24 (0.43)	0.24 (0.42)	0.25 (0.40)	0.25 (0.34)
Mean median household real income in 1985 (\$1000, in 1999 dollars)	50.17 (8.76)	50.23 (8.49)	50.26 (7.97)	50.24 (7.58)	50.22 (7.11)	50.09 (5.48)	50.28 (3.76)
Mean median household real income in 1999 (\$1000, in 1999 dollars)	57.64 (10.60)	57.25 (10.34)	56.90 (9.86)	56.71 (9.39)	56.53 (8.90)	56.03 (6.92)	56.18 (4.17)

Table 5 : Weak Instrument Variable Test

	neighborhood's minimum lot size restriction (100 m)	zoning of the land itself
R square	0.234	0.187
Shea's partial R square	0.002	0.001
First stage F statistics	1459.85	72.620

Note: There are 3351 observations in both 1985-1999 and 1999-2010.

Table 6: Estimates of the first stage model: Predicting minimum lot size zoning restrictions of the pixel and its neighborhood

	Model 1	Model 2
Dependent Variable: Minimum Lot Size Restrictions	Own pixel	Neighborhood
<i>Instruments</i>		
Soil suitability construction index for the pixel itself	0.020*** (3.136)	
Soil suitability construction index for the neighborhood (100 meter radius buffer)		0.028** (3.806)
<i>Pixel's characteristics</i>		
Distance to the nearest shoreline (km)	0.028 (1.495)	0.031 (1.613)
Distance to Providence Kennedy Plaza (km)	0.029*** (2.688)	0.028** (2.325)
Distance to the nearest highway exit (km)	0.001 (0.049)	0.002 (0.098)
Mean farmland soil productivity index (0 to 2, Prime = 1, Important = 2, Not = 0)	0.053** (2.147)	0.040** (2.025)
Slope category	-0.002 (-0.539)	-0.003 (-0.814)
Conserved by the state or non-state (1= Yes)	0.113** (1.964)	0.173*** (2.595)
Population density (1000 people per square kilometers) in each time period	-0.061 (-1.592)	-0.047 (-1.145)
Median household real income (\$1000, in 1999 dollars) in each time period	-0.001 (-0.372)	-0.003 (-0.834)
<i>Neighborhood's characteristics (100 meter radius buffer)</i>		
Average farmland soil productivity index	-0.088* (-1.785)	-0.062 (-1.326)
Average slope category	0.002 (0.171)	0.002 (0.148)
Average conservation status	-0.129 (-0.900)	-0.210 (-1.308)
Average population density (1000 people per square kilometers)	-0.184 (-1.552)	-0.212* (-1.718)
Average median household real income (\$1000, in 1999 dollars)	0.005 (1.251)	0.007*** (2.211)
Town fixed effect	Yes	Yes
Time fixed effect	Yes	Yes
R-squared	0.301	0.354
Observation	6050	6050

Note: The estimates are from stacked cross-sectional OLS models. The stars (***) p<0.01, ** p<0.05, * p<0.1) indicate level of significance. Z statistics are in parentheses.

Table 7: Second stage: Marginal effect estimates of minimum lot size restriction of the pixel and its neighborhood on urban development

	Dependent Variable = urban development (1=Yes , 0=No)	
	Model 1	Model 2
<i>Predicted variables (from the first stage)</i>		
Pixel's Minimum lot size restriction (hectares)	-1.548*** (-2.999)	
Neighborhood minimum lot size restriction (hectares, 100 meter radius buffer)		-1.671*** (-3. 665)
<i>Pixel's characteristics</i>		
Distance to the nearest shoreline (km)	0.025 (0.609)	0.033 (0.787)
Distance to Providence Kennedy Plaza (km)	0.055** (1.971)	0.055** (2.022)
Distance to the nearest highway exit (km)	0.005 (0.148)	0.007 (0.176)
Farmland soil productivity index	0.125* (1.812)	0.125* (1. 853)
Slope category	-0.010 (-0.701)	-0.010 (-0.659)
Conserved by the state or non-state (1= Yes)	-0.074 (-0.332)	0.034 (0.145)
Population density (1000 people per square kilometers) in each time period	-0.161* (-1.670)	-0. 143 (-1. 460)
Median household real income (\$1000, in 1999 dollars) in each time period	0.010 (1. 138)	0.009 (1. 895)
<i>Neighborhood's characteristics (100 meter radius buffer)</i>		
Average farmland soil productivity index	-0.098 (-0.913)	-0. 086 (-0.980)
Average slope category	-0.012 (-0. 366)	-0.015 (-0. 471)
Average conservation status	-0.426*** (-2.680)	-0.573*** (-3. 311)
Average population density (1000 people per square kilometers)	0.018 (-0.065)	-0.059 (-0.259)
Average median household real income (\$1000, in 1999 dollars)	-0.006 (-0.763)	-0.003 (-0. 347)
Town fixed effect	Yes	Yes
Time fixed effect	Yes	Yes
Log pseudolikelihood	-6070.105	-5416.963
Observations	6050	6050

Note: Probit model with instrumental variable to estimate the impacts of minimum lot size zoning restrictions (hectares) in Model (1) and neighborhood minimum lot size zoning restrictions (hectares) in Model (2) on urban development respectively. The stars (***) p<0.01, ** p<0.05, * p<0.1) indicate level of significance. Z statistics are in parentheses.

Table 8: Marginal effect estimates of minimum lot size restriction of the pixel on urban development using IV

	Dependent Variable = urban development (1=Yes , 0=No)						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model6	Model 7
Pixel's minimum lot size restriction (hectares)	-1.55*** (-3.00)	-1.56*** (-2.93)	-1.56*** (-2.73)	-1.57*** (-2.68)	-1.63*** (-2.84)	-1.76*** (-3.34)	-1.67*** (-3.13)
Distance used for define neighborhood	100m	250m	500m	750m	1000m	2000m	5000m
Observations	6050	6050	6050	6050	6050	6050	6050
Log pseudolikelihood	-6070.11	-6067.26	-6053.02	-6034.62	-6016.45	-5940.61	-5915.71

Notes: Each coefficient is estimated from Probit models with IV, using different distance to define neighborhood for their characteristics. All the models also include controls for land's own characteristic variables, including distance to the nearest shoreline (km), distance to Providence Kennedy Plaza (km), distance to the nearest highway exit (km), farmland soil productivity index, slope category, conserved by the state or non-state, population density and median household income. The neighbor's characteristics as well as sample weights and cluster errors at town level are also controlled for. We also control for town fixed effects and town fixed effects in the estimation. Z statistics are in parentheses. The stars (***) p<0.01, ** p<0.05, * p<0.1) indicate level of significance.

Table 9: Marginal effect estimates of neighborhood's minimum lot size restriction on urban development using IV

	Dependent Variable = urban development (1=Yes , 0=No)						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model6	Model 7
Distance used for defining neighborhood	100m	250m	500m	750m	1000m	2000m	5000m
Neighborhood minimum lot size restriction (hectares)	-1.67*** (-3.67)	-1.78*** (-5.61)	-1.84*** (-3.73)	-2.14*** (-2.79)	-2.42** (-2.47)	-3.81** (-2.02)	-6.47 (-4.09)
Observations	6050	6050	6050	6050	6050	6050	6050
Log pseudolikelihood	-5416.96	-4831.97	-3978.59	-3383.00	-2888.02	-1081.83	2358.14

Notes: Each coefficient is estimated from Probit models with IV, using different distance to define neighborhood for their characteristics. All the models also include controls for land's own characteristic variables, including distance to the nearest shoreline (km), distance to Providence Kennedy Plaza (km), distance to the nearest highway exit (km), farmland soil productivity index, slope category, conserved by the state or non-state, population density and median household income. The neighbor's characteristics as well as sample weights and cluster errors at town level are also controlled for. We also control for town fixed effects and town fixed effects in the estimation. Z statistics are in parentheses. The stars (***) p<0.01, ** p<0.05, * p<0.1) indicate level of significance.

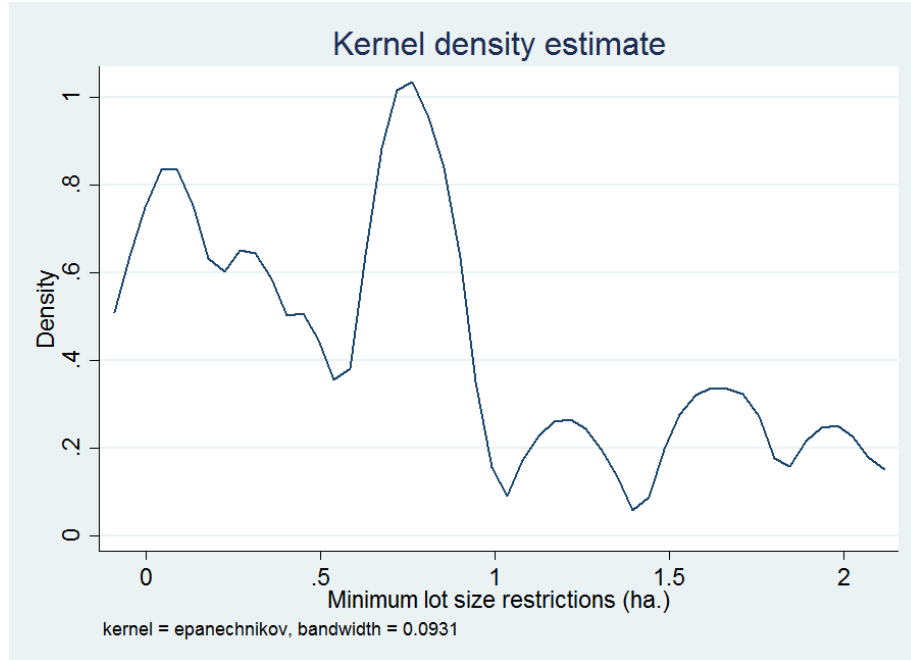


Figure 1: Kernel density plot of minimum lot size restriction of the pixel

Appendix Tables

Appendix Table 1.1: Land Use Conversion before Sampling (1985-1999)

Land Use Land Cover		1999			
		URBAN	AGRICULTURE	FOREST	OTHERS
1985	URBAN	100.00%	0.00%	0.00%	0.00%
	AGRICULTURE	3.75%	73.03%	21.18%	1.60%
	FOREST	4.42%	0.67%	93.16%	1.25%
	OTHERS	13.10%	0.57%	37.58%	48.50%

Appendix Table 1.2: Land Use Conversion after Sampling (1985-1999)

Land Use Land Cover		1999			
		URBAN	AGRICULTURE	FOREST	OTHERS
1985	URBAN	100.00%	0.00%	0.00%	0.00%
	AGRICULTURE	2.65%	75.83%	21.19%	0.33%
	FOREST	4.25%	0.63%	93.77%	1.35%
	OTHERS	13.29%	0.00%	42.77%	43.93%

Appendix Table 1.3: Land Use Conversion before Sampling (1999-2010)

Land Use Land Cover		1999			
		URBAN	AGRICULTURE	FOREST	OTHERS
1985	URBAN	89.79%	0.00%	5.64%	4.57%
	AGRICULTURE	0.29%	99.71%	0.00%	0.00%
	FOREST	9.27%	1.81%	83.38%	3.18%
	OTHERS	31.29%	0.00%	6.62%	62.08%

Appendix Table 1.4: Land Use Conversion after Sampling (1999-2010)

Land Use Land Cover		1999			
		URBAN	AGRICULTURE	FOREST	OTHERS
1985	URBAN	89.58%	0.00%	5.62%	4.80%
	AGRICULTURE	0.40%	99.60%	0.00%	0.00%
	FOREST	9.42%	1.38%	85.71%	3.49%
	OTHERS	33.06%	0.00%	5.65%	61.29%

Appendix Table 2: Number of observation before matching and after matching

Residential category of treated pixels	Before matching		Propensity score matching		Covariate Matching	
	treated	control	treated	control	treated	control
Low density Residential	82	2309	71	196	71	31
Medium low density residential	331	2309	283	715	283	87
Medium density residential	633	2309	472	1049	472	104
Medium high density residential	2280	2309	1087	1733	1087	293
High density residential	3971	2309	845	1309	845	238

Appendix Table 3: Matching statistical tests using Standardized bias

	propensity score matching + covariates matching(3 nearest neighbors)									
	1		2		3		4		5	
	U	M	U	M	U	M	U	M	U	M
Distance to the nearest shoreline (km)	-0.52	0.1	0.05	0.19	-0.39	-0.07	-0.02	0.15	1.3	0.11
Distance to Providence Kennedy Plaza (km)	-2.23	-0.12	-0.59	-0.11	0.32	0.05	0.35	-0.17	-0.03	-0.25
Distance to the nearest highway exit (km)	-1.95	-0.03	-0.06	-0.08	0.25	0.08	0.01	0	0.72	-0.02
Farmland soil productivity index	-0.67	-0.2	-0.16	-0.34	0.11	0.05	-0.09	-0.2	-0.27	-0.15
Soil construction constraint index	0.2	0.23	-0.2	0.04	-0.17	-0.01	0.02	0.11	0.15	0.08
Slope category	0.1	0.25	0.01	0.24	-0.02	0.01	0.22	0.2	0.18	-0.05
Conserved by the state or non-state (1= Yes)	-3.56	0	-1.07	-0.23	-0.96	-0.11	-0.69	-0.21	-0.58	-0.09
Population density (1000 people per square kilometers)	1.18	-0.09	0.61	0.08	-0.41	-0.25	-1.98	-0.12	-4.69	-0.07
Median household real income (\$1000, in 1999 dollars)	-0.39	-0.3	-0.38	-0.04	-0.31	-0.1	0.05	0.15	-0.34	0.14

Note: U=Unmatched, M=Matched. 1= Low density Residential, 2= Medium low density residential, 3= Medium density residential, 4= Medium high density residential, and 5= High density residential.

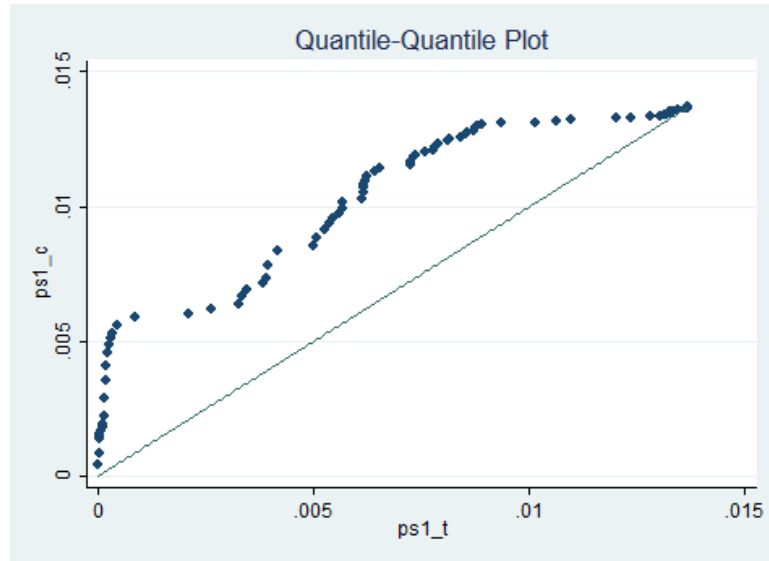
Appendix Table 4: Matching statistical tests using Ratio of variances

	propensity score matching + covariates matching(3 nearest neighbors)									
	1		2		3		4		5	
	U	M	U	M	U	M	U	M	U	M
Distance to the nearest shoreline (km)	0.34	0.84	0.69	0.9	0.66	0.97	0.59	1.23	0.72	0.87
Distance to Providence Kennedy Plaza (km)	0.26	0.82	0.38	0.69	0.57	0.86	0.5	0.69	0.38	1.12
Distance to the nearest highway exit (km)	0.14	0.46	0.69	0.9	0.48	0.95	0.51	0.94	0.74	0.92
Farmland soil productivity index	0.59	0.85	0.99	0.89	1.22	1.17	1.04	0.88	0.94	0.9
Soil construction constraint index	1.71	1.58	0.98	1.43	0.81	0.99	1	1.03	1.15	1.06
Slope category	0.75	1.2	0.77	0.83	0.92	0.95	0.95	0.95	0.99	0.97
Conserved by the state or non-state (1= Yes)	0.05	0	0.35	0.61	0.4	0.8	0.55	0.77	0.62	0.95
Population density (1000 people per square kilometers)	8.3	0.6	0.29	0.67	0.21	0.68	0.04	0.72	0.01	0.62
Median household real income (\$1000, in 1999 dollars)	3.78	1.48	0.47	1.09	0.67	1.14	0.25	0.66	0.22	1.32

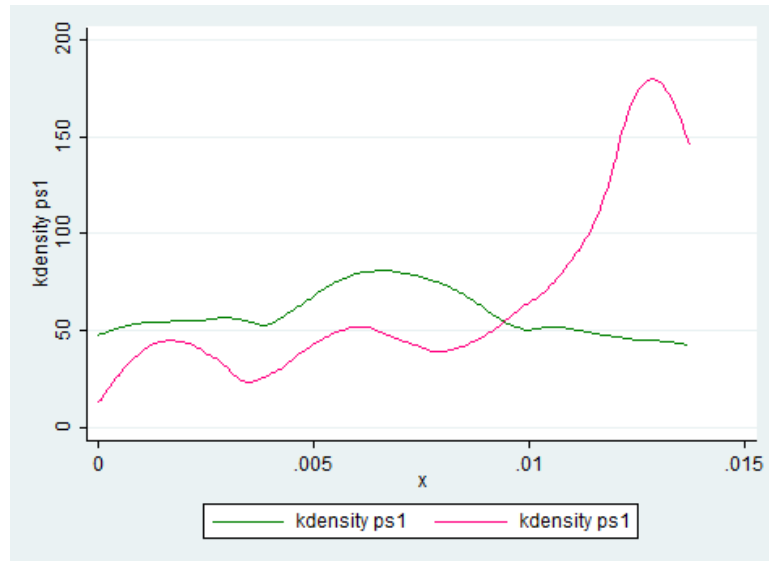
Note: U=Unmatched, M=Matched. 1= Low density Residential, 2= Medium low density residential, 3= Medium density residential, 4= Medium high density residential, and 5= High density residential.

Appendix Table 5: Weak Instrumental Variable Test

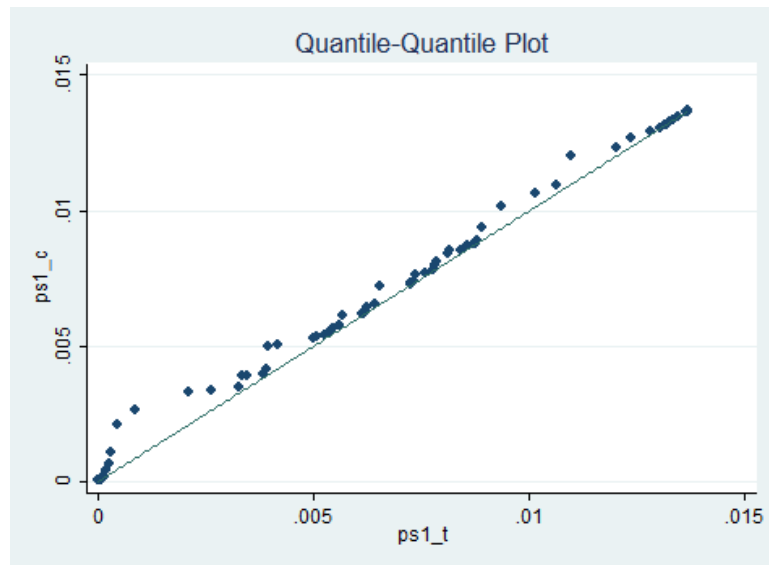
	100	250	500	750	1000	2000	5000	zoning of the pixel itself
R square	0.234	0.279	0.345	0.391	0.428	0.554	0.750	0.187
Shea's partial R square	0.002	0.005	0.019	0.036	0.06	0.182	0.402	0.001
First stage F statistics	1459.85	741.67	1107.51	464.75	334.3	701.93	5393.84	72.62



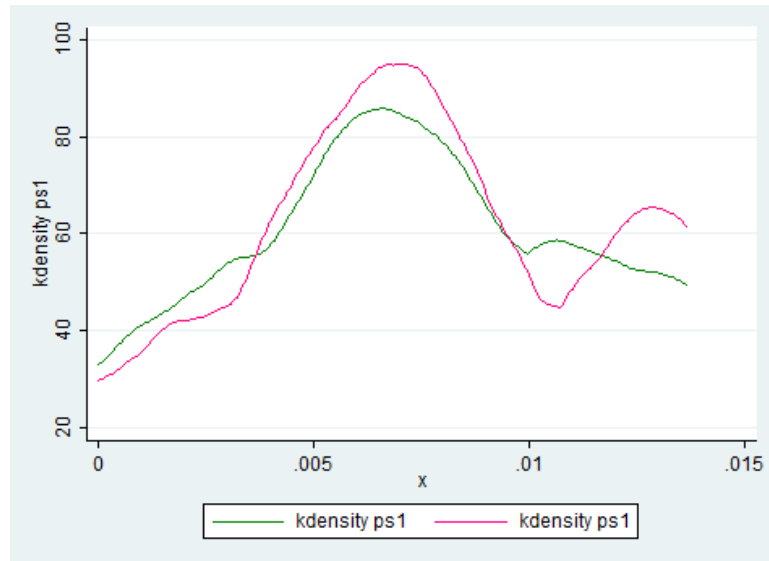
Appendix Figure 1: QQ plot for the treated and controlled group before propensity score matching in low density residential zoning area



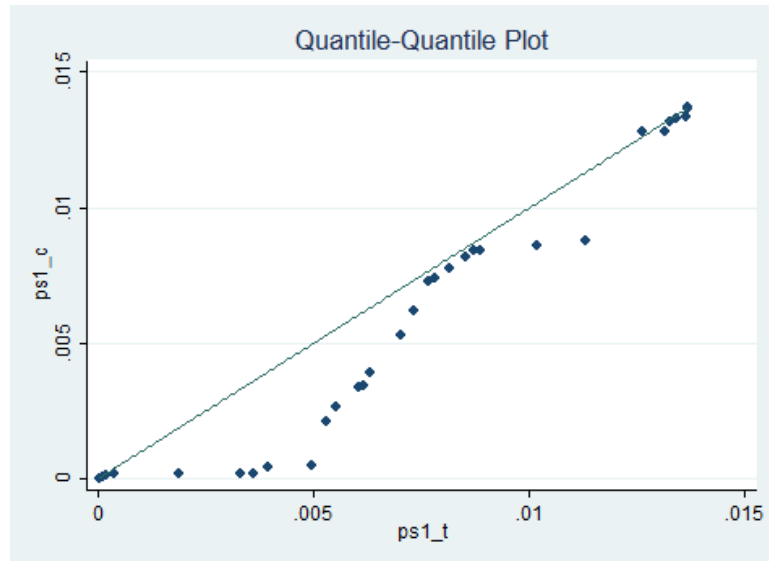
Appendix Figure 2: Two way kernel density plot for the treated and controlled group before propensity score matching in low density residential zoning area



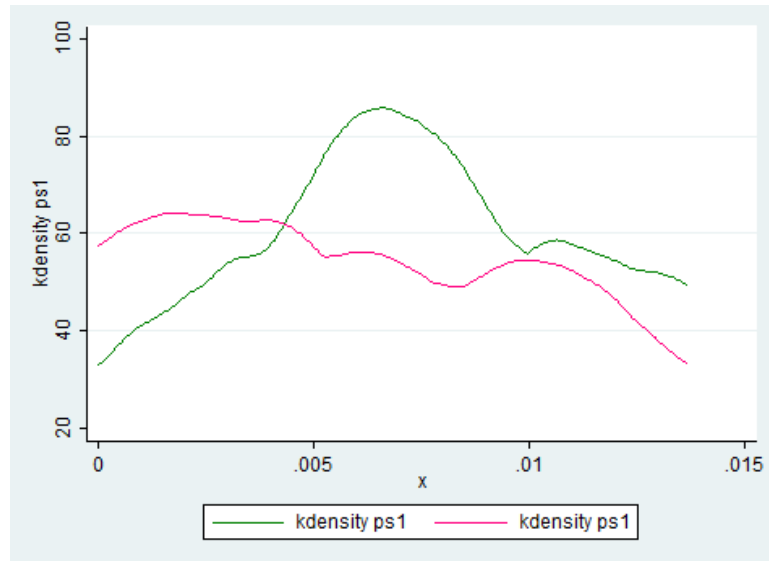
Appendix Figure 3: QQ plot for the treated and controlled group after propensity score matching in low density residential zoning area



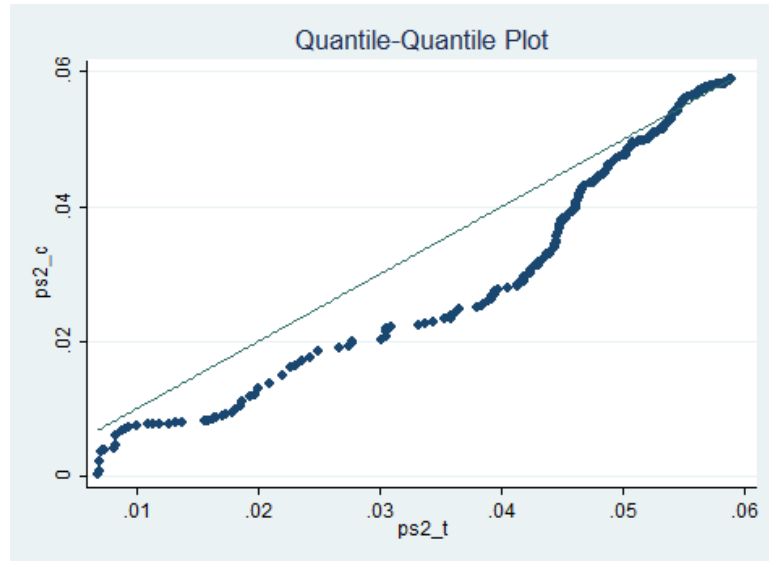
Appendix Figure 4: Two way kernel density plot for the treated and controlled group after propensity score matching in low density residential zoning area



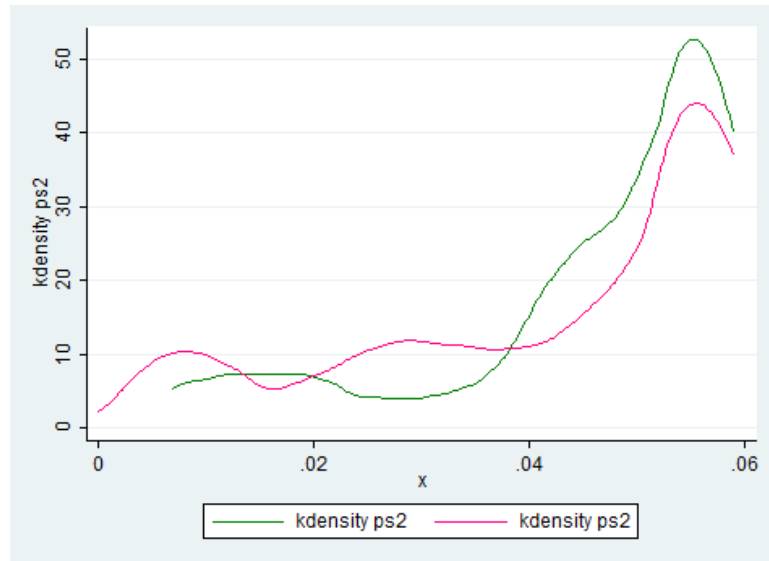
Appendix Figure 5: QQ plot for the treated and controlled group after covariate matching in low density residential zoning area



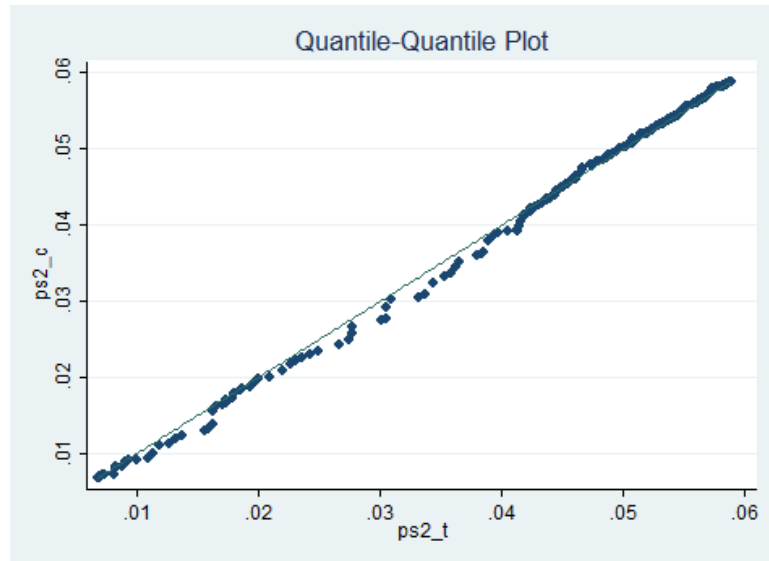
Appendix Figure 6: Two way kernel density plot for the treated and controlled group after covariate matching in low density residential zoning area



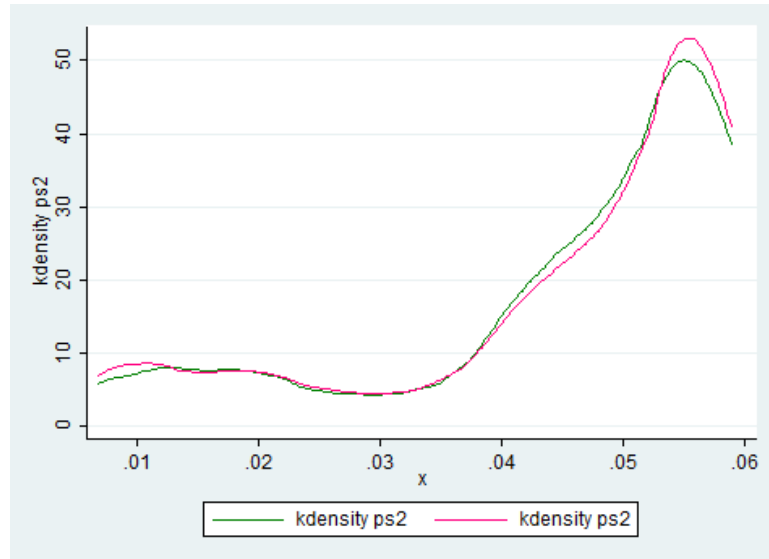
Appendix Figure 7: QQ plot for the treated and controlled group before propensity score matching in medium low density residential zoning area



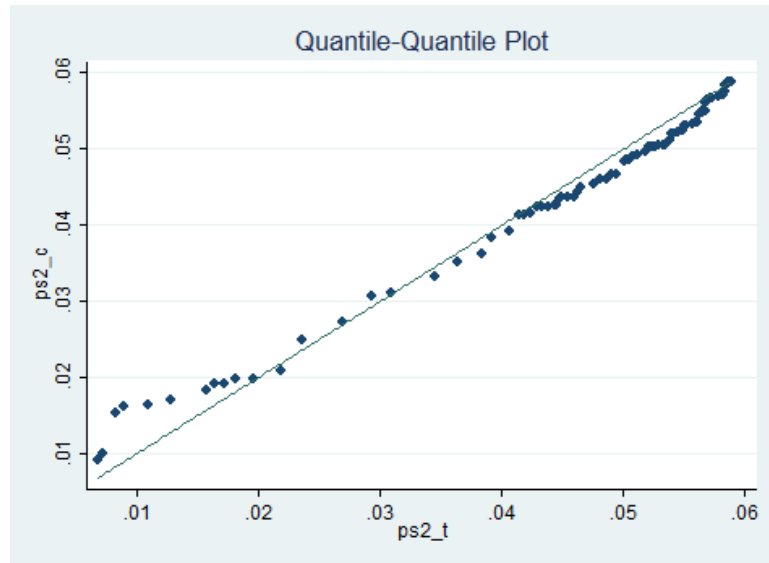
Appendix Figure 8: Two way kernel density plot for the treated and controlled group before propensity score matching in medium low density residential zoning area



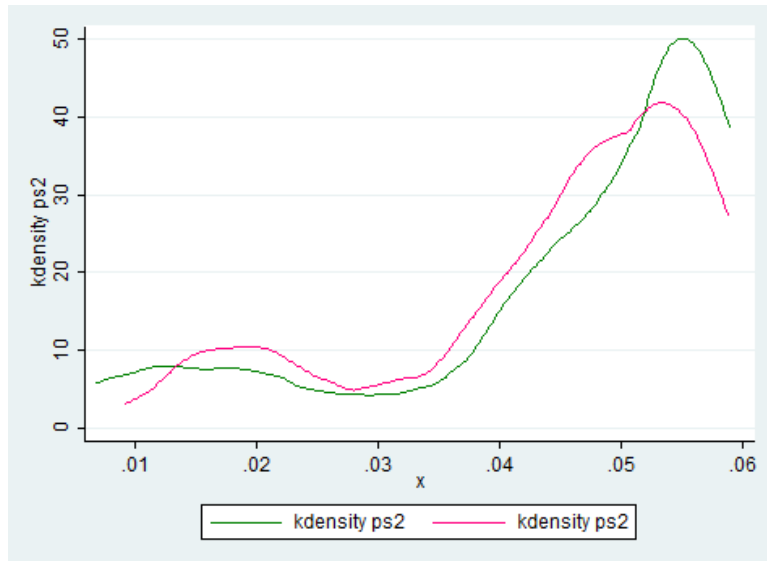
Appendix Figure 9: QQ plot for the treated and controlled group after propensity score matching in medium low density residential zoning area



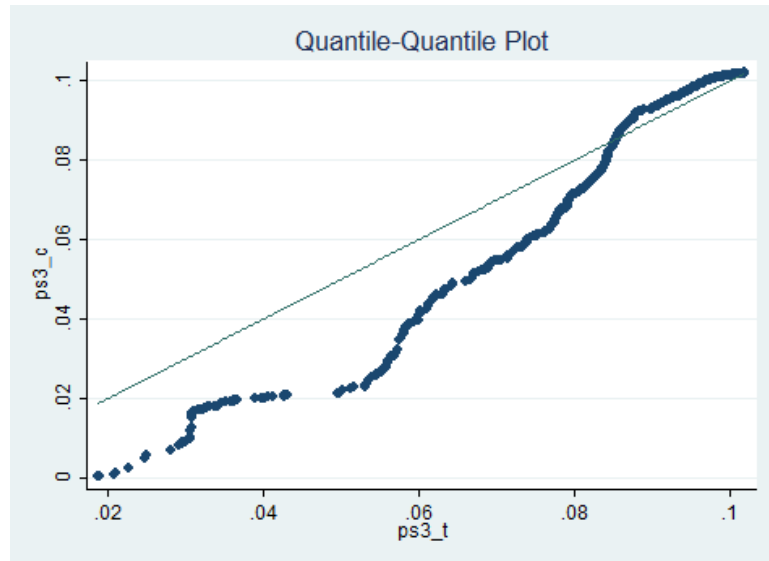
Appendix Figure 10: Two way kernel density plot for the treated and controlled group after propensity score matching in medium low density residential zoning area



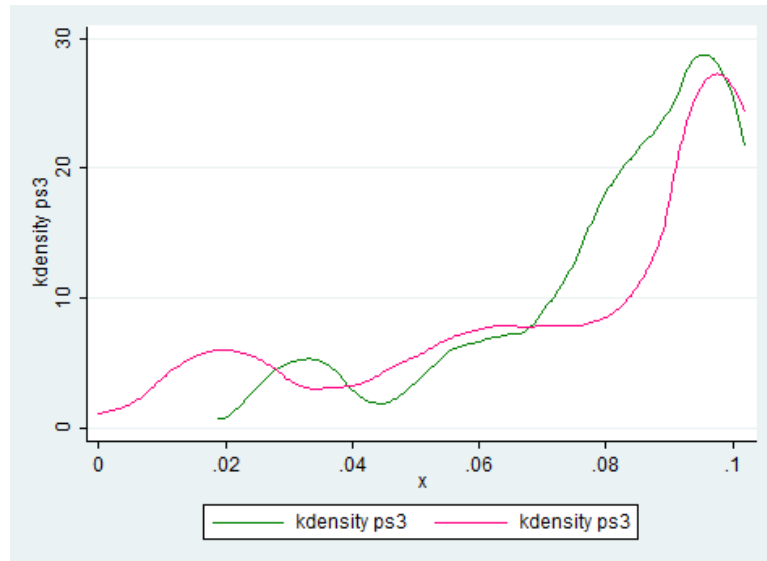
Appendix Figure 11: QQ plot for the treated and controlled group after covariate matching in medium low density residential zoning area



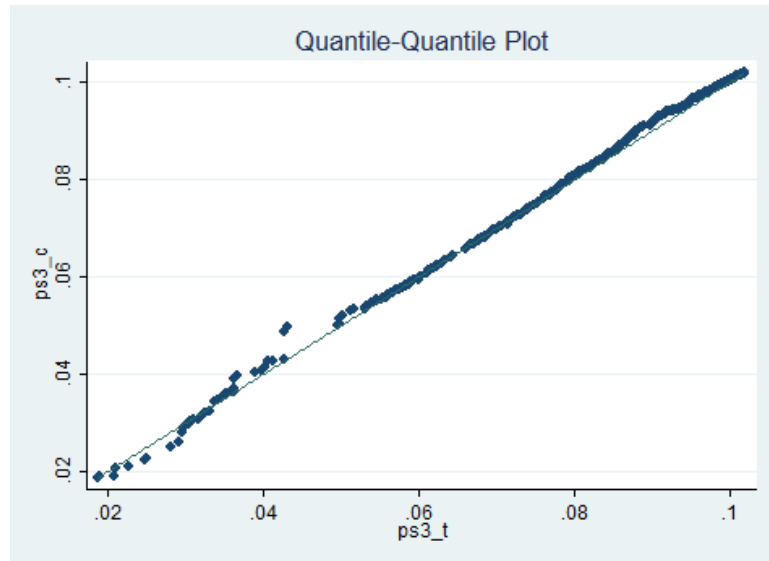
Appendix Figure 12: Two way kernel density plot for the treated and controlled group after covariate matching in medium low density residential zoning area



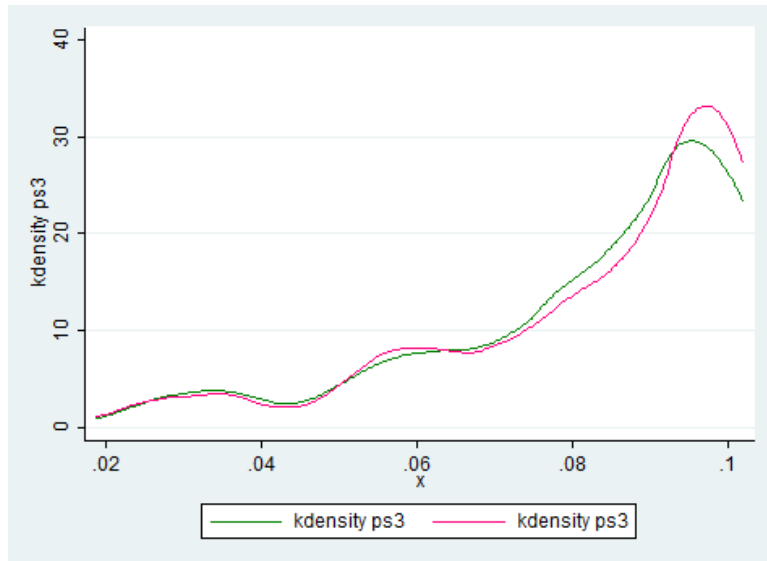
Appendix Figure 13: QQ plot for the treated and controlled group before propensity score matching in medium density residential zoning area



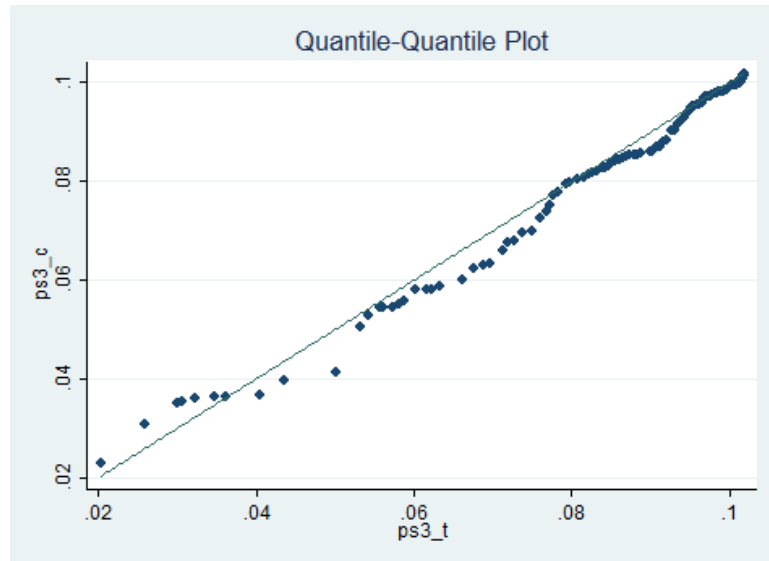
Appendix Figure 14: Two way kernel density plot for the treated and controlled group before propensity score matching in medium density residential zoning area



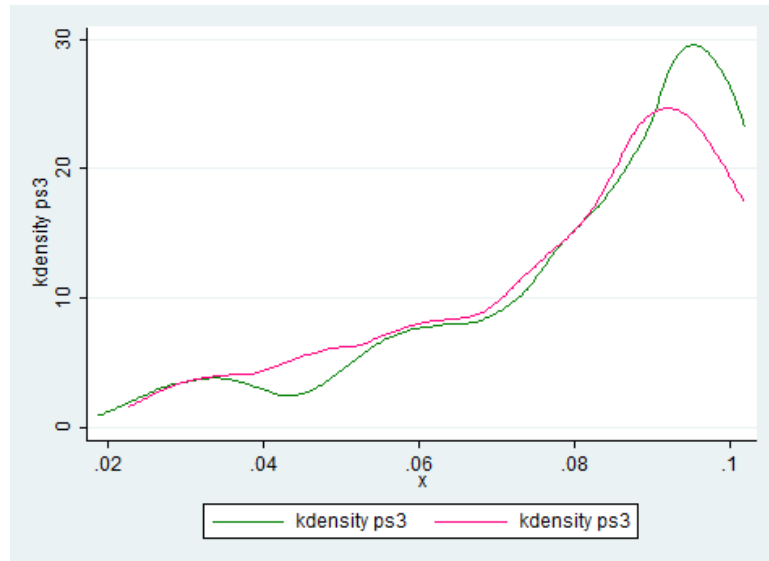
Appendix Figure 15: QQ plot for the treated and controlled group before propensity score matching in medium density residential zoning area



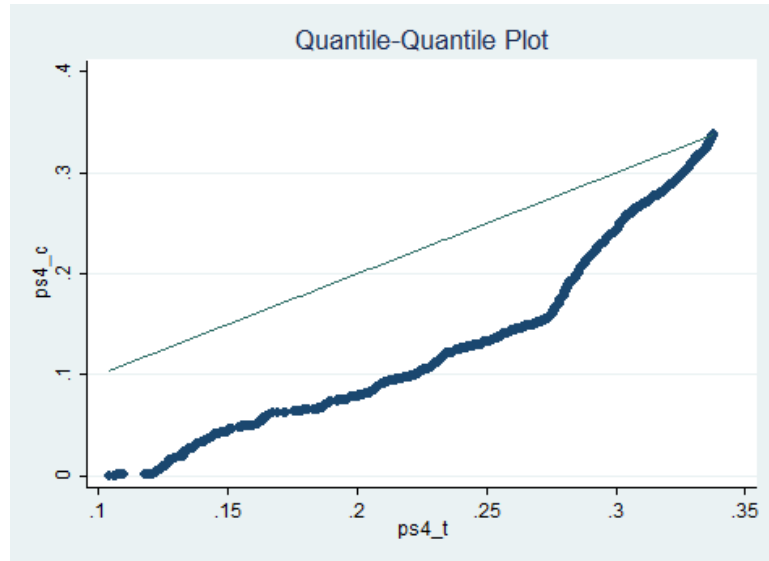
Appendix Figure 16: Two way kernel density plot for the treated and controlled group after propensity score matching in medium density residential zoning area



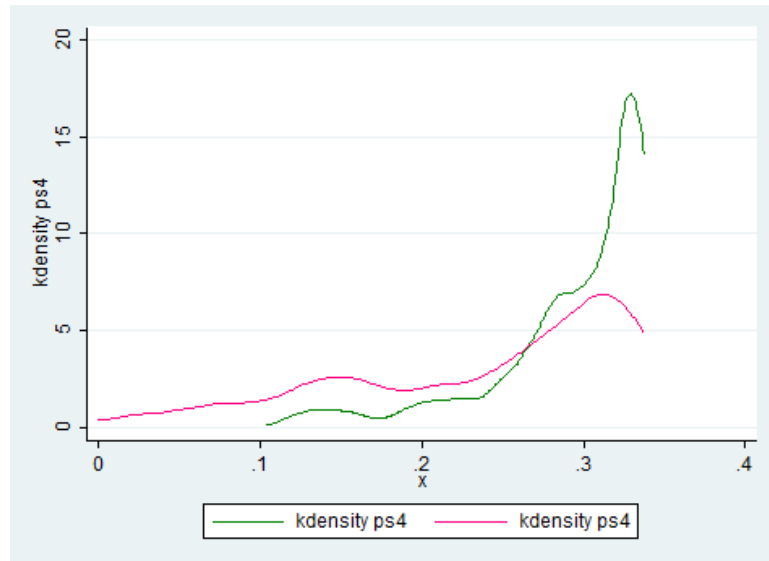
Appendix Figure 17: QQ plot for the treated and controlled group before covariate matching in medium density residential zoning area



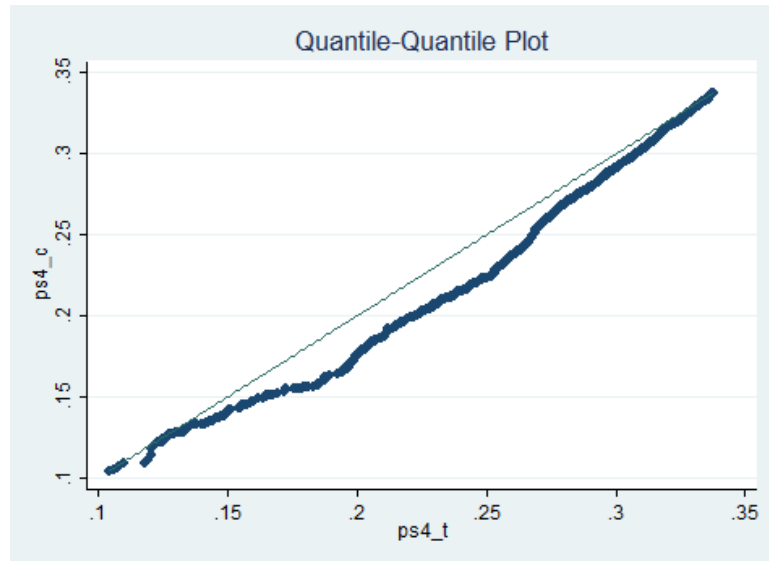
Appendix Figure 18: Two way kernel density plot for the treated and controlled group covariate matching in medium density residential zoning area



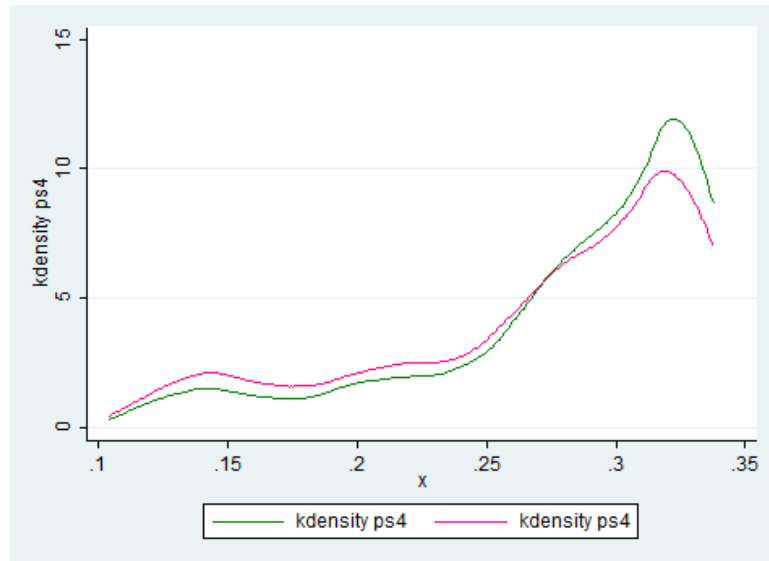
Appendix Figure 19: QQ plot for the treated and controlled group before propensity score matching in medium high density residential zoning area



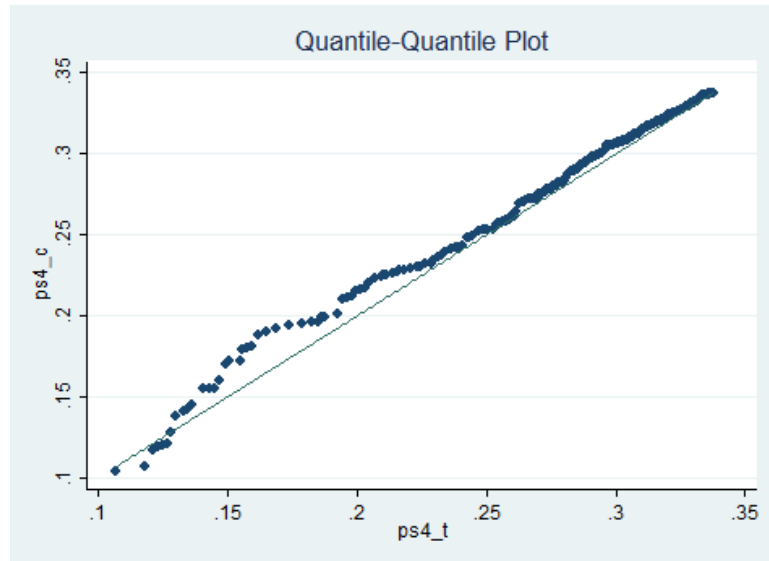
Appendix Figure 20: Two way kernel density plot for the treated and controlled group before propensity score matching in medium high density residential zoning area



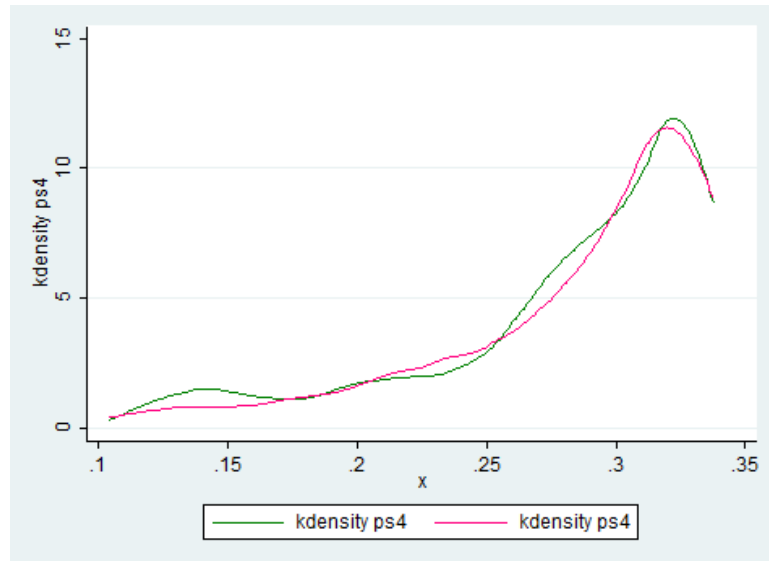
Appendix Figure 21: QQ plot for the treated and controlled group after propensity score matching in medium high density residential zoning area



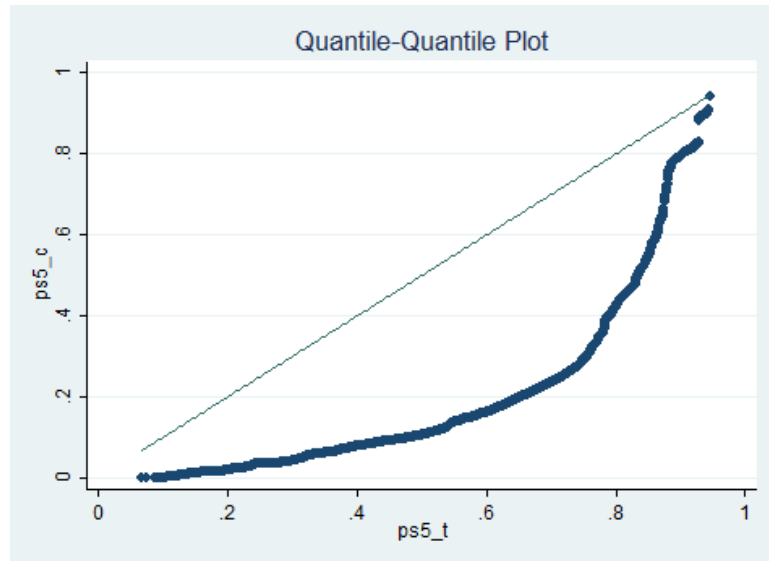
Appendix Figure 22: Two way kernel density plot for the treated and controlled group after propensity score matching in medium high density residential zoning area



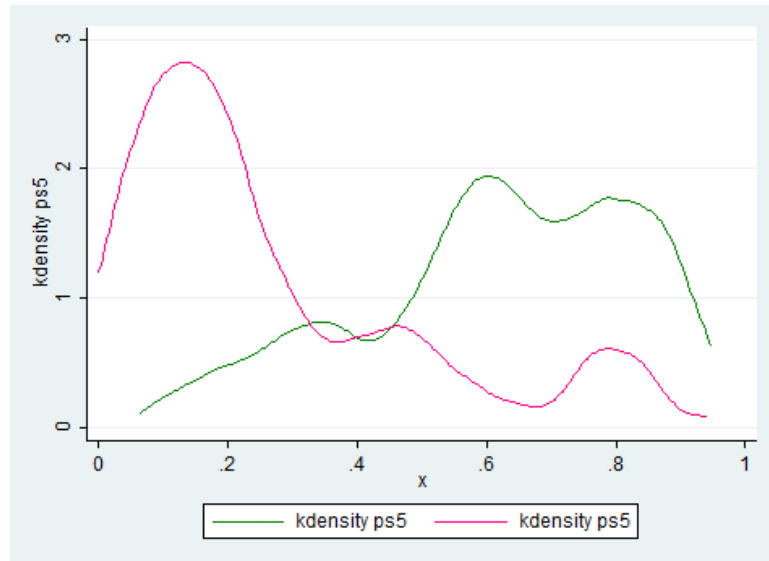
Appendix Figure 23: QQ plot for the treated and controlled group after covariate matching in medium high density residential zoning area



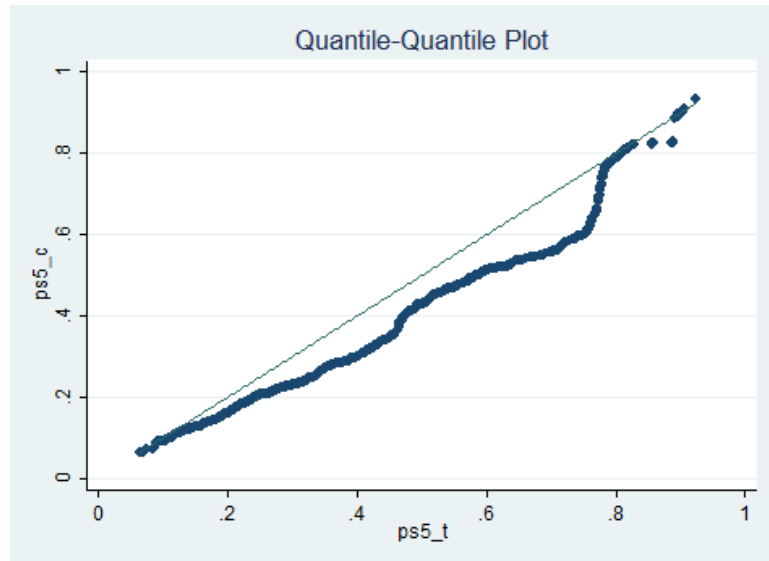
Appendix Figure 24: Two way kernel density plot for the treated and controlled group after covariate matching in medium high density residential zoning area



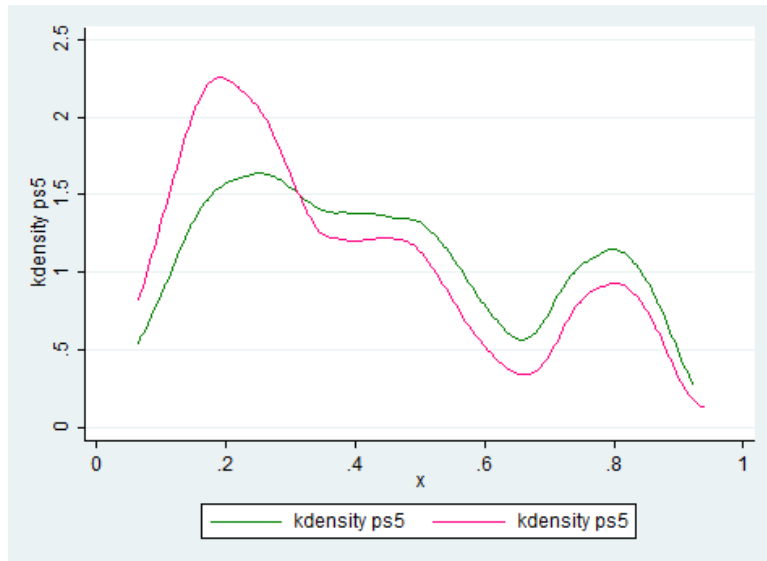
Appendix Figure 25: QQ plot for the treated and controlled group before propensity score matching in high density residential zoning area



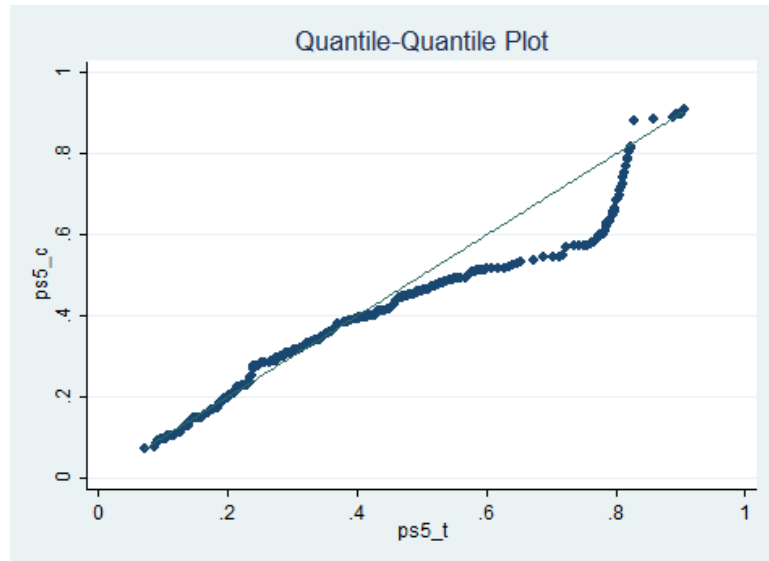
Appendix Figure 26: Two way kernel density plot for the treated and controlled group before propensity score matching in high density residential zoning area



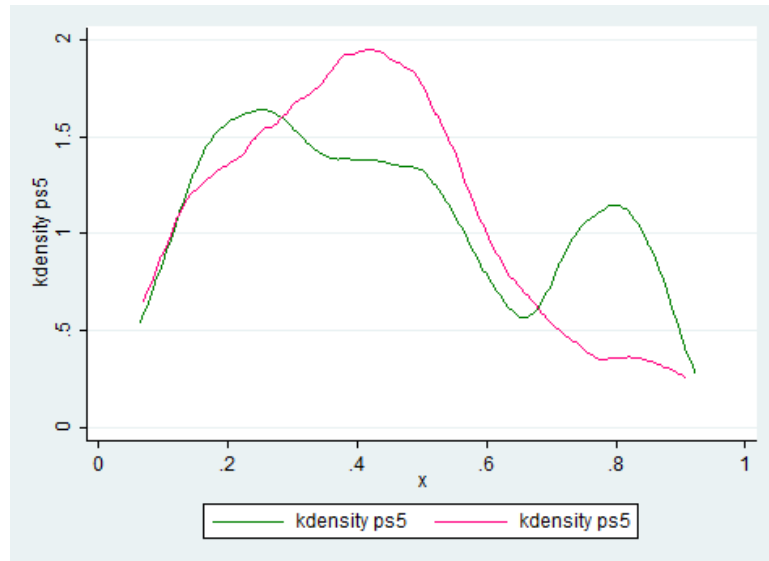
Appendix Figure 27: QQ plot for the treated and controlled group after propensity score matching in high density residential zoning area



Appendix Figure 28: Two way kernel density plot for the treated and controlled group after propensity score matching in high density residential zoning area



Appendix Figure 29: QQ plot for the treated and controlled group after covariate matching in high density residential zoning area



Appendix Figure 30: Two way kernel density plot for the treated and controlled group after covariate matching in high density residential zoning area

The impact of water quality improvement in Narragansett Bay on housing prices

Prepared for submission to Marine Resource Economics

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The impact of water quality improvement in Narragansett Bay on housing prices

Abstract: In this paper, we examine the impact of water quality in Narragansett Bay on housing prices in coastal towns and municipalities using hedonic housing price model. Compared with other water quality related hedonic studies, we use an inversed distance weighted (IDW) interpolation method, combined with regional water quality information to best capture the water quality in Narragansett. Additionally, we compare different measures of Chlorophyll concentration of coastal water quality. Our results show that coastal water quality, Chlorophyll concentration, has a negative impact on the housing prices, and the negative impact of water quality attenuates with increasing distance from the shoreline. We further estimate potential increases in the value of the housing stock associated with different scenarios for water quality improvements in Narragansett Bay.

Keywords: Hedonic modeling, interpolation, coastal water quality, scenario analysis, Narragansett Bay

I INTRODUCTION

The marine and coastal environment provides a wide range of ecosystem services to society. These services include, but are not limited to, aesthetic values, provision of seafood for consumption (both farmed and wild), recreational opportunities, nutrient cycling and filtration of wastes, coastal/natural hazard protection, and carbon storage for climate regulation (Chan & Ruckelshaus, 2010). However, estuarine and coastal ecosystem services are among the most heavily used, resulting in threats to natural systems (Barbier, 2011). Evidence is accumulating that, among all the factors that influence the provision of ecosystem services, land use change and climate change are the two of major drivers (Schröter et al., 2005). For example, human-related land use change and climate change have led to the deterioration in coastal ecosystem services, such as the loss of biodiversity, water contamination, ecosystem degradation, and coastal floods (Tinch, 2011). Despite the importance of coastal and marine ecosystem services and the critical issues that marine and coastal ecosystem services face, there are few studies evaluating the impact of coastal ecosystem services, particularly the environmental amenities of resultant coastal water quality that are captured by the changes in housing prices.

The goal of this research is to estimate the effect of water quality improvement on prices of residential properties adjacent to Narragansett Bay in Rhode Island using the hedonic housing price method. Compared to other coastal states, Rhode Island developed its land at a rate much higher than its historic trends. Developed land increased from approximately 143,000 to 205,000 acres between 1970 and 1995, which is about 43% increase from 1970. However this increase in developed land was coupled with a

population increase of only 5% indicating that traditionally populated cities and towns started to lose population while sprawl dominated growth in coastal region. With rampant increases in residential development happening in Rhode Island, both marine and coastal ecosystems are at risk. Narragansett Bay was listed as one of 20 most contaminated waterways in U.S. (Shane, 2011). The pollutants include the quantities of nitrogen and phosphorous as a result of failing septic systems, inadequate wastewater treatment, and agricultural and urban runoff (Durant & Raposa, 2011). As a consequence, Narragansett Bay is exhibiting an increasing array of eutrophic-associated symptoms, including low dissolved oxygen, fish kills, eelgrass loss, algae blooms, and loss of Submerged Aquatic Vegetation (Narragansett Bay Estuary Program, 2007).

I also simulate the potential benefits of nutrient reduction in the upper Narragansett Bay capitalized into housing prices to those who live near the Bay. In recent years, a handful of waste water treatment and nutrient reduction programs have been implemented. For instance, Rhode Island has passed a law to reduce 50% nitrogen loadings from the 1995-1996 level resulting from major waste water treatment facilities (WWTFs) to Narragansett Bay by 2008 (Narragansett Bay Estuary Program, 2007). In addition, a comprehensive combined sewer overflow (CSO) abatement program was approved in March, 1993, which is the most expensive public works project in RI history, with an estimated total cost of \$1.3 billion. Considering the great amount of effort that has been made on the regulations of the waste water treatment and water quality management programs, much less research focuses on measuring economic benefits from the resultant improvements in water quality.

So far, there have been two studies examining the potential benefits of water quality improvement in this region. Hayes et al. (1992) use contingent valuation method on people's willingness to pay to obtain the fishable and swimmable condition of the water quality. Their estimated aggregated benefits are in the range of \$30-70 million. Metcalf and Eddy (1983) implemented a cost benefit analysis for the CSO project and found the costs exceed the benefits. Compared to stated preference methods for valuation of ecosystem services, which derives value from response to hypothetical questions, hedonic models have an advantage of estimating values based on the actual choices reflected in the housing market (Freeman, 2003). Furthermore, hedonic housing price method can distinguish houses that are benefiting from aesthetic uses only, recreational uses only, and both aesthetic and recreational uses from those houses located further away by examining their proximity to coastal waters. Potential individual and aggregated changes in housing prices in towns and cities along the coastline of Narragansett Bay can be derived under alternative nutrient reduction scenarios, using the implicit price of marginal water quality improvement.

The hedonic price method is an indirect valuation method in which the values of non-market characteristics of a market good are inferred from observable market transactions (Taylor, 2003). It has been widely used to examine the relationship between the environmental amenities and housing prices since houses in different locations have different levels of environmental amenities (Paterson & Boyle, 2002). By examining the housing transaction prices and controlling for characteristics (e.g. size of house, size of lot, etc.), we can estimate the marginal implicit price of the environmental amenities. A great deal of research has been done on non-market valuation using hedonic housing

prices models, including air quality ((Harrison & Planning, 1978; Smith & Huang, 1995), open space (Bolitzer & Netusil, 2000; Irwin & Bockstael, 2004), wetlands (Mahan, Polasky, & Adams, 2000; Paterson & Boyle, 2002), as well as disamenities, such as landfill, odor from farms ((Boyle & Kiel, 2001; Ready & Abdalla, 2005). Among the water-related hedonic models, there is a great amount research focusing on the effect of water quality on the lakefront properties values (e.g., Gibbs et al., 2002; Lewis et al., 2009; Poor et al., 2007). Anderson and West (2006) found positive amenity values from proximity to a water body and this positive impact may extend to hundreds of meters into the surrounding neighborhood. Dornbusch and Barrager (1973) examined the effect of water pollution abatement programs on housing prices. They found that, although the majority of the water quality benefits occur within 600 to 900 meters from the waterfront, the benefits could potentially extend to up to 1200 meters. Walsh et al. (2011) examined the effects of enhanced water quality on both waterfront and non-waterfront property prices and found the value of increased water quality depends upon the property's location and proximity to waterfront. They also found that the aggregate benefits of non-waterfront homes from the water quality improvement dominate water-front homes.

To our knowledge, two recent studies which attempt to capture the effect of water quality on property values are Leggett and Bockstael (2000) and Bin and Szajkowski (2013). Leggett and Bockstael (2000) found that water quality has a significant effect on the property values along the Chesapeake Bay. They also address omitted variable bias by including several variables to proxy the direct effect of the source of the pollution. Bin and Szajkowski (2013) examined the impact of technical and non-technical measures of water quality on coastal waterfront property values in Martin County, South Florida.

Compared to these studies, our study estimates the impact of improved water quality in the estuaries on both waterfront and non-waterfront properties values using hedonic housing price approach.

One critical factor in assessing the amenity value of coastal water quality is the accuracy of the water quality data. As opposed to measures of lake water quality, which can be assumed to be relatively homogeneous throughout the water body, the spatial variation of water quality can be large within salt-water estuaries. Due to limited monitoring stations in estuaries, accurately measuring or predicting coastal water quality data is challenging since it is difficult to capture the spatially varying hydrodynamics, bathymetry and biochemistry using interpolation methods (Murphy et al., 2010). To our knowledge, none of previous water resource hedonic models have investigated relative performance of different interpolation methods while at the same time taking account of the accuracy of water quality in their analysis. The only exception is Leggett and Bockstael (2000), who used inverse distance-weighted (IDW) average of the nearest three monitoring stations to calculate fecal coliform counts (FECAL) in the Chesapeake Bay. We improve the IDW approach by incorporating water quality information from estuary sub-regions to capture some of the spatial diversity in hydrodynamics within the estuary, thus making our interpolated water quality data more credible.⁸⁰ The water quality data we use is from both fixed-site monitoring and buoys data in Narragansett Bay provided by collaboration of a number of agencies, measuring temperature, salinity, dissolved oxygen, PH and chlorophyll collected at fifteen minutes intervals.⁸¹

⁸⁰ Water quality sub-region information is based on Marine and Estuarine Waters: RI Integrated Water Quality Monitoring and Assessment Report 2010 (RIGIS,2014)

⁸¹ Rhode Island Department of Environmental Management – Office of Water Resources (DEM-OWR) is taking the lead role, the other cooperating agencies include: University of Rhode Island, Graduate School

Our study also differs from previous studies in the measurements of the water quality indicator. Most previous studies have used mean or median value regarding the water quality measures during the year of the sale (Leggett and Bockstael, 2000; Poor et al., 2007; Walsh et al., 2011; Bin and Szajkowski, 2013). The only exception is Gibbs et al. (2002) who use the minimum clarity reading for the year of the property sold, since it represents the poorest water quality for the year. In our study, different percentiles are used for a single water quality parameter, which allows us to test for the significance of the median level of water quality, as well as extreme events in water quality. The reason we test for the effect of water quality at various parts of the distribution is that homebuyers' perception on water quality likely being different. Some people may care about the extreme events, such as the color, the odor associate with high nutrients loadings while others may focus on the median level of water quality during summer months. Alternative measures allow us to better estimate the potential benefit due to the water quality improvement.

We also test whether homebuyers respond to recent changes in water quality or its long term trends. In order to understand the effects of water quality on housing prices, we need to understand how residents' perceptions of water quality are formed, since people's perceptions of water quality differ. We assume that housing buyers might be "myopic", and respond to very recent levels of water quality, or people might be "thoughtful", and respond to water quality over a longer period of time.

Additionally, water quality varies over time and residents might be affected by different elements of the temporal distribution of water quality. For example, it might be that residents' perceptions of water quality result from average or typical levels of water quality. Or it might be that residents' perceptions are most affected by extreme events when water quality is especially poor, and results in strong odors, algal blooms or even fish kills. Accordingly, we calculate the 50th (median), 90th percentile, 95th percentile, and 99th percentile of Chlorophyll concentration for both "myopic" and "thoughtful" house buyers. Since the perceptions of house buyers are not clear with regard of coastal water quality, it is necessary to examine different water quality parameters.

Our results show that, as expected, the water quality does influence the housing prices in coastal towns and municipalities of Narragansett Bay. The proximity effect is evident in our research implying being closer to the water adds a premium to housing prices, while being closer to poor water quality will decrease this premium. We show that different measurements of water quality can make a difference in the valuation of environmental amenities in the potential benefit associated with houses.

II STUDY AREA AND DATA

Study Area

Narragansett Bay is an estuary which has 148.6 square miles of surface water, 140 of which are in Rhode Island (Watershed Counts, 2014). The Narragansett Bay Watershed is more than ten times larger than the estuary, which covers a land area of 1675 square miles. 40% of the watershed is in Rhode Island and the other 60% of the watershed is in

Massachusetts (Figure 1).⁸³ Since there are more than 100 towns and cities of two states located in the watershed, it is extremely challenging to control pollutants entering Narragansett Bay and improve the water quality. Historically, the majority of pollutants are coming from the nutrients from both inland runoff and WWTFs (RIDEM, 2000).⁸⁴ With a 28% population increase from 1960 (3.8 million) to 2000 (4.9 million) in the watershed, infrastructure construction has increased the burden on WWTFs (EPA, 2007). Urban land has increased from 17280 ha to 24901 ha, which is more than 44% from the years 1972 to 2010 (Wang & Glenn, 2013). With land use being converted from forest or agricultural to urban use, a great deal of land has been paved had buildings constructed, or parking lots are built for residential, commercial as well as industrial purposes. Moreover, there have been significant land use conversions in the adjacent watershed of the coastal towns and cities. For instance, in Woonasquatucket River watershed there has been a 50% increase in urban land use with a decline of 47% and 34% of forest and agricultural land use. A large amount of pollutants from storm and snow runoff resulting from the increased impervious surfaces and the over-fertilization of the agricultural land and lawns as well as failing septic systems enter the Woonasquatucket River watershed. From there the water enters the Providence River and then on into Narragansett Bay.⁸⁵ The nutrient loadings have exacerbated the deterioration of water quality in Narragansett Bay. An increasing array of eutrophic-associated symptoms, including low level of dissolved oxygen, fish kills, eelgrass loss, microalgae blooms, are showing more often in

⁸³ A watershed is the area of land where all of the water that is under it or drains off of it goes into the same place (EPA, 2014).

⁸⁴ The pollutants include Nitrogen from inland WWTFs that discharge to rivers.

⁸⁵ The 18-mile-long Woonasquatucket River flows through six cities and towns in Rhode Island including Glocester, North Smithfield, Smithfield, Johnston, North Providence and Providence (Woonasquatucket River watershed council, 2014).

Narragansett Bay (RIDEM, 2003). For example, on August 20, 2003, more than one million fish were reported kill because of anoxia, a total depletion of oxygen (RIDEM, 2003). This event aroused people's attention on the health of Narragansett Bay. From then on, a great deal of programs including both regulatory and non-regulatory approaches have been implemented to improve the water quality, such as establishing water quality standards, water quality monitoring, habitat restoration plans and watershed action plans (RIDEM, 2003). Specific programs were implemented to target point sources and non-point sources pollution respectively, including upgrading of municipal WWTFs and Combined Sewage Overflow program (NBEP, 2005). Additionally, Rhode Island has passed a law in 2004 to cut down the nitrogen loadings by 50% of 1995-1996 levels from major WWTFs to Narragansett Bay by 2008 (NBEP,2008). The implementation of storm water regulations and the adoption of low-impact development approaches throughout the watershed hope to protect rivers and lakes, and thus contribute to improved water quality in the Bay (Watershed Counts, 2013).

Application of the Hedonic Housing Price Model

To examine the impact of improvement of water quality on ecosystem services in Narragansett Bay through increase housing price premiums, we focus on the coastal towns and municipalities of Rhode Island.⁸⁶ In this study, ten towns and cities are included: Barrington, Bristol, Cranston, East Providence, North Kingstown, Pawtucket, Providence, Warwick, East Greenwich, Warren. Since 1970s, these coastal towns and cities have experienced drastic land development comparing to other inland towns and cities.

⁸⁶ Coastal counties are counties that have shorelines access.

CSO project and WWTFs

The sewer system in the Providence metropolitan area combines stormwater and sanitary sewage in the same system of pipes. During significant storm events, this combined storm and sewage water is released untreated into Narragansett Bay. In order to avoid overwhelming the capacity of treatment facilities, the CSO project involves digging a tunnel system to store 65 million gallons of during storm events, to be treated and released in a controlled fashion following the event. The cost for CSO abatement program is also gigantic. Phase I cost a total of \$359 million. From 2008, the CSO Tunnel has prevented 4 billions of gallons of sewage contaminated storm water from entering local rivers and the Bay directly (Narragansett Bay Commission, 2014). Phase II is expected to cost \$363 million, and Phase III is expected to cost \$603 million for a total combination of \$1.3 billion. The overflow volume is expected to be reduced by about 98% due to Phase III. Additionally, the majority of WWTFs in Rhode Island and half of those in Massachusetts have completed upgrades. Water quality in some areas of Narragansett Bay is improving, with dissolved oxygen conditions approaching unimpaired level (Watershed Counts, 2013). However, the impact from the water quality improvement on ecosystem services has not been examined along with the significant increase of water quality.

Housing and neighborhood characteristics

We apply the hedonic housing price model to examine the impact of coastal water quality improvement on the prices of residential properties adjacent to Narragansett Bay under different nutrient reduction scenarios. The housing data we use has 316,553 housing transactions in Rhode Island over 1992 to 2013 period. To adjust the house price,

we choose to use the S&P/Case-Shiller Ma-Boston' home price index not only because it measures the average change in the total value of repeat-sales single-family housing prices in greater Boston metropolitan area, but the method is recognized as the most reliable means to measure housing price movements (Mortgage News Daily, 2014).⁸⁷ Using Boston quarter home price index, we adjust the entire housing transaction prices to the 2013 first quarter price. To ensure only arm's length sale, we have dropped the sales that are below \$40,000 after adjusting the house price index.⁸⁸ We overlay the geocoded property sales with our study area, ten coastal towns and cities in Rhode Island, and get 27040 single-family residential properties with a total of 40,433 housing transactions using ArcGIS software. Summary statistics of the property transactions are shown in Table 1.

A number of housing characteristics variables are controlled for in the hedonic regression to capture the factors that has been previously found to have an impact on the housing prices (Leggett and Bockstael, 2004; Poor et al., 2007; Bin and Cazjowski, 2013). Lot size (in acres), number of years since the house was renovated, number of fireplaces in the building, the exterior condition of the building (from a scale of 1 to 11(1=Unsound, 11=Excellent), living area (in 1000 square feet), number of bathrooms, number of half baths.⁸⁹ Square terms of lot size (in acres) and square terms of living area

⁸⁷ We used Boston home price index since Rhode Island belongs to the greater Boston Area and the housing market is similar to Boston. For the research interest, we also compare the home price index between Boston and National Average, we found that the magnitude of fluctuations in home price index of Boston is smaller(increases slowly and drops slowly) comparing to the national levels, before and after 2007 housing market depression

⁸⁸ Of or relating to transactions between two parties who are independent and do not have a close relationship with each other (Legal Information Institute, 2014).

⁸⁹ Detail of condition variable: 1=Unsound, 2=Poor ,3=Fair, 4=Fair-Average, 5=Average,6=Average-Good,7=Good,8=Good-Very Good,9=Very Good,10=Very Good-Excel, 11=Excellent

are also included to capture the non-linear relationship between the housing related characteristics and housing prices.

For neighborhood characteristics, we choose distance to downtown Providence (miles), distance to the nearest highway exit (miles), distance to the nearest shoreline in four categorical dummy variables: less than 100 meters, 100 meters to 750 meters, 750 meters to 1500 meters, and greater than 1500 meters, to capture nonlinear relationship between distances and housing prices. We have controlled for three additional variables: age above 65 years old, population density and median household income in census block. This information was obtained by overlaying census data with the housing transaction data through ArcGIS interface.

The measurement of water quality in Narragansett Bay

Water quality data in Narragansett Bay are measured by collaborative efforts of different government agencies and research institutes, such as RI Department of Environmental Management Water Resource Division, University of Rhode Island Graduate School of Oceanography, Narragansett Bay Commission, Roger Williams University, Narragansett Bay Estuarine Research Reserve, and Narragansett Bay Estuary Program and University of Rhode Island Coastal Institute (RI DEM, 2014). The water quality data are measured by both fixed-site monitoring stations and buoys (total 13 stations), which collect the data on temperature, salinity, dissolved oxygen, and chlorophyll every fifteen minutes.⁹⁰ The locations of the thirteen monitoring stations as well as the water quality sub-region category in Narragansett Bay are shown in Figure 2.

⁹⁰ Since the fish kill in 2002 in Greenwich Bay, more monitoring has been operated. Currently, there are 13 active stations including both off-shore stations (buoys) and near-shore stations (fixed-site, such as docks).

With a growing number of eutrophic related issues, such as algae blooms, low dissolved oxygen levels, and even fish kills in Narragansett Bay, the three primary water quality concerns for Narragansett Bay are eutrophication, nutrient loading and pathogens (NBEP, 2007). The major causes of abovementioned events are the inputs into the Bay, and particularly nitrogen loadings. Nutrient loading and subsequent eutrophication has a more far reaching impact on the ecosystem, compared to pathogens (fecal coliforms) whose primary impact is on recreational activity along the coastline, including swimming, surfing, and fishing. For example, excess amount of nitrogen will induce algal blooms in the warm months of spring through early September. When the algae use up all the nutrients, they die and sink to the bottom, where they are decomposed by bacteria. Bacteria consume oxygen in the process, and deplete oxygen levels near the bottom. Once the dissolved oxygen drops too low for too long, referred to as hypoxia and anoxia, sea life will be greatly impacted (RI DEM, 2014). Species that cannot flee from the poor water quality region become stressed or die (Watershed Counts, 2014). It may further influence the ecosystem by ripple effects and throw coastal ecosystem out of balance (Teach Ocean Science, 2014).

In this study, we focus on Chlorophyll concentration ($\mu\text{g/L}$), a water quality indicator which is highly correlated with nitrogen level, for the following reasons. First, Chlorophyll concentration is a measurement that reflects the concentration of phytoplankton (microscopic algae) in the water (RI DEM, 2014). As nitrogen is typically the limiting nutrient for algae growth in the marine environment, Chlorophyll concentration level can indicate excess nitrogen concentrations in the estuary (Cameron Engineering & Associates, 2012). Second, Chlorophyll concentration has been widely

used as the indicator for the color of the ocean since it provides an estimate of the live phytoplankton biomass in the surface water (Felip & Catalan, 2000). Third, compared to other water quality parameters, such as temperature, salinity, dissolved oxygen, and pH, which are also measured at monitoring stations, Chlorophyll concentration can be easily observed through the color (the green pigment) on the surface of coastal water. While pathogen may also influence the housing prices, pathogen monitoring data are not available for most parts of the estuary.⁹¹ As most of the water quality parameters are correlated, we only use Chlorophyll concentration as our water quality parameter.⁹²

In this study, Chlorophyll concentration data are collected and compiled from 13 monitoring stations from 1999 to 2013.⁹³ We aggregated the fifteen minute measurements into a daily average measurement of Chlorophyll concentration for each monitoring station. We use the state of Rhode Island integrated water quality monitoring and assessment report to assist interpolation and data analysis because water quality in the estuary is difficult to predict at locations without actual monitoring data due to tidal movements, flow patterns, and other geographical condition (Rhode Island Geographic Information System, 2014).⁹⁴ These assessment and report are based on the overall quality of waters in the state according to the federal Clean Water Act (RIDEM, 2010).

⁹¹ Bacteria sampling monitoring data are only available in the Upper Narragansett Bay, from Division Street Dock to Conimicut Point (Narragansett Bay Commission, 2014). The Narragansett Bay Commission began monitoring for fecal coliform in 2003 and for enterococci in 2006.

⁹² In general, during the summer, the better water quality region also report lower readings for temperature, chlorophyll and higher readings for salinity and dissolved oxygen. In the empirical section of this study, we also did a joint F test on all the water quality indices. The results failed to reject the hypothesis that all the other water quality parameters are significant different from zero.

⁹³ The limited monitoring stations in 1999 and from 2001 to 2004 (no monitoring observation data at 2000). After 2004, more monitoring stations have been put in use.

⁹⁴ These standards are based on the marine and estuarine waters: RI integrated water quality monitoring and assessment report, 2012. This water quality classification are based on the designated use of the waters, for example, some waters are designated as a source of public drinking water and some are designated for the primary contact recreational activities, some for fish and wildlife habitat, some for industrial cooling, or aquaculture and so on.

The CWA goals are measured by whether water is such that the water body can be used for its designated use. Assessment of impaired waters for dissolved oxygen in Narragansett Bay can also be derived (Watershed Counts, 2014) by using the number of days which low dissolved oxygen (hypoxia) occurs during the recruitment season based on the RIDEM monitoring data. Hypoxia events are episodic and last about one to two weeks while some events even last for the whole season. The monitoring stations combined with impaired water sub-region information are shown in Figure 2.

To better predict the water quality, we use the IDW method to interpolate the water quality within each water sub-region.

$$Chlorophyll = \frac{\sum_{i=1}^n 1/d_i Chlorophyll_i}{\sum_{i=1}^n 1/d_i} \quad (1)$$

Where d_i is the distance from the property to the i th closest monitoring stations in kilometers within the same water quality sub-region and $Chlorophyll_i$ is the Chlorophyll concentration level at monitoring station i . We use the Euclidian distance between the property and the monitoring stations to interpolate the water quality since the method provides a good proximate.⁹⁵ This implies that if there is only a single monitoring station within a water quality region, the measured water quality at that station is used for all properties in the sub-region. If there is more than one monitoring station within that water quality sub-region, the spatial distribution of water quality is measured by interpolating measures from the closest stations within the sub-region using IDW. There are 10 regions in the impaired water sub-region map: 3 sub-regions have two monitoring stations and the other seven have only one monitoring station within the water quality sub-region. One downside of this approach is that because the water quality is

⁹⁵ Compared to interpolate the water quality within the Bay first and then find the nearest water quality for each house using ArcGIS.

approximated using either the single monitoring station or multiple stations using IDW, there is inherently measurement error. We expect that the further away a property is from the monitoring stations, the less accurate of the predicted water quality.

As discussed above, homebuyers' perceptions of water quality might be affected by different aspects of the distribution of water quality. Perceptions of water quality might depend primarily on average quality, or perceptions might be influenced primarily by extreme events associated with the uncommon but highly visible incidents, such as those that cause algae blooms, unpleasant odors or fish kills. For this reason we not only investigate the effects of median chlorophyll concentration, but we also consider extreme events, including 99th percentile, 95th percentile and 90th percentile for Chlorophyll concentration in the summer months.

We use only the water quality in summer months, from May 1st to September 30th, because water conditions are more vulnerable to hypoxia and anoxia when the temperature is high (RI DEM, 2014). Under the assumption of "myopic" homebuyers, we assume that housing prices only depend on water quality during the summer in which the transaction occurred. Transaction summer also has a total of five months; however it differs from the calendar summer, depending on the month of the transaction. For example, if the transaction happens during May, the homebuyer can only capture the water quality at that particular month. The water quality in the following June, July, August and September will not influence the homebuyer since the purchase decision had already been made in May. Instead, the previous summer months may affect housing prices, since buyers may have a memory of the water quality in the previous summer months (from last June to last September). We have defined a number of rules for the

transaction summer. If the property is sold in May, then this May plus all four summer months, June, July, August, and September will be used for calculating water quality. If a purchase is made in June, then the summer transaction months will be this May, June plus all previous summer months except last May and June, more precisely, only last July, August and September will be included. Similarly, the transaction that happens in July, August, and September are calculated based on an analogous rule. If the property is sold before May, only last summer months monitoring data will be used, whereas if the property is sold after September, only current summer months monitoring data will be used.

Under the model of “thoughtful” homebuyers, a more general water quality indicator is calculated by aggregating water quality information of all summer months across all years from different monitoring stations.⁹⁶ In addition to the median of the chlorophyll concentration level, we are also concerned about the extreme events and their impacts to homebuyers’ decisions. As shown in Table 2, North Prudence has the highest 438.30 $\mu\text{g}/\text{L}$ measures of 99th percentile of Chlorophyll concentration, whereas Phillipsdale and Greenwich Bay have 67.15 and 62.90 $\mu\text{g}/\text{L}$. If the median measures are used, Chlorophyll concentrations at these three stations are 10.91, 8.69, and 19.50 $\mu\text{g}/\text{L}$ respectively.

Each property sale is assigned to the closest water quality region with correspondent monitoring data for seven sub-regions and water quality is interpolated at the location of each property using IDW approach for the other three sub-regions.⁹⁷

⁹⁶ Similar to the transaction summer, here we aggregated the data to calendar summer since there is only one general impression on the water quality during the last decade for each monitoring stations.

⁹⁷ Please see Figure 2.

III HEDONIC MODEL ESTIMATION

Hedonic housing price models have been used widely for non-market valuation to value the environmental goods and services which are not traded directly in the market (Hanley, Barbier, & Barbier, 2009). The theoretical framework of hedonic housing price model is built on the basic utility maximization problem of consumers (Taylor, 2003). When each consumer makes choices over differentiated goods and services, the price at the equilibrium will reflect the consumer's implicit price on the particular characteristics of that differentiated good or service, such as housing characteristics (Rosen et al., 1974). Take the housing market as an example. Each property can be characterized as three bundles of characteristics: characteristics of the property, characteristics of the surrounding neighborhood, and characteristics of the local environment. Each house provides a bundle of characteristics, and buyers can maximize their utilities through their selection of housing locations. From the supply side, each seller is trying to maximize his profit. In equilibrium, the hedonic housing price function can be expressed by:

$$Price = P(H, N, E) \quad (3)$$

Where *Price* is the property transaction price, and *H* is housing related characteristics, such as lot size, living area, number of bathrooms and conditions of the property. *N* represents neighborhood characteristics, for instance, the quality of school district, crime rate, public services provided in the neighborhoods as well as demographics of neighbors. *E* includes both environmental amenities and disamenities. In this study, we are interested in the impact of water quality in Narragansett Bay on housing prices in the coastal towns and cities of Rhode Island.

We adopt the double-log functional form, not only because double-log has been proved to outperform other functions forms in some hedonic literature (e.g. Palmquist, 1984; Poor et al., 2007; Taylor, 2003; Walsh et al., 2011) but also the Box-Cox test results support the double-log model.

For “thoughtful” homebuyers, hedonic housing price model can be written as:

$$\ln(\text{Price}_{it}) = \beta_0 + \beta_1 \ln(WQ_i) + \beta_2 \text{Distance}_i * \ln(WQ_i) + \beta_3 \text{Distance}_i + \beta_4 * H_i + \beta_5 * N_i + \beta_6 * \text{Town}_i + \beta_7 * \text{Year}_i + \varepsilon \quad (4)$$

Where Price_{it} is the transaction price for property i at time t , $\ln(WQ_i)$ is the corresponding water quality indicator. For the “myopic” homebuyer model, the difference is water quality will vary with time since they perceive water quality for one just transaction summer, thus $\ln(WQ_i)$ will be replaced with $\ln(WQ_{it})$.

Distance_i represents a series categorical dummies variables, measuring the proximity of the property to the nearest shoreline. More precisely, we have divided the proximity to the nearest shoreline into four categories, $\text{Distance}=0$ (baseline) if the proximity is greater than 1500 meters which we assume that the marine water quality has little impact on the housing prices; $\text{Distance}=1$ (D1) if the proximity is within 100 meters; $\text{Distance}=2$ (D2) if the proximity is greater than 100 meters but less than 750 meters; $\text{Distance}=3$ (D3) if the proximity is greater than 750 meters but less than 1500 meters. Compared to continuous distance variable, categorical dummy distance variables can capture non-linear relationships among the housing prices, water quality and distances.⁹⁸ Housing related characteristics H_i , such as lot size (in acres), number of years since renovation, number of fire places, condition of the house (eleven categories, 1=unsound, and

⁹⁸ We also tried continuous variable approach. Results can be provided upon request.

11=excellent), living area (in 1000 square feet), the square term of living area, number of bathrooms and half baths.⁹⁹ For the neighborhood characteristics, we include distance to downtown Providence, distance to the nearest highway exit since the proximity to the central market and commuting time are important determinant for housing location choices (Samuelson, 1983). We have also controlled for characteristics of the census block in which the property is located, including the percent of residents over 65, median household income and population density.

We expect the following variables are positively related to the housing transaction price: distance to downtown Providence, lot size, number of fire places, living area, number of bathroom, number of half baths, age above 65, and median house income in the neighborhood. However, other variables such as distance to the highway exit, number of years since renovation, and population density are predicted to be negative. Furthermore, the square term of living area is expected to be negative, suggesting the nonlinear relationship between the housing price and the square terms. With the increasing of the living area, the housing price increases at a decreasing rate.

The water quality measures, include, 50th percentile (median), 90th percentile, 95th percentile, 99th percentile measurement during aggregated summer months (from 1999 to 2013) for homebuyers. If water quality is high, houses near the shoreline are expected to sell at a higher price than houses further from shore, all else equal. As water quality declines, the price premium for being near the shoreline is reduced, possibly becoming negative if water quality is very poor. This implies proximity to shoreline has a positive effect, by the interaction between chlorophyll concentrations and proximity is negative. We expect distance dummy variable to be positive and decreasing (i.e. $D1 > D2 > D3$

⁹⁹ Please see footnote 89 for the eleven categories of house conditions.

>0). We further expect the interactions between chlorophyll concentrations and distance to be negative and decreasing in absolute value, so that water quality has the largest effect on price for properties located very close to the shoreline, while water quality has less of an effect on prices of properties that are further from the shoreline.

Town ($Town_i$) and year ($Year_i$) fixed effects serve as controls for unobserved characteristics at different coastal towns and different time periods. Town fixed effects captures time invariant town characteristics such as school quality, crime rate, and property tax rates. However, we are unable to control for time-variant factors that affect housing prices such as failure rate of septic systems, which is likely to be correlated with water quality. Such factors may bias the estimation results.

Lastly, heteroskedasticity is controlled for in the hedonic housing price estimation by allowing errors clustered at water quality region, since there might be some measurement errors or systemic errors in the process of predicting or interpolating water quality.

IV ESTIMATION RESULTS

Results for the “thoughtful” homebuyers model

Separate double-log linear models were estimated with different percentile measurements for Chlorophyll concentrations: 50th percentile (median), 90th percentile, 95th percentile, 99th percentile of Chlorophyll concentration level respectively of the summer months across years (Models 1-4). Distance dummy variables and interaction terms between distance and water quality show the expected positive sign and the declining of magnitude as distance increases in all four models. Our base category are the houses which locate greater than 1500 meters. The estimation results show that compared

to the houses that reside 1500 meters away from Narragansett Bay, a house located within 100 meters of the shoreline adds a significant premium (at 1% level) to housing prices if other characteristics are being held constant. As the distance from houses to the shoreline increases, the premium for location decreases. Model 1-4 also show the consistency of the decrease in the magnitude of the coefficient on the distance dummy variables due to the increase of distance to the coastal water. The regression results are reported in Table 4. For the interaction terms of distance with Chlorophyll concentration, compared to the houses which are located greater than 1500 meters (base category), all four models show a consistent result of the impact of water quality attenuating with an increase of distance to Narragansett Bay.

The signs on our variable of interest, the interaction terms between Chlorophyll and distance dummy variable are both negative and significant as expected. It indicates that water quality has a negative impact within a certain distance of the coastline. However, this impact declines in magnitude with an increase in distance from the Bay. Consider Model 1 as an example; water quality has a negative impact on houses within 100 meters of the shoreline, with a magnitude of 0.030 with significance at 5% level. As the distance increase to above 100 meters but less than 750 meters, the negative impact of water quality on houses within the distance radius drops to 0.016 with significance at 10% level. For houses further away from shoreline (between 750 meters and 1500 meters), the negative impact of water quality on housing prices decreases to 0.015 with significance at 1% level.

The coefficient on Chlorophyll concentration for the base category of houses is positive for most models (Model 1-3) but not significant, which means that the water

quality may not influence the base case houses, further than 1500 meters from the shore, as we expected. This result is consistent with the literature, since these properties are located about a mile away from the shoreline. It is unlikely that changes in water quality will have a significant effect on properties a mile or more from the shoreline. Furthermore, the square terms of Chlorophyll concentration, which is to capture the non-linear relationship between housing prices and the water quality is negative but not significant for our base category.

Results from the “myopic” homebuyers model

Similar to the “thoughtful” models, separate double-log linear model were estimated with different Chlorophyll measures: 50th percentile (median), 90th percentile, 95th percentile, 99th percentile of Chlorophyll concentration levels respectively for the summer transaction observations (Models 1-4). As opposed to the “thoughtful” model, we find the Chlorophyll concentration has a negative and significant impact (at 1% level) on the houses further than 1500 meters (base category) from the shore (Table 5). The square terms of Chlorophyll concentration is positive and significant at 1% level, which means that the impact on housing prices is negative but can decrease at a decreasing rate or increase at an increase rate with the increase of Chlorophyll concentration level.¹⁰⁰ For the proximity effect, the distance dummy variables from alternative models show a consistent positive impact by living close to the Bay. However comparing to houses located further than 1500 meters, we find that houses locate between 750 meters and

¹⁰⁰ It depends on the level of Chlorophyll concentration. We can find the minimum point of quadratic function by taking the derivative with respect to the $\ln(\text{Chl})$ and make it equal to 0. When Chlorophyll concentration is in the range of 25.4 to 31.2, the impact is the minimum. Before this range, the impact is decreasing at a decrease rate, after this range, the impact is increasing at an increase rate.

1500 meters have a slightly higher premium compared to those located between 100 meters to 750 meters. In comparison to “thoughtful” model, the interaction terms between the distance dummy variables and water quality are negative but only significant for the houses within 100 meters of the shoreline. We also do not observe the decrease of magnitude in the interaction terms. The possible explanation of the results in this model is that homebuyers prefer to live very close to the coastline (<100 meters), but they do not have a strong preference between 150-750 meters over 750-1500 meters.

The “thoughtful” model is more consistent with prior expectations based on theory. Furthermore, the “thoughtful” model also has a higher R^2 , and is also preferred in terms of other criteria, including AIC and BIC.¹⁰¹ Therefore, we adopt the “thoughtful” model for policy analysis, described below.

V SCENARIO ANALYSIS AND IMPLICIT VALUE OF WATER QUALITY

Our scenario analysis attempts to predict the potential benefits capitalized into housing prices for those who live near Narragansett Bay under different water management programs scenarios in the upper Narragansett Bay. It is important to note that this is only one category of benefits, and it is likely that there are other water quality benefits associated with recreational use, nonuse values, etc. Hence, the results below are likely to understate the full range of benefits of water quality improvements.

The first scenario we examine is a nitrogen intervention scenario that results in a 25% reduction in Chlorophyll concentration, which is based on the Phase I prototype of the Narragansett-3VS model (Industrial Economics Inc. et al. , 2012). This nitrogen reduction intervention scenario is comprised of a combination of six actions gradually

¹⁰¹ AIC and BIC Results can be provided upon request.

implemented between 2010 and 2050, including 50% reduction in loadings from WWTFs of 2014 level, 50% of independent sewage disposal system (ISDS) upgrading, 50% reduction in loadings from atmospheric deposition, livestock, agricultural fertilizer of baseline level respectively, and low impact development since 2015.¹⁰² Industrial Economics Inc. et al. (2012) first tested and simulated water quality using Narragansett-3VS model indicated that by 2050, nitrogen interventions will reverse the upward trend due to the atmospheric deposition and greatly reduce the nitrogen loadings from the baseline. Furthermore, their results also demonstrate the corresponding nitrogen concentration in water, which is reduced by about 50% by 2050.¹⁰³ Building on their simulation results, we examine the impact of nitrogen intervention on the housing stock in the coastal towns and cities of upper Narragansett Bay. To reflect the corresponding changes in Chlorophyll concentration, coastal water quality indicator in our hedonic housing price model, we followed Dettmann et al. (2005) on the effect of nitrogen loading on Chlorophyll concentration.¹⁰⁴ Since Chlorophyll has a more significant impact on water quality during the summer when water temperatures are higher, we adopt the Dettmann et al.(2005) summer formula for Chlorophyll concentrations:¹⁰⁵

$$\text{Chlorophyll } a = 57.5 * (\text{Nitrogen concentration in water})^{2.09}$$

¹⁰² ISDS upgrading target those located within two kilometers of the bay. For more information about the six intervention, please see page 17, Appendix A and E of Narragansett Bay Sustainability Pilot Phase I Report.

¹⁰³ See page 18, exhibits 7A and 7B of Narragansett Bay Sustainability Pilot Phase I Report.

¹⁰⁴ See Appendix B of Narragansett Bay Sustainability Pilot Phase I Report.

¹⁰⁵ One limitation of Dettmann's model is that it is based on median-response, and hence the predicted level of Chlorophyll concentration may be biased for high or low nitrogen concentration levels. The science behind this relationship for extreme values is not well understood.

Besides nitrogen reduction intervention scenario developed by Industrial Economics Inc. et al. (2012), which is about 50% reduction in nitrogen concentration (roughly equal to 25% reduction of Chlorophyll concentration), we also include another three alternative scenarios, including 10% and 50%, and 75% reduction in Chlorophyll concentration.¹⁰⁶ It is important to note that these are purely hypothetical scenarios intended to represent a range of water quality management actions ranging from relatively modest to very ambitious, and the scenarios are not intended to be considered to be recommendations, or even feasible water quality goals. Using the Dettman et al (2005) relationship between nitrogen and chlorophyll concentrations, these reductions in chlorophyll concentrations correspond to hypothetical reductions in N concentration of 33%, 72%, and 87%.

All scenarios are compared against the baseline, which is status quo. Additionally, to simplify the process of the simulation under different scenarios, we assume that there will be the same reductions in chlorophyll concentrations at all monitoring sites in each water quality sub-region instantly in Narragansett Bay. The scenarios demonstrate the effects of nitrogen reduction interventions and other alternative scenarios for reductions in chlorophyll concentrations in the Bay. We use different percentile measurements for chlorophyll concentrations to examine the impacts of the water quality interventions on housing prices. Ideally, GIS data should be used to get counts of houses in different regions. However, due to limited information on characteristics of all houses within the

¹⁰⁶ 51.5% reduction in N concentration in water is equal to 25% reduction in Chlorophyll concentration when other factor, such as light, turbidity, temperature, and other variables hold based on Dettmann et al.(2005). 75% reduction is used as the high end for water quality improvement reduction scenario, since roughly a 75% reduction in chlorophyll can bring the Seekonk river to the threshold for good water quality (Personal Communication, Nicloe Rohr, 2014). However, we note that extreme hypothetical scenario may go beyond the historical levels of water quality where the current water quality is high such as at the GSO dock.

coastal towns and cities, we assume that houses sold are representative of the larger population of all houses in the region. We find a representative house for each distance radius within a given water quality sub-region, by taking the average of characteristics all property sales. Table 6 shows the number of houses in water quality sub-region of upper Narragansett Bay.

Welfare changes

The potential benefits are expected to increase with the water quality improvement under different nutrient reduction scenarios. To make our welfare measurement easier, we assume that hedonic housing price function does not change and also the change in water quality does not affect the costs of supplying housing amenities for producers (Freeman, 2003). The welfare change as a result of a reduction in Chlorophyll concentration x % (from WQ_0 to WQ_1) for a representative house can be expressed as:

$$\Delta W = P(H, N, WQ_1) - P(H, N, WQ_0) \quad (9)$$

Equation (9) is similar to equation (3), where housing price is a function of H (housing related characteristics), N (neighborhood characteristics), and environmental quality. In this particular case, welfare can be reflected in a representative house when there is an increase in water quality, and Chlorophyll concentration changes from WQ_0 to WQ_1 .

According to equation (6), the implicit marginal price is not constant, thus the welfare change for an individual can also be written as follows:

$$\Delta W = \int_{WQ_0}^{WQ_1} \left(\frac{\partial Price_{it}}{\partial WQ_i} \right) d(WQ) \quad (10)$$

Aggregated welfare change can be written based on individual welfare:

$$\Delta W = \sum_{i=1}^n \int_{WQ_0}^{WQ_1} \left(\frac{\partial Price_{it}}{\partial WQ_i} \right) d(WQ) \quad (11)$$

where i represents the individual house, total welfare change can be aggregated from each individual house to all houses in the region. In our research, we simply this process by finding a representative house and number of house in each region. For more information on the welfare change is included in Appendix II.

Simulation results for both individual and aggregated welfare change

Table 7-10 show the results of both the individual and aggregate benefits in each water quality sub-region in upper Narragansett Bay using different water quality measurements, from Chlorophyll 99th percentile, 95th percentile, 90th percentile and 50th percentile (median) of summer water quality (Model1-4). The individual benefits are declining for most of water sub-regions with the increasing distance to the shoreline. Additionally, with the increasing Chlorophyll concentration reduction in the water, individual benefits increase. Take Table 7 for example, the Phillipsdale water sub-region, which encompasses the Seekonk River between Providence and East Providence, is one of the worst impaired waters listed (RI DEM, 2014). With the Chlorophyll concentration level being reduced by 10% compared to the baseline, the individual benefit for a representative house within 100 meters is about \$1,000.¹⁰⁷ The individual benefit will increase the price of the average house by about \$400 for those houses located in the 100-750 meters or 750-1500 meters distance radius. If the nitrogen reduction intervention scenario were successfully implemented, which means about 25% reduction of Chlorophyll concentration by 2050; it will increase an average house price by \$2,800 if

¹⁰⁷ An average house is also referred to the representative house in a particular distance band of a particular water quality region. The average house characteristics are calculated based on the real transaction data.

the house is within the 100 meters distance of the shoreline.¹⁰⁸ For an average house in this region that is located between 100 meters and 750 meters from the shoreline, a 25% reduction in chlorophyll concentration will increase the price of the house by \$1,100. For the house located greater than 750 meters but within 1500 meters of the coastline of Narragansett Bay, there is a \$1,000 increase in the price.

The aggregated benefits are calculated based on the E911 point data, which includes the actual address for all buildings and other significant infrastructures for the state of Rhode Island as of March 2014 (RI DEM, 2014). Similar to the single-family transaction data being used in the hedonic house price models, we select only the single-family houses to estimate the aggregated benefits for the houses in the coastal towns and municipalities. Table 5 shows the number of houses within each distance radius in different water quality sub-region of upper Narragansett Bay. Phillipsdale has the most houses in total, 38,183; however it has only 106 houses located within 100 meters of the shoreline. North Prudence has the fewest houses in total, 2,942. Combined with the individual benefit for a representative house within a certain distance radius of a certain water quality region, we are able to estimate the total benefits for all the houses locate near that water quality sub-region.

Applying the assumed 25% reduction in chlorophyll concentrations to all regions results in an aggregate increase in housing prices of about 64.4 million dollars. Different water quality sub-region and different distance radii may benefit differently from the reduction. For example, Bullock's Reach and Greenwich Bay water quality sub-region will benefit 19.2 and 8.4 million dollars from the 25% reduction in chlorophyll

¹⁰⁸ Comparing to continuing the future nitrogen loadings scenario, which are mostly driven by projected population growth, urban development and increase use of fertilizer (IEC, 2012).

concentrations. In Bullock's Reach sub-region, houses located between 100 and 750 meters benefit most, 9.0 million dollars, compared to other distance radius. Whereas in Greenwich Bay sub-region, houses located within a distance radius 750-1500m, will benefit most as a consequence with the same reduction interventions.

Table 7-10 estimates individual and aggregate benefits for Chlorophyll reduction using Chlorophyll concentration of 99th percentile, 95th percentile, 90th percentile, and 50th percentile (median) measures. We notice that the magnitude varies within alternative measures used for simulations. For example, the 25% nitrogen reduction intervention scenario, the individual benefits vary from \$2,900 to \$7,300 using different water quality measurements for the distance radius (<100 meters) of Greenwich Bay (Table 9 and 10). In general, the estimated results from Table 8-10 are consistent with Table 7 in terms of increasing individual benefits with increased reductions in Chlorophyll concentration within the same distance radius and the same water quality sub-region. The aggregated benefits are also consistent with Table 7.

However, we notice that the magnitude of individual benefits is significantly larger when Chlorophyll 50th percentile (median) measurement is used (Table 10). Take North Prudence for example, a 75% reduction in Chlorophyll concentration results in about 20 thousand dollars for an average house within 100 meters, which is almost 3 times the effect on the same average house, 57 thousand dollars, if 99th percentile and 50th percentile (median) Chlorophyll concentration level are used as the water quality measurements. For total aggregate benefits, under 75% reduction in Chlorophyll concentration scenario, Bullock's Reach will benefit \$376.9 million using 50th percentile (median) measures, which is about 4 times of the benefit (\$93.7 million) if we use 99th

percentile measures instead. This implies that the water quality measurements are crucial for the valuation of environmental goods and services. The values could be hugely different if one measurement is chosen against another. If people value the median water quality in Narragansett Bay more compared to the extreme events, the median water quality should be chosen instead of the 99th percentile of the water quality. However, without adequate information on homebuyers' perceptions on water quality, using multiple water quality measures to estimate the impact of water quality on coastal housing prices could give us a better understanding of potential benefits capitalized into housing prices to those close to the Bay from the improvement of water quality in the upper Narragansett Bay. It might be informative for policy makers to know the upper bound and lower bound of potential benefits due to the uncertainty of homebuyers' perceptions, especially when estimating the potential benefit associated with water quality improvement.

VI CONCLUSION AND DISCUSSION

This study examined the impact of nutrient reduction and water quality improvement on the housing prices in Narragansett Bay using hedonic housing price method. We use Chlorophyll concentration as a water quality indicator since it correlates with can be easily observable water quality characteristics such as color, odor, or even algae blooms if the Chlorophyll concentration level is extremely high. We also compiled 15-minute data from both fixed-sites and buoy monitoring data in Narragansett Bay from 1999 to 2013 to assess the impacts of water quality on housing prices. The consistent results from hedonic estimation (Model 1-4, Table 4) demonstrate that the water quality has

influenced the housing prices in the coastal towns and municipalities in Narragansett Bay. Compared to the houses located greater than 1500 meters from the bay, the proximity to the shoreline adds a premium to the housing prices. However proximity to poor quality water will decrease the premium. To be more specific, compared to the base category, houses located more than 1500 meters, poor water quality will have a negative impact on the all houses within 1500 meters. As the distance from the poor water increase, the negative impact decreases. In contrast to the previous literature which mostly used median or average measurement of water quality, we investigated the impacts from median level and extreme events, using 99th percentile, 95th percentile, 90th percentile measurements. The estimation results from all four models show that the magnitude of the estimated parameters (both proximity impact and the interaction of proximity with water quality) varies slightly among different measure. The difference is relatively large in terms of the coefficient estimate as well as potential benefits associated if the 50th (median) level of Chlorophyll concentration is used for water quality measurement. This suggests that alternative measures for the same water quality parameter can make a considerable difference in the marginal implicit price associated with marginal change in water quality.

Under the nitrogen reduction intervention scenario (25% reduction in Chlorophyll concentration), the potential benefits gained by housing stock market near the coastline of Narragansett Bay varies from 65 to 261 million dollars depending on the choice of water quality measurement. Since there is a substantial difference among the estimations using different percentiles of water quality indicator, it suggests that decision makers should be aware of the consequential difference in potential benefits gained by houses near to

Narragansett Bay. Although this study provides substantial evidence that the houses in coastal towns and cities of Narragansett Bay are benefiting from water quality improvement, there are a few caveats that need to be addressed in the future research. First of all, we did not account for spatial errors and correlations in the empirical study, which can lead to potential bias of the estimates. Secondly, in order to provide more pertinent information on potential benefits to the houses near to Narragansett Bay under different water quality management programs, more investigation needs to focus on homebuyers' perceptions of water quality. Thirdly, a more general approach is to explore the relationship between distribution of water quality parameters and housing prices. For example, instead of specifying the percentile for the Chlorophyll concentrations, another approach would be to estimate the shape and scale parameters of the gamma distribution for each station. Policy scenarios might be more informative since the nutrient reductions programs can potentially shift gamma distributions of each monitoring station to a better water quality status. Finally, in this analysis we do not account for the dynamics between changes in the demand and supply corresponding to the change in water quality. In reality, the hedonic housing price functions will shift as a consequence of the change in the water quality; however our approach provides only approximates for the true welfare change (Freeman, 2003).

Despite the limitations, our scenarios analysis combines both the nitrogen reduction intervention scenarios and other alternative nutrient reduction scenarios, which gives an example and a simplified illustration of potential benefits gained by houses prices to those reside near Narragansett Bay with the improved water quality. It is important to note that hedonic housing price approach aims to capture marginal benefit of marginal

changes in water quality that are capitalized into values of houses. The aggregation of potential benefits is made based on the assumptions, such as the hedonic price function will not change in response to the water quality improvement. Possible changes in the supply side of the housing market have not been considered. At last, there are other benefits from water quality improvement that are not accounted for in this valuation, such as the recreation use by people who live further from the bay, non-use values such as existence values, as well as economic benefits from recovered Rhode Island fishery industry including shellfish.

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Table 1: Variables and Descriptive statistics of housing transaction in coastal counties of Narragansett Bay(1992-20013)

Variable	Units	Mean	Std. Dev.	Min	Max
Log format of adjusted housing price (in the first quarter of 2013 housing price index)	\$1000,in 2013 dollars	12.55	0.64	10.60	16.39
Distance to downtown Providence	mile	1.98	1.56	0.03	7.05
Distance to the nearest highway exit	mile	6.95	4.54	0.18	22.95
Distance to the nearest shoreline	mile	1.34	1.30	0.00	7.71
Lot size	acres	0.42	1.27	0.00	25.18
Number of years since renovation	-	59.08	31.36	2.00	334.00
Number of fireplaces in the building	-	0.42	0.60	0.00	6.00
Exterior condition of the house(1 to 11, 1=unsound, 11=excellent)	-	5.40	0.89	1.00	11.00
Living area	1000 square feet	1.62	0.77	0.00	15.84
Number of bathrooms	-	1.54	0.69	0.00	9.00
Number of half bath	-	0.48	0.54	0.00	5.00
Age(>65) in the neighborhood	%	0.16	0.07	0.00	0.57
Population density in the neighborhood	1000 people per square mile	5.41	5.60	0.00	48.52
Median household income in the neighborhood	\$1000,in 2000 dollars	53.54	22.34	0.00	125.97

Table 2: Water Quality statistics for Narragansett Bay (May-September, 2001-2013)

Name of Monitoring Stations	Observations	Chl 50 th percentile	Chl 90 th percentile	Chl95 th percentile	Chl99 th percentile	Mean	Std. Dev.	Min	Max
Bullock Reach	1522	17.54	38.26	46.55	60.60	20.55	12.65	2.07	86.80
Conimicut Point	1194	13.52	25.37	30.17	41.79	15.08	7.85	1.60	53.89
GSO Dock	533	3.77	7.26	8.87	11.89	4.25	2.26	0.74	15.07
Greenwich Bay	1162	19.50	36.10	43.80	62.90	23.07	22.17	1.06	322.70
Mt. Hope Bay	1096	10.17	19.01	23.44	31.26	11.34	5.89	0.35	37.30
Mt. View	1065	9.81	20.25	22.11	24.22	11.11	5.55	1.57	33.28
North Prudence	1430	10.91	62.75	161.00	438.30	33.43	78.43	1.88	493.10
Phillipsdale	881	8.69	37.23	48.97	67.15	14.93	15.22	1.20	98.49
Popposquash Pt.	1118	9.24	18.96	23.20	40.52	10.83	7.13	0.65	51.41
Quonset Pt.	1029	6.84	16.31	19.22	20.92	8.19	4.83	1.12	21.94
Sally Rock	776	10.79	20.96	25.36	43.77	12.56	7.41	2.09	51.41
T-Wharf	139	3.62	8.58	11.26	14.20	4.60	2.87	1.66	15.26
GSO Upper Bay	82	17.10	54.60	121.91	141.25	28.84	31.69	3.66	141.25

Note: water quality is calculated based on the analyzed daily water quality (May to September 2001-2013). Potter's Cove are not included because its proximity to Jamestown. However, Jamestown and Newport are not included in our study since their unique location and we assume they have a different housing market comparing to our nine coastal counties.

Table 3: Distribution of the property transaction in the coastal towns of Rhode Island(1992-2013)

Distance to the nearest Shoreline	Number of property transactions	% of Total Transactions	Cumulative % of Total Transactions
Less than 100 meters	592	4.22	4.22
100-750 meters	3519	25.10	29.32
750-1500 meters	2451	17.48	46.80
Greater than 1500 meters	7458	53.20	100

Table 4: Estimation results for “thoughtful” homebuyers with different water quality parameter

VARIABLES	log_price			
	(1) Chl99	(2) Chl95	(3) Ch90	(4) Chl50
ln(Chlorophyll)	0.007 (0.294)	0.009 (0.332)	0.008 (0.200)	-0.032 (-0.683)
ln(Chlorophyll)^2	-0.001 (-0.180)	-0.001 (-0.244)	-0.002 (-0.177)	0.009 (0.665)
ln(Chlorophyll)*Distance Dummy(<100m)	-0.030** (-1.984)	-0.033** (-2.077)	-0.030** (-1.955)	-0.037* (-1.578)
ln(Chlorophyll)*Distance Dummy(100-750m)	-0.016* (-1.380)	-0.019* (-1.446)	-0.021* (-1.395)	-0.020 (-1.133)
ln(Chlorophyll)*Distance Dummy(750-1500m)	-0.015*** (-3.144)	-0.016** (-3.112)	-0.018** (-3.296)	-0.021*** (-4.186)
Distance Dummy(<100m)	0.301*** (5.614)	0.302*** (5.753)	0.289*** (5.771)	0.283*** (5.167)
Distance Dummy(100-750m)	0.167** (2.489)	0.169** (2.515)	0.172** (2.480)	0.156** (2.500)
Distance Dummy(750-1500m)	0.095*** (4.177)	0.095*** (4.235)	0.097*** (4.367)	0.092*** (4.964)
Observations	13,959	13,959	13,959	13,959
R-squared	0.780	0.780	0.780	0.780

Notes: Chl99, Chl90, Chl90, and Chl50 are different measurements of water quality parameter, and they represent Chlorophyll concentration at 99th, 95th, 90th, and 50th percentile respectively. All the models also include controls for both characteristics of houses, including lot size(in acres), square term of lot size, number of years since renovation, number of fire places, conditions, living area(in 1000 square feet), square term of living area, number of bathrooms, number of half bath, as well as distance to the nearest highway exit. We also control for neighborhood characteristics, distance to downtown Providence (mile), distance to the closest highway exit (km), We also control for town fixed effects and time fixed effects in the estimation. Robust t statistics are in parentheses. The stars (***) p<0.01, ** p<0.05, * p<0.1) indicate level of significance

Table 5: Estimation results for “myopic” homebuyers with different water quality parameter

VARIABLES	log_price			
	(1)	(2)	(3)	(4)
	Ch199	Ch195	Ch90	Ch150
ln(Chlorophyll)	-0.872*** (-6.044)	-0.646*** (-4.906)	-0.492*** (-4.634)	-1.398*** (-7.508)
ln(Chlorophyll)^2	0.136*** (6.560)	0.109*** (6.161)	0.091*** (6.701)	0.316*** (8.072)
ln(Chlorophyll)*Distance Dummy(<100m)	-0.064 (-1.324)	-0.080** (-1.998)	-0.095** (-2.651)	-0.062 (-1.322)
ln(Chlorophyll)*Distance Dummy(100-750m)	-0.008 (-0.238)	-0.010 (-0.324)	-0.019 (-0.586)	0.011 (0.226)
ln(Chlorophyll)*Distance Dummy(750-1500m)	-0.039* (-1.466)	-0.031 (-1.102)	-0.036 (-0.995)	-0.016 (-0.283)
Distance Dummy(<100m)	0.446** (2.602)	0.480*** (3.659)	0.509*** (4.915)	0.383*** (3.457)
Distance Dummy(100-750m)	0.144* (1.710)	0.150** (2.123)	0.173** (2.499)	0.098 (1.194)
Distance Dummy(750-1500m)	0.212*** (2.934)	0.181** (2.505)	0.187** (2.256)	0.125 (1.226)
Observations	8,037	8,037	8,037	8,309
R-squared	0.642	0.642	0.642	0.637

Notes: Ch199, Ch190, Ch190, and Ch150 are different measurements of water quality parameter, and they represent Chlorophyll concentration at 99th, 95th, 90th, and 50th percentile respectively. All the models also include controls for both characteristics of houses, including lot size(in acres), square term of lot size, number of years since renovation, number of fire places, conditions, living area(in 1000 square feet), square term of living area, number of bathrooms, number of half bath, as well as distance to the nearest highway exit. We also control for neighborhood characteristics, distance to downtown Providence (mile), distance to the closest highway exit (km), We also control for town fixed effects and time fixed effects in the estimation. Robust t statistics are in parentheses. The stars (*** p<0.01, ** p<0.05, * p<0.1) indicate level of significance

Table 6: Numbers of houses in water quality region of upper Narragansett Bay

Distance	Water quality regions					
	Phillipsdale	Bullock's Reach	Conimicut Point	North Prudence	Sally Rock	Greenwich Bay
<100 meters	106	1,619	755	236	629	340
100 -750 meters	5,769	8,588	5,902	2,082	2,115	2,213
750-1500 meters	9,084	5,986	741	612	317	4,032
> 1500 meters	23,224	13,786	0	12	0	11,878
Total	38,183	29,979	7,398	2,942	3,061	18,463

Table 7: Individual and Aggregate benefits for Chlorophyll reduction at different water regions in upper Narragansett Bay using Chlorophyll 99th percentile measure

Water Region	Chl concentration reduction	Individual benefits (\$1000)			Aggregate benefits (\$million)			Total aggregate benefits (\$million)
		<100 meters	100 -750 meters	750-1500 meters	<100 meters	100 -750 meters	750-1500 meters	
Phillipsdale	10%	1.0	0.4	0.4	0.1	2.4	3.5	5.9
	25%	2.8	1.1	1.0	0.3	6.4	9.5	16.2
	50%	6.8	2.7	2.5	0.7	15.5	22.9	39.1
	75%	13.7	5.4	5.1	1.5	31.2	45.9	78.6
Bullock's Reach	10%	1.0	0.4	0.4	1.6	3.3	2.1	7.0
	25%	2.8	1.0	1.0	4.5	9.0	5.7	19.2
	50%	6.7	2.5	2.3	10.9	21.8	13.9	46.5
	75%	13.6	5.1	4.7	22.0	43.8	27.9	93.7
Conimicut Point	10%	1.3	0.5	0.4	1.0	2.9	0.3	4.1
	25%	3.5	1.3	1.1	2.7	7.9	0.8	11.3
	50%	8.5	3.2	2.6	6.4	19.1	1.9	27.4
	75%	17.2	6.5	5.2	13.0	38.3	3.8	55.1
North Prudence	10%	1.5	0.6	0.5	0.4	1.2	0.3	1.9
	25%	4.1	1.6	1.3	1.0	3.4	0.8	5.2
	50%	10.0	3.9	3.2	2.4	8.1	2.0	12.4
	75%	20.2	7.8	6.5	4.8	16.3	3.9	25.0
Sally Rock	10%	1.0	0.3	0.3	0.6	0.7	0.1	1.5
	25%	2.8	0.9	0.9	1.8	2.0	0.3	4.0
	50%	6.8	2.3	2.1	4.2	4.8	0.7	9.7
	75%	13.6	4.6	4.2	8.6	9.7	1.3	19.6
Greenwich Bay	10%	1.0	0.4	0.4	0.4	0.9	1.8	3.1
	25%	2.8	1.2	1.2	1.0	2.6	4.9	8.4
	50%	6.9	2.9	3.0	2.3	6.2	11.9	20.4
	75%	14.0	5.9	5.9	4.7	12.4	23.9	41.0
All stations	10%	6.9	2.7	2.4	4.1	11.4	8.0	23.5
	25%	18.8	7.3	6.5	11.1	31.2	22.0	64.4
	50%	45.7	17.6	15.7	27.0	75.5	53.2	155.7
	75%	92.3	35.3	31.5	54.6	151.7	106.8	313.1

Table 8: Individual and Aggregate benefits for Chlorophyll reduction at different water regions in upper Narragansett Bay using Chlorophyll 95th percentile measure

Water Region	Chl concentration reduction	Individual benefits (\$1000)			Aggregate benefits (\$million)			Total aggregate benefits (\$ million)
		<100 meters	100 -750 meters	750-1500 meters	<100 meters	100 -750 meters	750-1500 meters	
Phillipsdale	10%	1.1	0.4	0.4	0.1	2.5	3.6	6.2
	25%	3.0	1.2	1.1	0.3	6.9	9.8	17.0
	50%	7.3	2.9	2.6	0.8	16.8	23.6	41.2
	75%	14.8	5.9	5.2	1.6	33.8	47.4	82.7
Bullock's Reach	10%	1.1	0.4	0.4	1.8	3.6	2.2	7.5
	25%	3.0	1.1	1.0	4.8	9.7	5.9	20.5
	50%	7.3	2.7	2.4	11.7	23.5	14.3	49.6
	75%	14.7	5.5	4.8	23.7	47.3	28.7	99.8
Conimicut Point	10%	1.4	0.5	0.4	1.0	3.1	0.3	4.4
	25%	3.7	1.4	1.1	2.8	8.5	0.8	12.1
	50%	9.1	3.5	2.7	6.9	20.5	2.0	29.4
	75%	18.4	7.0	5.3	13.9	41.3	4.0	59.1
North Prudence	10%	1.6	0.6	0.5	0.4	1.3	0.3	2.0
	25%	4.4	1.7	1.4	1.0	3.6	0.8	5.5
	50%	10.7	4.2	3.3	2.5	8.7	2.0	13.3
	75%	21.6	8.4	6.6	5.1	17.6	4.1	26.7
Sally Rock	10%	1.1	0.4	0.3	0.7	0.8	0.1	1.6
	25%	3.0	1.0	0.9	1.9	2.2	0.3	4.3
	50%	7.3	2.5	2.2	4.6	5.2	0.7	10.5
	75%	14.7	5.0	4.3	9.3	10.5	1.4	21.1
Greenwich Bay	10%	1.1	0.5	0.5	0.4	1.0	1.9	3.2
	25%	3.1	1.3	1.3	1.0	2.7	5.1	8.9
	50%	7.4	3.1	3.0	2.5	6.6	12.3	21.4
	75%	15.0	6.3	6.1	5.1	13.4	24.7	43.1
All stations	10%	7.4	2.9	2.4	4.4	12.3	8.3	25.0
	25%	20.2	7.8	6.7	12.0	33.7	22.7	68.3
	50%	49.0	18.9	16.2	29.0	81.4	54.9	165.3
	75%	99.1	38.1	32.5	58.6	163.7	110.2	332.5

Table 9: Individual and Aggregate benefits for Chlorophyll reduction at different water regions in upper Narragansett Bay using Chlorophyll 90th percentile measure

Water Region	Chl concentration reduction	Individual benefits (\$1000)			Aggregate benefits (\$million)			Total aggregate benefits (\$ million)
		<100 meters	100 -750 meters	750-1500 meters	<100 meters	100 -750 meters	750-1500 meters	
Phillipsdale	10%	1.0	0.5	0.5	0.1	3.1	4.3	7.5
	25%	2.8	1.5	1.3	0.3	8.5	11.7	20.5
	50%	6.9	3.5	3.1	0.7	20.5	28.3	49.5
	75%	14.0	7.1	6.3	1.5	41.2	56.9	99.6
Bullock's Reach	10%	1.0	0.5	0.4	1.7	4.3	2.6	8.6
	25%	2.8	1.4	1.2	4.6	11.9	7.1	23.5
	50%	6.9	3.3	2.9	11.1	28.7	17.2	57.0
	75%	13.9	6.7	5.8	22.5	57.7	34.5	114.7
Conimicut Point	10%	1.3	0.6	0.5	1.0	3.8	0.4	5.2
	25%	3.6	1.8	1.3	2.7	10.4	1.0	14.1
	50%	8.7	4.3	3.2	6.6	25.1	2.4	34.1
	75%	17.6	8.6	6.4	13.3	50.5	4.8	68.6
North Prudence	10%	1.6	0.8	0.6	0.4	1.6	0.4	2.4
	25%	4.3	2.1	1.7	1.0	4.4	1.0	6.5
	50%	10.4	5.2	4.0	2.5	10.7	2.4	15.6
	75%	21.0	10.4	8.0	5.0	21.6	4.9	31.5
Sally Rock	10%	1.0	0.5	0.4	0.7	1.0	0.1	1.7
	25%	2.8	1.2	1.1	1.8	2.6	0.3	4.8
	50%	6.9	3.0	2.6	4.3	6.4	0.8	11.5
	75%	13.9	6.0	5.2	8.8	12.8	1.7	23.2
Greenwich Bay	10%	1.1	0.6	0.6	0.4	1.2	2.2	3.8
	25%	2.9	1.6	1.5	1.0	3.3	6.1	10.4
	50%	7.0	3.8	3.6	2.4	8.1	14.7	25.2
	75%	14.2	7.7	7.3	4.8	16.3	29.6	50.7
All stations	10%	7.0	3.5	2.9	4.2	15.0	9.9	29.2
	25%	19.3	9.6	8.0	11.4	41.1	27.2	79.7
	50%	46.8	23.1	19.4	27.6	99.5	65.8	192.9
	75%	94.7	46.6	39.0	55.8	200.1	132.3	388.2

Table 10: Individual and Aggregate benefits for Chlorophyll reduction at different water regions in upper Narragansett Bay using Chlorophyll 50th percentile measure

Water Region	Chl concentration reduction	Individual benefits (\$1000)			Aggregate benefits (\$million)			Total aggregate benefits (\$ million)
		<100 meters	100 -750 meters	750-1500 meters	<100 meters	100 -750 meters	750-1500 meters	
Phillipsdale	10%	2.6	1.7	1.7	0.3	9.9	15.5	25.8
	25%	7.2	4.7	4.7	0.8	27.3	42.7	70.7
	50%	17.6	11.5	11.5	1.9	66.5	104.1	172.4
	75%	36.2	23.5	23.4	3.8	135.5	212.5	351.9
Bullock's Reach	10%	2.6	1.6	1.6	4.2	13.9	9.4	27.6
	25%	7.1	4.4	4.3	11.6	38.2	25.9	75.6
	50%	17.5	10.8	10.5	28.3	93.1	63.1	184.5
	75%	35.9	22.1	21.5	58.2	189.9	128.8	376.9
Conimicut Point	10%	3.3	2.1	1.8	2.5	12.2	1.3	15.9
	25%	9.1	5.7	4.8	6.9	33.4	3.6	43.8
	50%	22.2	13.8	11.7	16.8	81.3	8.7	106.8
	75%	45.7	28.1	24.0	34.5	165.9	17.8	218.1
North Prudence	10%	4.1	2.6	2.2	1.0	5.3	1.4	7.7
	25%	11.3	7.0	6.2	2.7	14.6	3.8	21.0
	50%	27.6	17.1	15.0	6.5	35.6	9.2	51.3
	75%	56.6	34.9	30.6	13.4	72.7	18.7	104.8
Sally Rock	10%	2.6	1.5	1.4	1.6	3.1	0.5	5.2
	25%	7.2	4.0	3.9	4.5	8.5	1.2	14.2
	50%	17.5	9.7	9.5	11.0	20.6	3.0	34.7
	75%	36.1	19.9	19.5	22.7	42.1	6.2	70.9
Greenwich Bay	10%	2.7	1.9	2.0	0.9	3.9	8.1	12.9
	25%	7.3	5.1	5.5	2.5	10.8	22.2	35.4
	50%	17.9	12.4	13.4	6.1	26.3	54.1	86.4
	75%	36.9	25.4	27.4	12.5	53.6	110.4	176.6
All stations	10%	17.9	11.3	10.7	10.5	48.4	36.2	95.0
	25%	49.2	31.0	29.4	28.8	132.7	99.3	260.8
	50%	120.3	75.4	71.7	70.6	323.4	242.1	636.1
	75%	247.3	153.9	146.3	145.1	659.8	494.3	1299.2

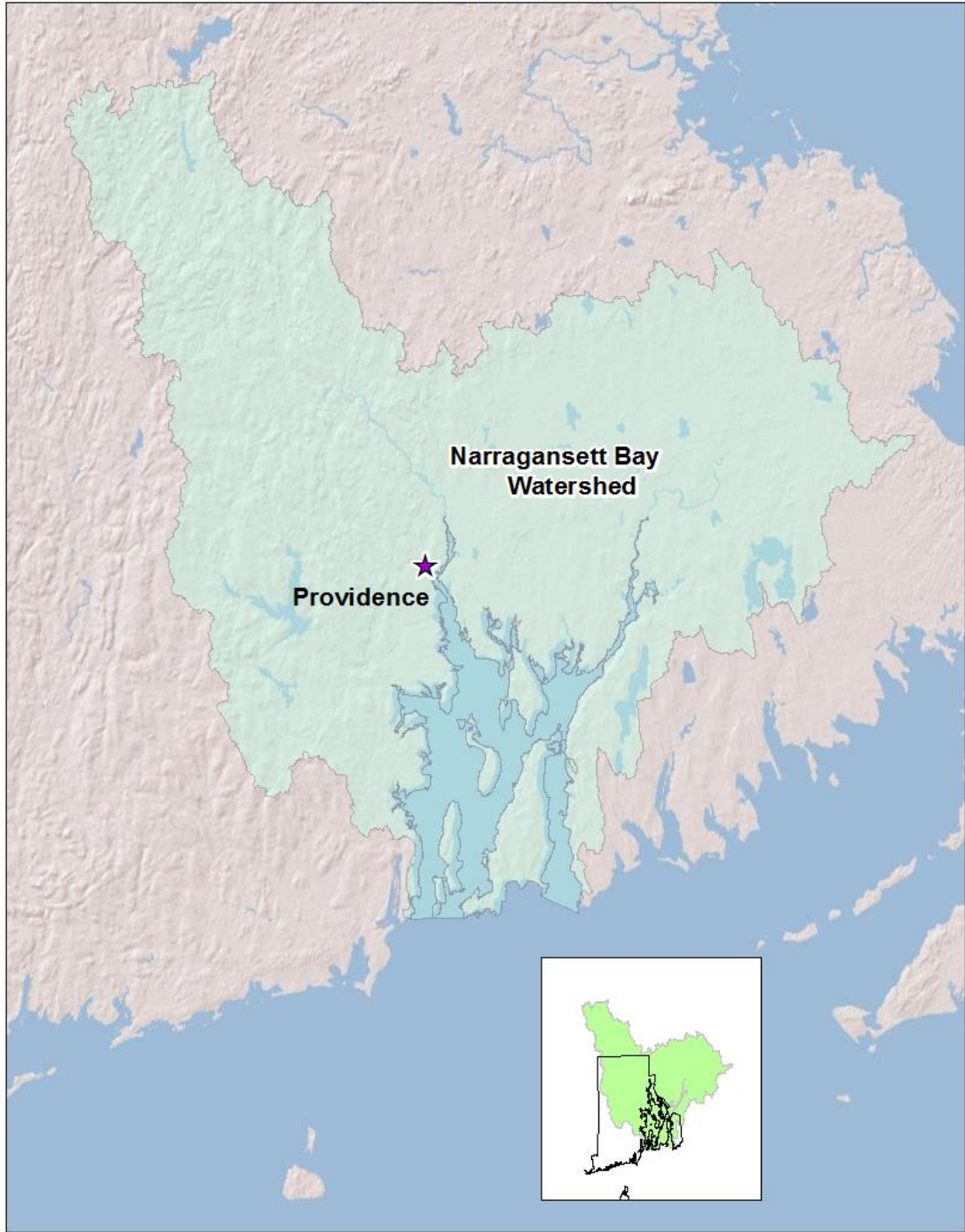


Figure 1: Location map of Narragansett Bay Watershed

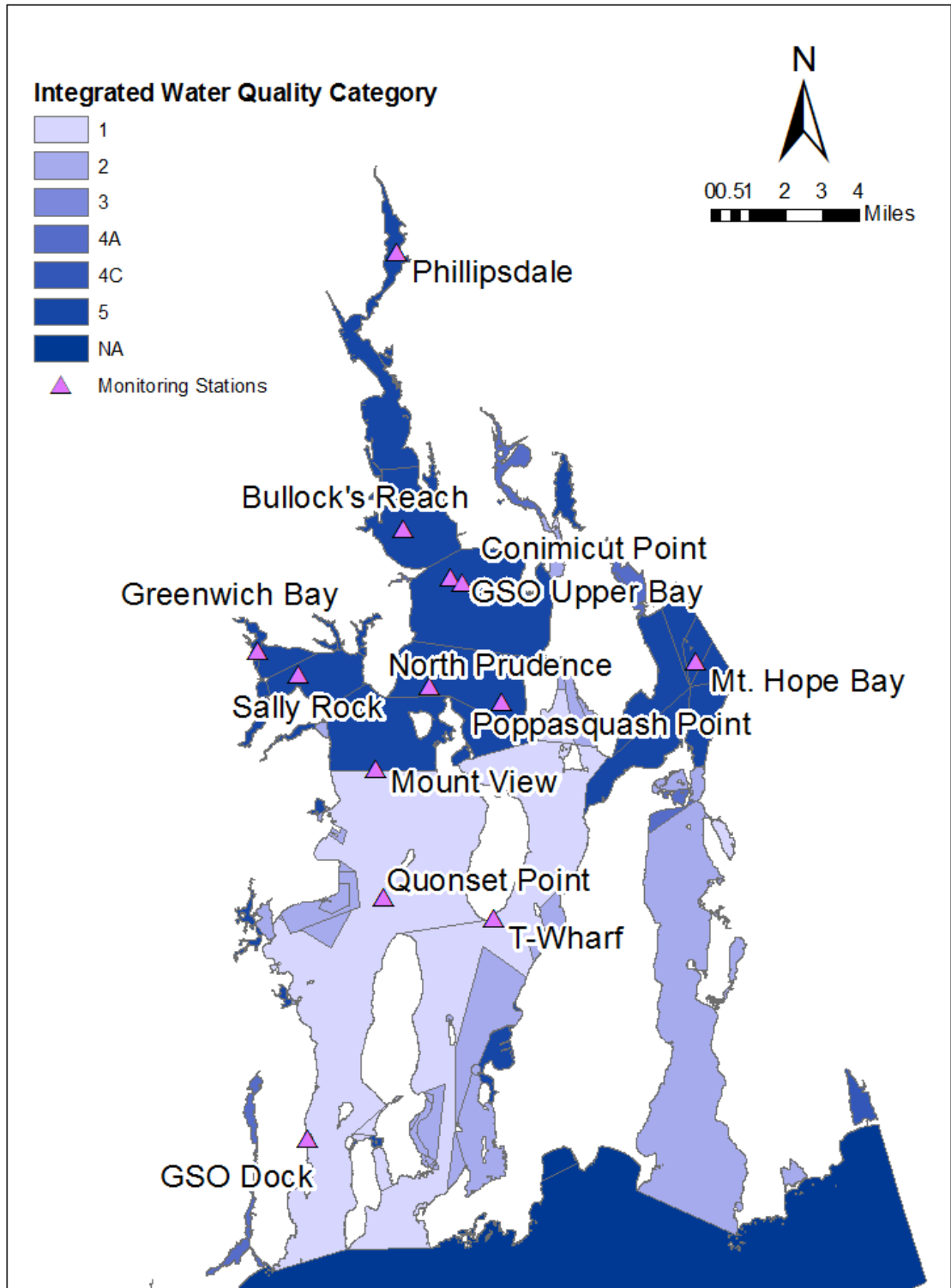


Figure 2: Location map of monitoring stations and water quality sub-regions in Narragansett Bay

Appendix I: The impact of water quality improvement in Narragansett Bay on housing prices

HYPOTHESIS OF CONTROL VARIABLES AND ESTIMATION RESULTS

Most of our control variables such as house characteristics and neighborhood characteristics are also has expected signs and the estimation results are consistent in different models (Model 1-4). For example, Lot size, number of fire places, condition of the house, living area, number of bathrooms, number of half bath, percentage of senior people (age greater than 65) and median household income in the neighborhood all have a positive and significant (1% level) impact on housing prices. Negative and significant variables are distance to the nearest highway exit and it is significant at 1% level. The square terms of lot size are negative and significant (5% level), which means that although lot size has a positive impact on housing prices but influences are getting smaller with the increase of the lot size. The other square term, square of living area also has a negative impact; it is close to the 10% significant level even though it is not significant. It also intends to capture the housing prices are increasing with living area but at a decreasing rate.

Distance to downtown Providence is positive and significant at 5% level, which may seem surprising at first glance. It is not unexpected since it validates the fact that urban sprawl starts from the center of Providence, more development are happening in the area that are more developable. Population density has a negative sign as expected despite the fact it is not significant.

Appendix Table 1: Estimation Results with Different Water Quality Measurements (Full Model)

VARIABLES	log_price			
	(1)	(2)	(3)	(4)
	Chl99	Chl95	Ch90	Chl50
ln(Chlorophyll)	0.007 (0.294)	0.009 (0.332)	0.008 (0.200)	-0.032 (-0.683)
ln(Chlorophyll)^2	-0.001 (-0.180)	-0.001 (-0.244)	-0.002 (-0.177)	0.009 (0.665)
ln(Chlorophyll)*Distance Dummy(<100m)	-0.030** (-1.984)	-0.033** (-2.077)	-0.030** (-1.955)	-0.037* (-1.578)
ln(Chlorophyll)*Distance Dummy(100-750m)	-0.016* (-1.380)	-0.019* (-1.446)	-0.021* (-1.395)	-0.020 (-1.133)
ln(Chlorophyll)*Distance Dummy(750-1500m)	-0.015*** (-3.144)	-0.016** (-3.112)	-0.018** (-3.296)	-0.021*** (-4.186)
Distance Dummy(<100m)	0.301*** (5.614)	0.302*** (5.753)	0.289*** (5.771)	0.283*** (5.167)
Distance Dummy(100-750m)	0.167** (2.489)	0.169** (2.515)	0.172** (2.480)	0.156** (2.500)
Distance Dummy(750-1500m)	0.095*** (4.177)	0.095*** (4.235)	0.097*** (4.367)	0.092*** (4.964)
Distance to the nearest highway exit(mile)	-0.031*** (-4.011)	-0.031*** (-4.001)	-0.031*** (-4.068)	-0.032*** (-4.068)
Distance to downtown Providence(mile)	0.011** (2.433)	0.011** (2.432)	0.011** (2.422)	0.011** (2.412)

Lot size(acres)	0.062** (3.294)	0.062** (3.297)	0.062** (3.312)	0.062** (3.305)
Square of lot size	-0.002** (-2.809)	-0.002** (-2.813)	-0.002** (-2.820)	-0.002** (-2.834)
Number of years since renovation	-0.001** (-3.010)	-0.001** (-3.027)	-0.001** (-3.032)	-0.001** (-3.011)
Number of fireplaces in the building	0.079*** (3.928)	0.079*** (3.928)	0.079*** (3.923)	0.079*** (3.922)
Exterior condition of the house(1 to 11, 1=unsound, 11=excellent)	0.044*** (5.777)	0.044*** (5.749)	0.044*** (5.757)	0.044*** (5.774)
Living area (in 1000 square feet)	0.244*** (5.078)	0.244*** (5.077)	0.244*** (5.070)	0.244*** (5.059)
Square of living area	-0.011 (-1.778)	-0.011 (-1.779)	-0.011 (-1.781)	-0.011 (-1.771)
Number of bathrooms	0.142*** (13.294)	0.142*** (13.295)	0.142*** (13.291)	0.142*** (13.172)
Number of half bath	0.118*** (9.983)	0.118*** (9.999)	0.118*** (10.004)	0.118*** (9.990)
Age (>65) in the neighborhood (%)	0.448*** (8.100)	0.448*** (8.117)	0.447*** (8.141)	0.447*** (8.135)
Population density in the neighborhood(1000 people per square mile)	-0.004 (-0.455)	-0.004 (-0.438)	-0.004 (-0.467)	-0.000 (-0.497)
Median household income in the neighborhood (\$1000,in 2000 dollars)	0.004*** (5.520)	0.004*** (5.520)	0.004*** (5.513)	0.003*** (5.522)

Year Dummy (Year=1993)	-0.033* (-2.152)	-0.033* (-2.161)	-0.033* (-2.177)	-0.032* (-2.123)
Year Dummy (Year=1994)	-0.063*** (-6.252)	-0.032* (-2.077)	-0.032* (-2.086)	-0.031* (-1.965)
Year Dummy (Year=1995)	-0.032* (-2.066)	-0.063*** (-6.346)	-0.063*** (-6.442)	-0.062*** (-6.855)
Year Dummy (Year=1996)	-0.048** (-2.823)	-0.048** (-2.801)	-0.048** (-2.818)	-0.048** (-2.647)
Year Dummy (Year=1997)	-0.078*** (-4.781)	-0.078*** (-4.816)	-0.078*** (-4.897)	-0.078*** (-4.807)
Year Dummy (Year=1998)	-0.045 (-1.763)	-0.045 (-1.758)	-0.045 (-1.767)	-0.044 (-1.657)
Year Dummy (Year=1999)	0.006 (0.397)	0.006 (0.386)	0.006 (0.373)	0.007 (0.394)
Year Dummy (Year=2000)	0.098*** (5.092)	0.098*** (5.053)	0.097*** (5.033)	0.098*** (4.765)
Year Dummy (Year=2001)	0.263*** (6.218)	0.263*** (6.192)	0.263*** (6.220)	0.264*** (5.974)
Year Dummy (Year=2002)	0.431*** (17.645)	0.431*** (17.641)	0.431*** (17.651)	0.432*** (17.703)
Year Dummy (Year=2003)	0.615*** (64.102)	0.615*** (63.778)	0.614*** (63.429)	0.615*** (61.249)

Year Dummy (Year=2004)	0.768*** (66.145)	0.768*** (65.251)	0.767*** (64.319)	0.768*** (58.017)
Year Dummy (Year=2005)	0.895*** (62.304)	0.895*** (62.484)	0.894*** (61.883)	0.895*** (63.293)
Year Dummy (Year=2006)	0.887*** (73.408)	0.888*** (73.346)	0.887*** (72.111)	0.889*** (72.450)
Year Dummy (Year=2007)	0.845*** (41.144)	0.845*** (41.410)	0.844*** (40.843)	0.846*** (41.648)
Year Dummy (Year=2008)	0.697*** (29.988)	0.697*** (29.694)	0.697*** (29.484)	0.697*** (27.718)
Year Dummy (Year=2009)	0.575*** (17.666)	0.574*** (17.603)	0.574*** (17.494)	0.575*** (16.979)
Year Dummy (Year=2010)	0.626*** (33.989)	0.626*** (33.724)	0.626*** (33.791)	0.627*** (31.971)
Year Dummy (Year=2011)	0.663*** (38.199)	0.663*** (38.106)	0.663*** (38.533)	0.664*** (38.729)
Year Dummy (Year=2012)	0.528*** (29.684)	0.528*** (29.372)	0.527*** (29.474)	0.529*** (27.013)
Town Dummy (Town=Bristol)	-0.150** (-2.888)	-0.152** (-3.003)	-0.158** (-3.277)	-0.165** (-3.467)
Town Dummy (Town=Cranston)	-0.120** (-2.879)	-0.122** (-3.025)	-0.122** (-3.034)	-0.121** (-3.015)
Town Dummy	-0.170***	-0.171***	-0.171***	-0.170***

	(Town=East Providence)	(-6.281)	(-6.676)	(-6.701)	(-6.715)
	Town Dummy (Town=North Kingstown)	-0.121* (-1.999)	-0.123* (-2.032)	-0.123* (-2.021)	-0.121* (-1.951)
	Town Dummy (Town=Providence)	-0.240*** (-6.222)	-0.242*** (-6.532)	-0.242*** (-6.533)	-0.241*** (-6.512)
	Town Dummy (Town=Warwick)	-0.221*** (-7.447)	-0.222*** (-7.791)	-0.222*** (-7.816)	-0.222*** (-7.778)
	Town Dummy (Town=Warren)	-0.132** (-3.124)	-0.134** (-3.149)	-0.134** (-3.127)	-0.132** (-3.021)
206	Observations	13,959	13,959	13,959	13,959
	R-squared	0.780	0.780	0.780	0.780

Notes: Chl99, Chl90, Chl90, and Chl50 are different measurements of water quality parameter, and they represent Chlorophyll concentration at 99th, 95th, 90th, and 50th percentile respectively. All the models control for town fixed effects and time fixed effects in the estimation. Robust t statistics are in parentheses. The stars (***) p<0.01, ** p<0.05, * p<0.1) indicate level of significance

Appendix II: Calculation of aggregated welfare change

1st way:

$$\frac{\partial Price_{it}}{\partial WQ_i} = \frac{Price_{it}}{WQ_i} (\beta_1 + 2\beta_2 \ln(WQ_i) + \beta_3 Distance_i) \quad (1)$$

$$\Delta W = \sum_{i=1}^n \int_{WQ_0}^{WQ_1} \left(\frac{\partial Price_{it}}{\partial WQ_i} \right) d(WQ) \quad (2)$$

Plug equations (6) into (11), we can get

$$\Delta W = \sum_{i=1}^n \int_{WQ_0}^{WQ_1} \left(\frac{Price_{it}}{WQ_i} (\beta_1 + 2\beta_2 \ln(WQ_i) + \beta_3 Distance_i) \right) d(WQ) \quad (3)$$

If we move $\frac{1}{WQ_i}$ outside of parentheses, and move it into $d(WQ)$,

$$\begin{aligned} \Delta W &= \sum_{i=1}^n \int_{WQ_0}^{WQ_1} (Price_{it} (\beta_1 + 2\beta_2 \ln(WQ_i) + \beta_3 Distance_i)) d(\ln(WQ)) \quad (4) \\ &= \sum_{i=1}^n \int_{WQ_0}^{WQ_1} (e^{(\ln(Price_{it}))} (\beta_1 + 2\beta_2 \ln(WQ_i) + \beta_3 Distance_i)) d(\ln(WQ)) \end{aligned}$$

$$= \sum_{i=1}^n \int_{WQ_0}^{WQ_1} \left(e^{\left(\beta_0 + \beta_1 \ln(WQ_i) + \beta_2 [\ln(WQ_i)]^2 + \beta_3 \text{Distance}_i * \ln(WQ_i) + \beta_4 \text{Distance}_i + \beta_5 * H_i + \beta_6 * N_i + \beta_7 * \text{Town}_i + \beta_8 * \text{Year}_i + \varepsilon \right)} (\beta_1 + 2\beta_2 \ln(WQ_i) + \beta_3 \text{Distance}_i) \right) d(\ln(WQ))$$

$$= \sum_{i=1}^n \int_{WQ_0}^{WQ_1} d \left(e^{\left(\beta_0 + \beta_1 \ln(WQ_i) + \beta_2 [\ln(WQ_i)]^2 + \beta_3 \text{Distance}_i * \ln(WQ_i) + \beta_4 \text{Distance}_i + \beta_5 * H_i + \beta_6 * N_i + \beta_7 * \text{Town}_i + \beta_8 * \text{Year}_i + \varepsilon \right)} \right)$$

$$= \sum_{i=1}^n \int_{WQ_0}^{WQ_1} d \left(e^{\ln(\text{Price}_{it})} \right)$$

$$= \sum_{i=1}^n (e^{\ln(\text{Price}_{it}(WQ_1))} - e^{\ln(\text{Price}_{it}(WQ_0))}) \quad (14)$$

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2nd way: From equation (9),

$$\Delta W = P(H, N, WQ_1) - P(H, N, WQ_0) \quad (9)$$

$$\Delta W = \sum_{i=1}^n (e^{\ln(\text{Price}_{it}(WQ_1))} - e^{\ln(\text{Price}_{it}(WQ_0))}) \quad (14)$$

CONCLUSION

Since mid-1960s, King (1966), Krutilla (1967) and other economists has started the ecosystem related research, including the concept, function and valuation. Recently, there has been an exponential growth in the number of published papers on ecosystem services and related topics (Fisher et al. 2009). Traditionally, among most ecosystem services related studies, ecologists and other scientists are working on biophysical processes through which ecosystem produce outcomes that are valued by society (Brown et al. 2007, Carpenter et al. 2009, Daily 1997). Economists, on the other hand, focus more on the valuation of ecosystem goods and services using non-market valuation methods (Bauer and Johnston, 2013).

In contrast to earlier studies of ecosystem services, more recent studies emphasize both the biological outcomes and economic valuation of ecosystem services (Wainger and Mazzotta 2011). This research is among recent attempts to integrate ecological process, such as water quality, and quantity, and crop yield using a spatial explicit hydrological model, Soil Water Assessment Tool (SWAT) with economic valuation in first manuscript. Mapping approach helps visualize the tradeoff and heterogeneity in providing ecosystem services within the watershed. It can be informative for policymakers to decide where to prioritize conservation investments to get the “biggest bang for the buck”.

I use two non-market valuation methods to simulate potential change due to land use change, climate change, and change in management practices. Benefit transfer studies, which is always referred as the second best approach, are often criticized since people’s willingness to pay for particular ecosystem service may vary across sites and

even time specific (National Research Council, 2004). Errors may occur if researchers rely on the prior studies and transfer others' estimates directly into their own analysis. In manuscript one, benefit transfer method serves as a low cost screen technique for further valuation studies. In manuscript three, hedonic housing price method is used to examine the impact of water quality on housing prices. Individuals can choose their effective consumption of public goods and environmental quality (water quality), among other factors, through housing choices (Freeman, 2003). Through price differentials, I estimate the marginal benefits due to a marginal change in water quality.

I acknowledge the caveats in research on quantification and valuation the changes in ecosystem services, and assessment on the effectiveness of policy for land use management. For example, in my first manuscript I only include relevant ecosystem services and do not provide a complete accounting of all private and public benefits and costs associated with land uses in the watershed examined such as timber production, biodiversity, carbon sequestration and crop pollination. Any application of my method would need to include those ecosystem services deemed relevant to the land uses and policy context of interest.

In manuscript two, I only had access to zoning information from 17 out of 39 towns and municipalities in Rhode Island and this data set is also limited to cross-sectional information on the most recent digitized zoning ordinances. However, my study is still valid even though there have been changes in the terms of subdivision for residential zoning. First, residential zoning has been largely stable across time (Personal Communication with Nancy Hess, 2013). Moreover, zoning tends to be "sticky". A comparison of bylaws over time for a sample of jurisdictions reveals that the

fundamentals of zoning bylaws – such as the establishment of zoning districts or the uses allowed in those districts – are altered very rarely, perhaps only once every 20 to 30 years (Schuetz, 2007). Future direction of examining the effectiveness of zoning and its spillover effect will take into account of the dynamics between land use land cover change and zoning regulations accordingly.

Despite all the limitations, this research presented in the dissertation provides some insights from modelling production of ecosystem services, tradeoff analysis to valuation of ecosystem services through hedonic housing price approach. This research integrates biological process, such as hydrological modelling, and scenarios analysis into empirical analysis. Additionally, the three manuscripts provide a starting point for government officials to enhance ecosystem services through land use planning, management, nutrient reduction programs.

Further research is needed on homebuyers' perception of ecosystem services in order to improve land use management and achieve sustainable development. Since the perception of ecosystem goods and services can vary by person, better understanding the people's awareness may provide more insights on implicit marginal price and potential benefits.

We would also like to account for uncertainty in quantifying ecosystem services in a landscape in future work, so that policymakers can make more effective policies and they can adapt management approaches in the face of uncertainty. Most previous research has ignored the uncertainty associated with modeling of production of ecosystem services and future land use scenarios with the exception of a handful of studies that have valued ecosystem services with uncertainty (Daily and Matson, 2008; National Research

Council, 2004; Johnston et al, 2012). However, if the uncertainty in the biophysical production of ecosystem services is substantial, it may influence the validity of uncertainty analysis in the valuation of ecosystem services.

Another future research direction is to incorporate the endogeneity of land use decision in examining the impact of the land use change on ecosystem services. Potentially by linking the manuscript 1 and manuscript 2, a more informative production of ecosystem services could be simulated.

Overall, the research presented in this dissertation provides some insights on how to examine the effectiveness of policy for land use management. It also gives simple illustrations of modeling the production of multiple ecosystem services and estimate potential impacts and welfare changes due to the change in ecosystem services at watershed level.