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Working Paper Series

Working Paper # 15-02
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**Abstract**: While the mean global sea level has climbed by an average of 3.2 mm/year since 1993—and is projected to increase another 0.18 – 0.82 meters by 2100—coastal populations have continued to expand. Coastal communities may be compelled to adapt to these competing forces, and at an increasing frequency in the near future. This paper explores the property price impact of several adaptation structures that can help bolster the shoreline and protect homes from sea level rise (SLR) in Anne Arundel County, MD. Our study uses a novel dataset on coastal features that is very spatially explicit, and contains the location of all adaptation structures. We also use maps of SLR zones to explore how property price impacts vary depending on vulnerability to sea level rise.

Results indicate that sea level rise and adaption structures, such as bulkheads and rip-raps, can have a significant impact on waterfront home prices, with the impact varying across risks and type of adaption structure. A home located in the most threatened SLR zone that is unprotected by an adaptation structure sells for 19-23% less, on average. On the other hand, homes in threatened SLR zones with certain adaptation structures see a 21% increase in property price, approximately compensating for the threatened location. Since sea level in the Chesapeake Bay is projected to rise approximately two feet over the next century, the results here suggest that property markets are incorporating this information. Our results should be useful to policy makers, developers, insurers, and other parties involved in coastal management, who trade off the costs and benefits of development and adaptation.
**Keywords**: Sea level rise, hedonic regression, coastal resources, environmental economics, benefit cost analysis, valuation.

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## I. Introduction/Background

Coastal areas are facing two transformative forces. On the one hand, global sea level has climbed by an average of 3.2 mm/year since 1993, and is projected to increase by another 0.26 – 0.82 meters by 2100.[1][2] On the other hand, the projected increase in US coastal shoreline population density from 2010-2020 is 37 additional people per square mile, compared to 11 people/sq mi in the US as a whole.[3] So there will be more people living in a shrinking area.

Accelerating sea level rise (SLR) is causing novel challenges along the US coast. North Carolina attracted national interest in recent debates over SLR. After state scientists identified 39 inches as the official SLR forecast by 2100, business and lobbying firms organized massive efforts to block any state zoning or planning policy that used the 39 inch SLR zone. Residents within that zone described it as a "death sentence for ever trying to sell your home."[4] The state is now considering only 30 year forecasts for planning purposes.

This paper examines some of the economic impacts of adapting to SLR and related challenges such as storm surges and flooding in the Chesapeake Bay area. Adaptation is an important local topic, since SLR in the Bay has been double the global average, and is believed to be increasing (Sallenger et al., 2012). Our specific focus is on Anne Arundel County, which is about 15 miles east of Washington, DC, and is bordered by the Chesapeake Bay on the East and the Patuxent River on the west, resulting in approximately 530 miles of shoreline. In fact, almost two-thirds of the County's residents live within two miles of the Bay's tidal waters (Nuckols et al., 2010).

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[1] IPCC 2014 Climate Change 2014 Synthesis Report, Intergovernmental Panel on Climate Change, http://www.ipcc.ch/report/ar5/syr/, accessed Dec. 2014.
[2] According to more recent research (Hay et al., (2015), this may actually be a significant underestimate.
[3] NOAA's State of the Coast: http://stateofthecoast.noaa.gov/population/welcome.html, accessed Jan. 2014.
[4] *The Washington Post* "On NC's Outer Banks, Scary Climate-Change Predictions Prompt a Change of Forecast." June 26, 2014.

The results of a recent survey (Akerlof, 2012) in Anne Arundel County indicate that 55% of county residents believe that sea-level rise is occurring and that coastal flooding has become more of a problem in recent years. Furthermore, a recent report (MD DNR, 2011) estimates that 2,193 acres in Anne Arundel, valued at almost $3 billion, would be threatened by a SLR of 2 feet.[5] Nuckols et al., (2010) project that, given the amount of urbanized and high-value land in Anne Arundel, as well as current coastal policies, development trends, and shoreline practices (Figure 1), 68% of the shoreline is "almost certain" to be protected from SLR using approaches such as shoreline armoring, elevating land, or beach nourishment.

Given the amount of future adaptation projected in this area, as well as the broader coastal areas in the US, it is important to start examining the associated economic impacts. This paper looks at the property value impacts from a subset of adaptation structures. We hypothesize that if local residents perceive risks from SLR, then the potential for adverse outcomes should be capitalized in property values. Further, if such risks are mitigated by the presence of adaption structures, all else constant, protected property values should reflect a premium.

There are a wide variety of ways to protect shoreline from flooding, storm surge, and SLR, including both structural and non-structural approaches, such as wetlands. We focus on the structural measures used most commonly in the Chesapeake Bay area: bulkheads, ripraps, and groinfields. Bulkheads and ripraps in particular are widely deployed in Anne Arundel County, and these and other structures will likely play a part in future protection, particularly in developed areas. We utilize a novel and spatially explicit GIS dataset of structural adaption measures in the Chesapeake Bay that was jointly developed by the Virginia Institute of Marine

[5] Of course this $3 billion figure is not necessarily the value lost from a 2 foot rise in SLR. Making such claims would require assumptions that inundated lands have zero value, current land uses and assessed values remain constant given no SLR, and that the hedonic equilibrium does not adjust (for example, inland parcels that become waterfront do not increase in value). The actual loss could be greater or less.

Science (VIMS), the Maryland Department of Natural Resources (MD DNR), and the National Oceanic and Atmospheric Agency (NOAA). Adaption structures were mapped and catalogued using GPS units and cameras during detailed surveys conducted from boats traveling along the entire shoreline. These features were then verified and augmented using satellite imagery.

Our results indicate that certain types of adaption structures can yield a significant property price increase. These impacts are found to be strongest in areas threatened by SLR. The property market appears to be incorporating the threat of SLR, although this effect is likely not exclusive because of the protection offered from existing threats like flooding and storm surges. Although previous literature has examined flood zone and hurricane-related impacts on property values, this is the first study to specifically examine adaptation to SLR.

## II. Literature Review

Sea level rise and other impacts of climate change have received some previous interest in the hedonics literature. Beach erosion, flood zones, and general climate conditions have been examined, and large shoreline protection structures (dikes) have been analyzed at the regional level. However, our paper is the first to examine the impact of adaptation structures and the risk of SLR on individual homes.

Several studies have examined coastal property damage using relatively simple approaches that calculate rough estimates of real estate damages using assessed values rather than hedonic or other regression-based models (Yohe et al., 1995; Darwin and Tol, 2001). A more recent paper (Bin et al., 2011) takes a spatially explicit approach to the costs of SLR in North Carolina by using satellite-based LIDAR data and the assessed values of individual homes. Michael (2007) expands this literature by illustrating that the values of inundated properties may only be a portion of the total damages of SLR. In three Chesapeake Bay communities, he finds that episodic flooding associated with rising seas can cause 9 to 28 times more damage than the value of inundated properties, but he does not consider how adaptation can lessen such damages.

The preceding papers show that there could be substantial damages associated with living in areas threatened by SLR. However, the hedonic literature investigating residents' responses to these threats is somewhat sparse. Dorfman et al., (1996) look at the risk reduction provided by large concrete structures used to reduce erosion. They use stated preference results to calculate a measure of erosion risk that accounts for the structures, and they find that the risk variable is negatively related to home prices. Landry et al., (2003) also examine erosion protection structures in a hedonic property analysis but find statistically insignificant results.[6] Finally, Hamilton (2007) examines the impact of dikes, which may deter damages from SLR and erosion, on average nearby county hotel prices. The structures have a negative impact on hotel prices, but since there is a tradeoff between these structures (measured in aggregate at miles of structure) and recreational beaches, these impacts on average hotel price are not too surprising..

Another topic related to SLR is flood zones, which are projected to expand as the water level rises. Early papers found it difficult to disentangle the benefit of living close to the water from the impact of flood zones (Bin and Kruse, 2006). However, later papers use more sophisticated GIS techniques to isolate individual properties, and find that, all else equal, flood zones do negatively impact home values (Bin et al., 2008a). Bin et al., (2008b) find that the capitalized price differentials from living in flood zones are approximately equivalent to insurance premiums. Daniel et al. (2009) conduct a meta-analysis on hedonic studies of flood risk, and find that an increase in flood risk of 1% in a year corresponds to a -0.6% decrease in transaction price. Finally, Bin and Landry (2013) use difference-in-difference methods to

[6] Other erosion-related papers, which look at beach width, include Landry and Hindsley (2011) and Ranson (2012).

examine flood zone impacts to property values before and after hurricanes. Although they find significant impacts from hurricanes, the effect diminishes over time, suggesting that home buyers may not have full information about flood zone locations.

## III. Data

We use property sales data from Anne Arundel County, MD, which were obtained from MD PropertyView (a state manager of sales data). These data include a wealth of information on each home, such as structural characteristics (for example, square feet and number of bedrooms), land characteristics (e.g. lot size, zoning information), as well as GIS maps that allow the parcels to be matched to a variety of other location-based attributes. Since the focus is on shoreline adaptation structures, we narrow our focus to all waterfront property sales from 2003-2007.

The data on adaptation structures comes from a joint program between the Virginia Institute of Marine Science (VIMS), the Maryland Department of Natural Resources (MD DNR), and the National Oceanic and Atmospheric Agency (NOAA). Data were obtained during 2004-2006 by navigating the entire coastline of the Chesapeake Bay and its major tributaries in small shoal draft vessels, parallel to the shore. Onboard the vessels GPS units and cameras were used to catalog shoreline features and location; these observations were later cross checked with satellite images. This resulted in a comprehensive GIS database of the shoreline and its attributes, with several layers focusing on shoreline adaption structures. This dataset is a particular strength of our analysis, as it contains a spatially explicit accounting of the local shoreline. The data are basically a snapshot of the shore during this three-year period, so we know what was in existence at that time, but unfortunately we do not know the age of the structures. We therefore limit the property sales to a window around those three years. Figure 2 contains a map of the Severna Park area, which has quite a few structures. The waterfront homes we analyze are the black dots and the structures are represented by various colored lines.

The four types of adaptation structures used in this area are breakwaters, groinfields, riprap revetments, and bulkheads. Breakwaters are structures that sit parallel to the shore and generally occur in a series, looking like a dashed line along the shore from overhead, as illustrated in the top left picture in Figure 3. However, due to their extremely low number in our sample, we are not able to analyze this structure.

Groinfields sit perpendicular to the shore and also normally occur in a series, as shown in the top right picture of Figure 3. They are designed to trap sediment moving along the shore, and they can offer protection to the area behind the system. Individual parts of groinfields can resemble stone jetties. Their effectiveness is heavily dependent on proper setup and local conditions (Barnard, 1993). Also, in many cases the immediate downstream area next to the groinfield experiences a net loss of beach, as seen on the bottom of the groinfield picture in Figure 3.

Riprap revetments sit directly along the shore and are typically composed of large rock deposits, and look like stream armoring projects common in many rural areas. They are meant to withstand wave energy and prevent erosion. Riprap also provide habitat benefits as several species of crab, fish, and other animals are known to use them as shelter (Barnard, 1993).

Finally, bulkheads are wood, steel, or plastic walls designed to withstand incoming waves. The bulkhead pictured in Figure 3 is a smaller wood variation. They are vertical structures built slightly seaward and backfilled with suitable fill material. Bulkheads are designed to prevent erosion and related problems. Although some variations of bulkheads in high wave areas can cause erosion on their unprotected sides, it is common to build them with “return walls" on the sides to minimize this problem. A wooden bulkhead has an average lifespan of 20-25 years, although steel and concrete version can last much longer (Barnard, 1993).

All four adaption structures are classified by hydrologists and ecologists into two categories. Breakwaters and groinfields are considered offensive structures, while ripraps and bulkheads are classified as defensive structures. Generally speaking, defensive structures are designed to armor or protect the shoreline from the rising water and incoming waves, whereas offensive structures are designed to work with the natural currents to reduce erosion and adverse impacts. It is difficult to compare the effectiveness of the various structures since that depends on a complex interaction of local water, soil, elevation, and other conditions, as well as proper construction parameters. Offensive and defensive structures can also be used in tandem to armor the same sections of shoreline. However, bulkheads are probably the least environmentally preferred, as they fix the shoreline and provide minimal habitat. Ripraps, which also fix the shoreline, have habitat benefits, and tend to absorb wave energy, as compared to bulkheads, which reflect it. However, bulkheads can support boating and attached docks, whereas the other types of structure do not. Breakwaters are also environmentally preferred, since they provide habitat, can create marsh behind them, and extend the shoreline.

These structural shoreline protection approaches contrast nonstructural approaches like planting native wetland vegetation. Structural approaches, particularly bulkheads and seawalls[7], can exacerbate erosion at nearby shore areas by disrupting sediment transport and increasing wave reflection (NRC, 2007). The cumulative impacts of regional-scale shoreline "hardening" are understudied but can include loss of intertidal and beach habitat (NRC, 2007). Groinfields and breakwaters can be designed to allow some movement of sand along the shore and to

[7] Seawalls are similar to bulkheads but can withstand greater wave energy and are typically build along oceanfront property (NRC 2007).

minimize habitat destruction. Structural approaches typically have higher upfront costs than non-structural methods, though ongoing maintenance costs may be lower. Despite their drawbacks, structural approaches are more effective than non-structural at protecting shorelines in areas with greater wave energy, deeper water, and higher rates of erosion (Luscher and Hollingsworth, 2007).[8]

Structural approaches were most common during the 20th century, but state policies have promoted non-structural approaches in recent decades because they offer benefits such as riparian habitat protection and reduced sediment runoff. Maryland issued regulations effective in 2013 implementing the state's Living Shorelines Protection Act of 2008 (Annotated Code of MD, 2013). While the state previously encouraged the use of tidal wetland vegetation for shoreline stabilization, the new regulations required it wherever technologically and ecologically feasible. Structural approaches are now only allowed in designated areas or through a waiver process. Where allowed, structural approaches must be considered in the following order of preference: beach nourishment; breakwater; groin or jetty; revetment; and bulkhead. New bulkheads are only permissible when all other non-structural and structural approaches are infeasible.

Due to data limitations, we are only able to evaluate the impact of bulkheads, riprap, and groinfields on property values. The effect of non-structural protection approaches remains an area for further research. It is worth noting that our data on adaptation structures were collected prior to the 2013 regulations that sharply restricted the use of structural approaches to shoreline protection. Also, while the 2013 regulations limit the construction of new structural projects, the existing stock will continue to influence home prices for some time.

[8] It is quite difficult to obtain information on the origin of the structures and who paid for them. Although there are some publicly funded adaptation structures, local County contacts indicated that most of them were built by either property developers or added privately later.

The SLR zone data were produced in a joint project between NOAA, the MD Commission on Climate Change, and Towson University. High resolution LIDAR data and data from NOAA tidal stations (for mean sea level determinations) were used to produce GIS maps of the inundation zones of a vertical 2 or 5 foot rise in sea level. Figure 4 contains a map of these zones and illustrates the magnitude of the problem in Anne Arundel County, and Figure 2 illustrates a close-up of these zones in Severna Park. Additionally, FEMA floodzone maps, provided by MDpropertyView, are used to create dummy variables indicating homes facing a 1% annual flood risk (at current sea levels).

Based on location, homes were matched to SLR zones, flood zones, and adaptation structures,[9] as well as land use, census, and other location-based data (such as distance to Baltimore) in ArcGIS. These location-based characteristics supplement the numerous housing structure attributes used to define a housing bundle. Table 1 contains descriptive statistics of the final property sales dataset, which entails 2,846 transactions of single-family homes and townhomes located on the waterfront. Since focus is drawn to waterfront homes, the average price is relatively high at $817,393. The majority of homes are in medium-density areas and border water with an average depth of 1.7 m. Also, the average home age is 35 years, 11% of the sample is townhomes, 4% have a pool, and 24% have a pier (or similar structure). After 2005-2006, home sales start to decline in the area, illustrating the impact of the recession (a topic we investigate in detail later).

With respect to the SLR variables, only 4% and 10% of transactions are of homes in the 2 foot and 5 foot SLR zones, respectively. Fifty seven percent of homes are located in front of at least one adaptation structure, predominantly bulkheads (35%) and ripraps (23%). Among our sample of waterfront home sales, 20% are bulkhead neighbors (but do not have their own

[9] Thiessen polygons were used to determine adjacency to adaption structures in ArcGIS.

bulkhead), and 26% are riprap neighbors (but do not have their own riprap). About 5% of observations neighbor both a riprap and a bulkhead (but do not have their own structure). Table 2 illustrates the distribution of structures across homes by SLR zone. Bulkheads are the most common structure in the 2 foot SLR zone, whereas groinfields are quite rare. In fact, groinfields only occur in combination with defensive structures in the 2 foot and 5 foot SLR zones.

## IV. Methods

The hedonic property value model is based on the idea that the price of a home is a function of its characteristics. The model used in this paper sorts characteristics into home structural characteristics (H), location-based and neighborhood characteristics (N), and the environmental variables of interest (S and Z). The central model appears in equation (1), where the price enters in log form, as is common in the hedonic literature[10]:

$$\ln(P) = \beta_0 + \beta_H \mathbf{H} + \beta_N \mathbf{N} + \beta_S \mathbf{S} + \beta_Z \mathbf{Z} + \sum_{A=1}^{An} \sum_{R=1}^{Rn} \beta_{AR} S_A Z_R + \gamma \mathbf{T} + \delta \mathbf{F} + \varepsilon \tag{1}$$

The vectors **T** and **F** represent time dummies and spatial fixed effects, and **S** and **Z** are vectors denoting the presence of the different adaption structures or being located in an SLR zone, respectively. The coefficients of particular interest are $\boldsymbol{\beta}_S$, which represents the impact of an adaption structure, and $\boldsymbol{\beta}_Z$, which is the impact of being located in an SLR zone.

Additionally, we employ a difference-in-difference (DID) approach where the "treatment" we are looking at is the presence of an adaptation structure on homes in SLR zones, and thus where SLR is a particular threat. Since the data include more than one SLR zone and structure, the situation is somewhat more complicated than usual. Nonetheless, for a particular combination of SLR zone and structure, homes outside of the SLR zones can be thought of as the

[10] Double log specifications, where the non-dummy independent variables appear in natural log form, were also explored and had the same qualitative results with respect to the variables of interest.

"control group." Because we do not have the exact counterfactual for the treatment—the same home during the same time that did not have a structure – we compare other homes between treated and untreated populations, conditional on all observables noted in equation 1. The first differencing can be denoted as ($P_{S,\,NSLR}$ – $P_{NS,\,NSLR}$), where S and NS refer to structure and no structure, and NSLR refers to not being in an SLR zone. This first difference is captured by $\beta_S$ in equation 1. In order to better isolate the impacts of an adaption structure in the SLR zone, we look at a second differencing, or the difference-in-difference, which is ($P_{S,\,SLR}$ – $P_{NS,\,SLR}$) – ($P_{S,\,NSLR}$ – $P_{NS,\,NSLR}$), where SLR denotes being in an SLR zone. This DID estimate is captured by $\beta_{AR}$. So the total impact of having a structure when a home is located in an SLR zone is $\beta_S + \beta_{AR}$, and is simply $\beta_S$ for homes located outside of SLR zones. Our hypothesis is that homes in the SLR zones have a higher value for adaption structures, and so we expect $\beta_{AR} > 0$. This DID framework allows for a thorough investigation into the housing market's incorporation of SLR threats and approaches to mitigate those threats. Note that we only include SLR interactions terms for the bulkhead and riprap structures due to insufficient home transactions with groinfields in the 0-2 and 2-5 foot SLR zones.

We also pursue a second specification that includes "neighbors" of adaptation structures. As mentioned above, there may be some externality effects associated with the structures. Living not directly adjacent, but next door, to an adaptation structure could have an impact on your shoreline. The impact may be positive or negative, depending on the construction of the structure, the shape of the coastline, strength and direction of the current (which may vary with the tide), and several other factors. As it is not possible to accurately capture all of these directional effects, we include a dummy variable indicating whether a home is a neighbor to either a bulkhead or riprap.[11] (We do not investigate groinfield neighbors in the regression due to the small number of observations for this category.) Equation 2 illustrates the inclusion of the neighbor variables (NE):

$$\ln(P) = \beta_0 + \beta_H \mathbf{H} + \beta_N \mathbf{N} + \beta_S \mathbf{S} + \beta_Z \mathbf{Z} + \sum_{A=1}^{An} \sum_{R=1}^{Rn} \beta_{AR} S_A Z_R + \beta_{NE} \mathbf{NE} + \gamma \mathbf{T} + \delta \mathbf{F} + \varepsilon \qquad (2)$$

The price variable has been adjusted by the Federal Housing Finance Agency's (FHFA) seasonally adjusted house price index to control for general trends in the real estate market. We also present three specifications that vary according to fixed effects. Legislative (according to the six local legislative areas in the County[12]), Census Tract (51 different Tracts represented), and Census Block Group (131 different Block Groups in the sample) fixed effects are used.

There have been concerns with the impact of the recent financial crisis on hedonic studies (Boyle et al., 2012), and there is no general consensus on how to treat hedonic estimates in the rise of a real estate bubble. Since our data occur during that time, we pursue several analyses recommended by Boyle et al. (2012). First, Figure 5 contains a graph of average annual sales price for our sample (Anne Arundel County waterfront sales), waterfront sales across Maryland, all of Anne Arundel county, all of Maryland, and the US average. Our sample mirrors the average MD waterfront sales pretty closely, and exhibits the same general trend as the other averages. The main difference apparent in the figure is the price premium between waterfront and non-waterfront sales. Boyle et al. also suggest looking for increases in the number of vacant homes. Figure 6 contains a graph of the percent of all home sales in the county that were vacant (waterfront and non-waterfront). The graph shows a relatively flat trend after 2005, which does not solicit any red flags. So overall, we do not see any warning signs for disequilibrium behavior,

[11] Homes can have a riprap and be a bulkhead neighbor, but a home with a bulkhead cannot be a bulkhead neighbor. Different neighbor specifications did not have an appreciable impact on results.

[12] For additional information, see http://www.aacounty.org/elections/councilmaps.cfm.

although the literature in this area is still unsettled. Nonetheless, as depicted in equation (1), we include annual and quarterly time indicators to account for overall year-to-year fluctuations and seasonal cycles in property prices.

## V. Results

Estimation results appear in Table 3. The coefficients related to SLR and adaptation are presented here, while the other coefficients appear in an appendix available upon request. Most of the variables not shown had the expected signs. For example, distance to wastewater treatment plants is positive and significantly related to home price, indicating that people want to live farther from them. The depth of the waterbody is significant and positive, perhaps indicating a preference for boatable waters. Also, home square footage, parcel acreage, basements, and piers are all significant and positively related to home price.

Table 3 contains three model specifications and within each model there are three variations based on fixed effects (legislative, tract, or block). The first model is a basic specification that includes the SLR zones and adaptation structure variables but omits the interactions between them. The SLR zone variables are insignificant across all three specifications, suggesting perhaps surprisingly that living in a threatened area does not impact home price. The adaptation structure variables are consistently positive and significant across all three FE specifications (except groinfield in the tract regression) indicating that adaptation structures generally have a positive impact on home price. However, homes having both a bulkhead and a groinfield carry a smaller price premium compared to homes with a bulkhead alone, as can be seen by summing the coefficients on groinfield, bulkhead, and the bulkhead-groinfield interaction. This suggests that the additional protection afforded by the groinfield is crowded out by other offsetting impacts, such as a decrease in recreation. Groinfields can interfere with having a dock and boating access, which may explain this negative impact. Consistent with that explanation, the riprap*groinfield interaction term is insignificant in all specifications. Ripraps are not usually conducive to docks, so adding a groinfield does not necessarily decrease that type of recreation.

The second model in Table 3 is the difference-in-difference model that includes interaction terms between the SLR and adaptation structure variables. These interaction terms allow us to differentiate between protected and unprotected parcels within a SLR zone; in this way we can focus on homes most threatened by SLR. In these columns, the 0-2 foot SLR coefficients represent the impact to homes most threatened by SLR that are not covered by an adaptation structure. The coefficients are negative and are now three to four times larger in magnitude than the previous model. Also, they are statistically significant in two of the three specifications. The significant estimates suggest a 19-23% decrease in home price for unprotected homes in the 0-2 foot SLR zone. The 2-5 foot SLR zone coefficients are still small in magnitude and are not statistically different from zero, indicating that the risk of sea level rise that is not projected to occur for several decades is not capitalized into property values. Moving on to the coefficients for the structures, the groinfield, bulkhead, and riprap variables are similar in size and significance to the first model.

The interactions between the SLR and structure variables contained in this model confirm some hypotheses about the differential impacts of these variables. For instance, the interaction term between the 2 foot SLR zone and bulkhead is significant and positive in all three FE variations, ranging from 0.19 – 0.27. Based on our identification strategy, the total impact of living in the 2 foot SLR zone if you have a bulkhead is $\beta_Z + \beta_{AR}$, which is close to zero in all three FE variations. This suggests that the market perceives that the adaption structure roughly compensates for the potential loss in home value of living in a 0-2 foot SLR zone. Furthermore, all homes adjacent to a bulkhead, regardless of SLR zone, receive an additional statistically significant price premium ranging from 0.08-0.13 (as indicated by $\beta_S$), indicating substantial benefits from these structures beyond SLR protection, such as erosion, storm surge, and flood protection, or recreational amenities. There is generally not a statistically significant interaction between bulkheads and the 2-5 foot SLR zone (except at the 10% level in the block model), which is consistent with home buyers not internalizing the effects of more distant sea level rise projections.

The effect is similar for ripraps: the interaction term with the 0-2 foot SLR zone is positive (though not always statistically significant), and the magnitude offsets much of the disamenity value of living in the 0-2 foot SLR zone. There is also a substantial premium for homes with ripraps regardless of SLR zone. For homes located in the 0-2 foot SLR zone, the total effect of having either a bulkhead or a riprap is similar in magnitude.

The third model variation in Table 3 includes neighbor variables. When these are added, there are only minor differences with the other variables, indicating that the story about adaptation structures and SLR zones is not largely affected by controlling for neighbors. The only significant neighbor variables are bulkhead neighbors, suggesting that living next to a home with a bulkhead conveys a small positive impact to home sales price. This may suggest perceived positive externality-type effects of proximity to a bulkhead. Unfortunately data deficiencies did not allow us to explore neighbor differences across SLR zones.[13]

Although our data did not unfortunately allow a comparison to other approaches beyond bulkheads and ripraps, the strong positive impact of bulkheads is somewhat surprising, given that

[13] This is something we hope to explore in future research with data from additional counties.

the other types of structures are environmentally preferred and may have longer expected lifetimes (Barnard, 1993). However, Anne Arundel County has a long history of boating recreation, with the 11th highest number of recreational vessels among US counties.[14] Since bulkheads are better suited to docks and boating, these results may reflect a preference for boating friendly structures. Also, a properly built bulkhead can be quite effective at deflecting wave energy and rising tides. Softer approaches like groinfields and breakwaters may not be as effective due to their lower average height.

While these results show important interactions between SLR zones and adaptation structures, there may also be other confounding factors involved. As discussed earlier, adaptation structures may also protect against related disamenities like storm surge and other storm related activity. To test the robustness of the effects, we estimate additional models that include a variable related to the threat of storm surge from hurricanes. The data come from a computerized model run by the National Weather Service (the SLOSH Model) to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes.[15] This variable takes a value of 0-4, corresponding to the category of hurricane that would impact the parcel, so being located in a level 2 hazard zone means that a category 2 hurricane would threaten that parcel. Table 4 shows the distribution of homes in these zones, also separated by if they are in the SLR 0-2 zone. It indicates that hazard zone and the 0-2 foot SLR zone are indeed correlated; all homes in the 0-2 foot SLR zone are at risk of storm surge, though most fall into hazard level 1, indicating only moderate risk.

We estimate two additional models that include the hazard zone variable, with results appearing in Table 5, again distinguished by fixed effects. The first model in the first three

[14] As seen on http://www.boatinfoworld.com/

[15] The GIS data used for this variable were obtained from VIMS.

columns excludes the interactions between SLR 0-2 and the adaptation structures, while the second model includes them in the DID approach. The hazard zone variable is insignificant in all columns. The sign and significance of the SLR and adaptation structure variables, however, are quite robust to the inclusion of this variable. Results were similar when the hazard zone variable was broken into dummy variables.

## VI. Conclusion

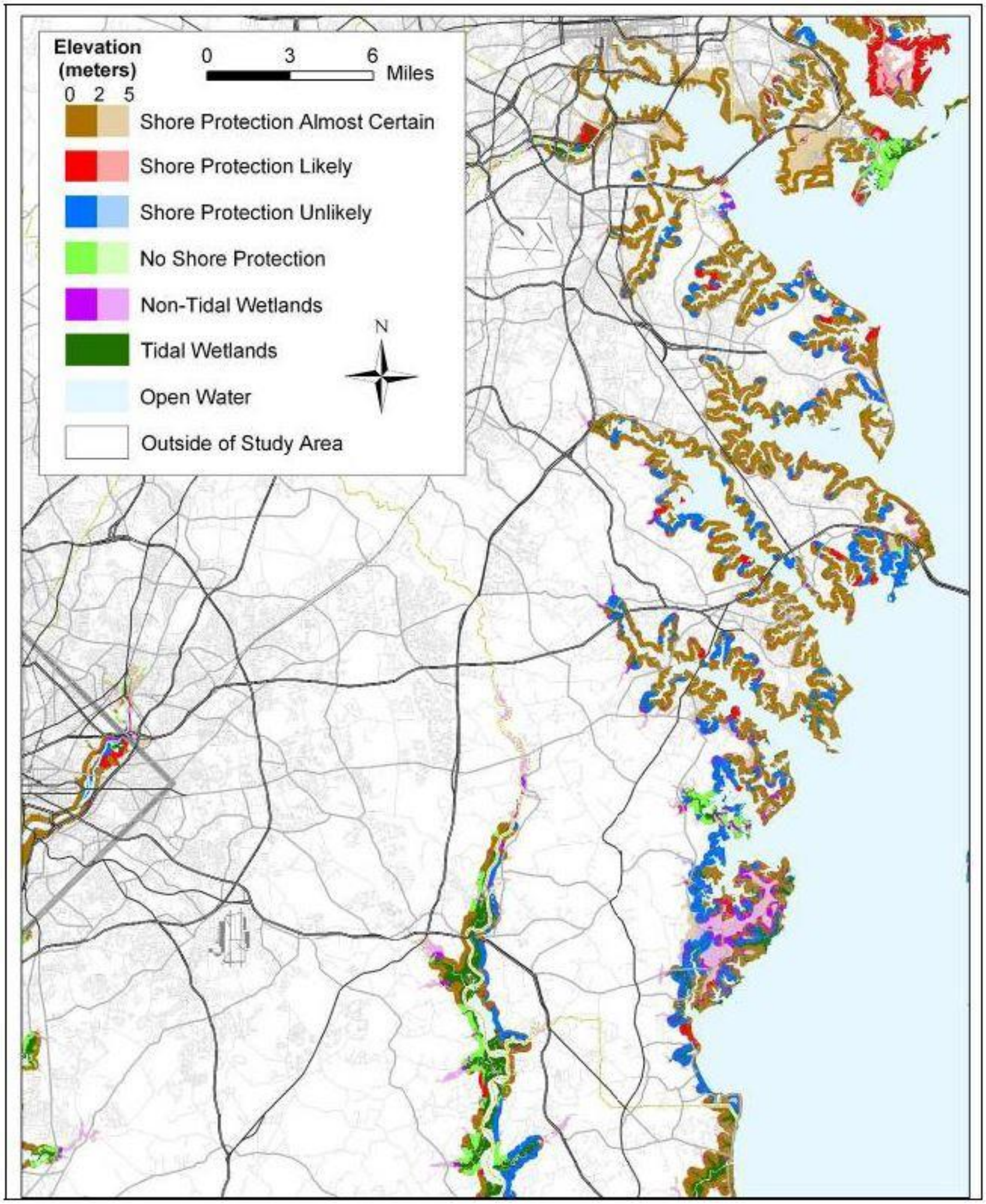
This is the first hedonic paper to examine the impact of sea level rise zones on property values. We also use a novel, spatially explicit dataset on adaptation structures to compare protected and unprotected homes in a DID model. In this framework we find evidence of a negative impact for homes located in the 0-2 foot sea level rise zone. Since the sea level in the study area is projected to rise at least one foot by 2100 (MD DNR, 2011), the 0-2 foot zone faces the most salient risk.

To represent protected and unprotected homes we used data on structural approaches to defending against SLR. Results indicate that having a bulkhead protecting the property can compensate for the negative impact of being located in the 0-2 foot SLR zone. The evidence for ripraps is similar, though the interaction between these structures and the 0-2 foot SLR zone is somewhat weaker. Bulkheads and ripraps also yield a substantial premium for homes regardless of sea level rise zone, indicating that they provide other amenities, possibly related to storm projection or recreation. Groinfields were also found to have a positive impact on home sales price, although we lacked the data to investigate differences across SLR zones. We propose several explanations for these results; in particular, bulkheads are the most compatible with boating, and can visually appear to be the most protective. Anne Arundel County has a long history of boating and bulkheads are the most conducive to docks.

Given recent changes in local policy, these results have several important implications. Anne Arundel County recently banned the construction of new bulkheads, instead favoring vegetative and other non-structural approaches to shoreline protection. Since this policy effectively fixes the supply of homes with bulkheads, it may drive up their price premium in the short term. If current coastal policies and development trends continue in the face of a rising sea level, current research indicates that additional shoreline protection will be deployed (MD DNR, 2011). It is therefore important to study the local economic impacts of SLR and shoreline protection. To better inform the discussion, we hope to examine the impacts of vegetative and other non-structural approaches in future work.

## Tables and Figures

**Figure 1: EPA Projections of Likelihood of Shore Protection in Anne Arundel County**




Source: (Nuckols et al., 2010)

**Figure 2: Adaptation Structures, SLR Zones, and Census Block Group Boundaries**

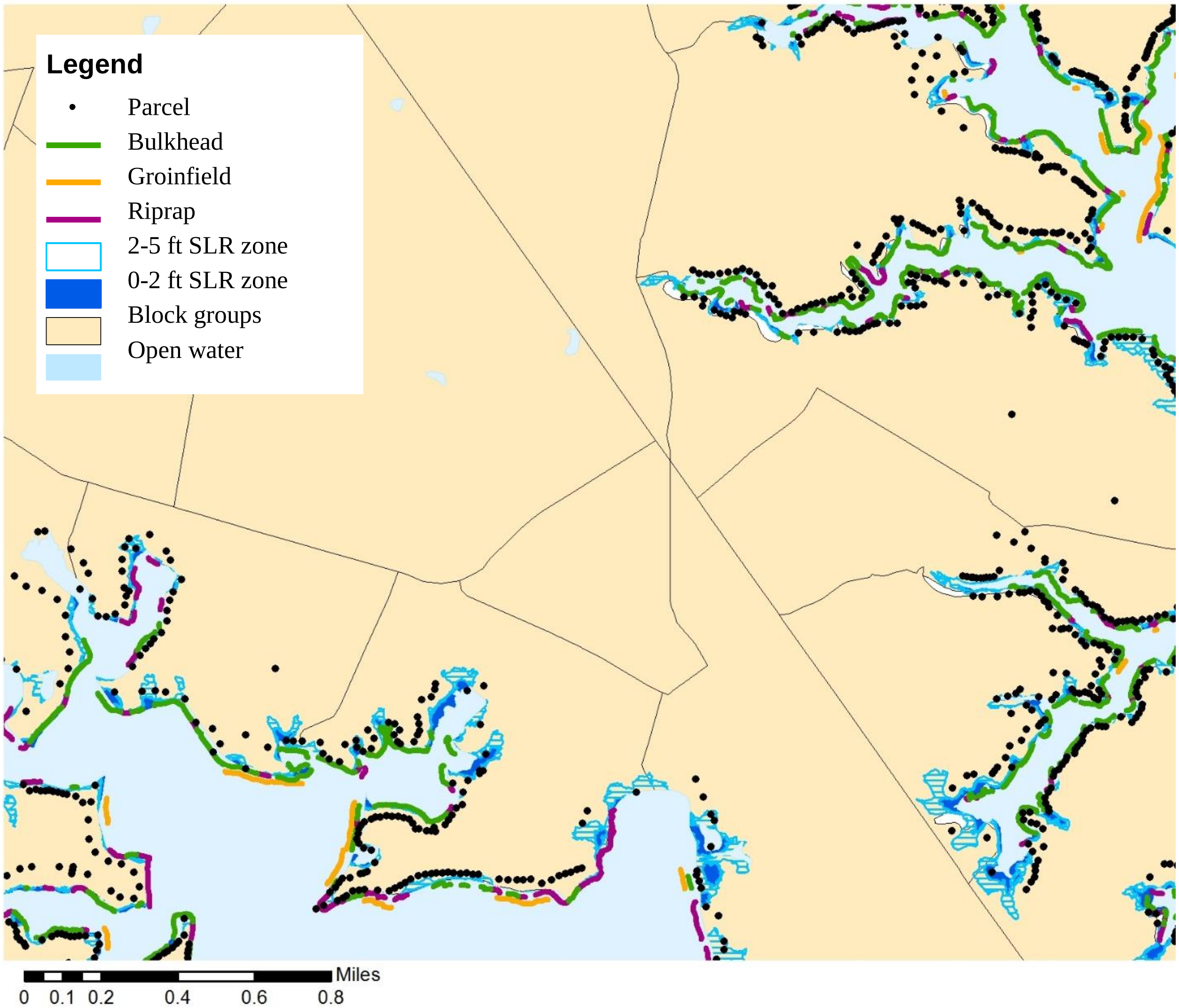
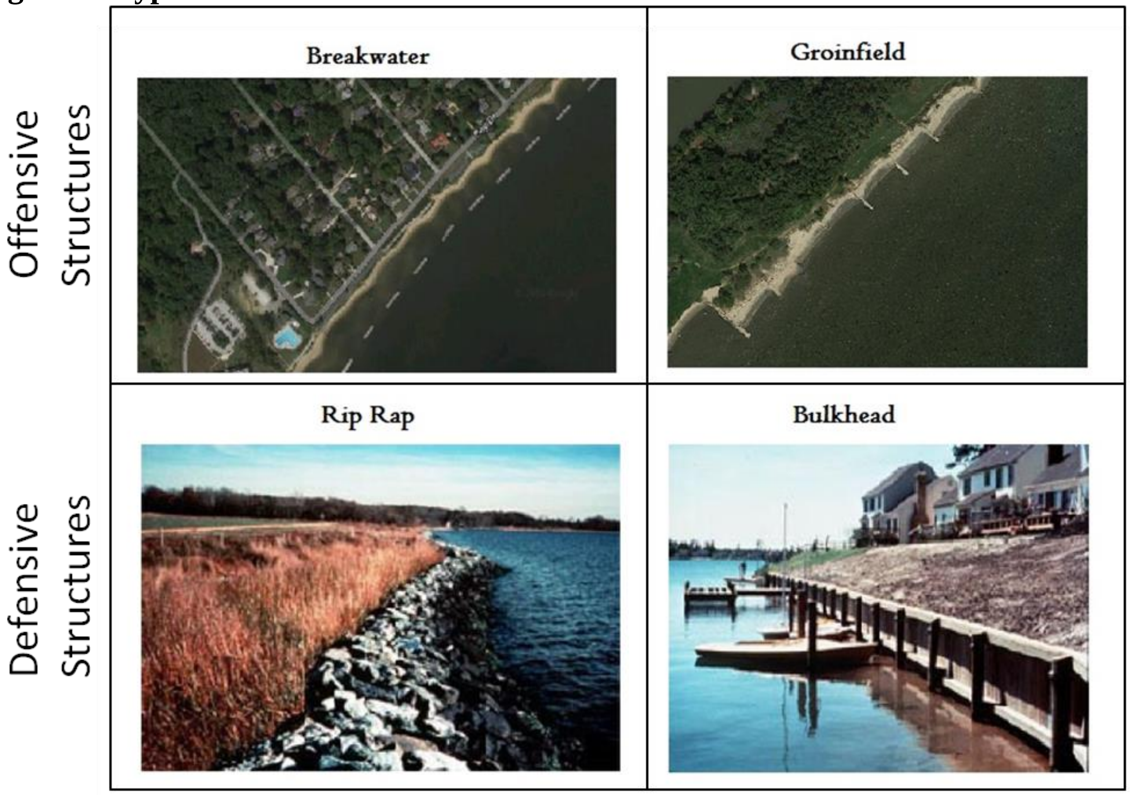


**Figure 3: Types of Structures**




Source: Google Maps and Barnard (1993)

**Figure 4: Sea Level Rise Zones in Anne Arundel County**

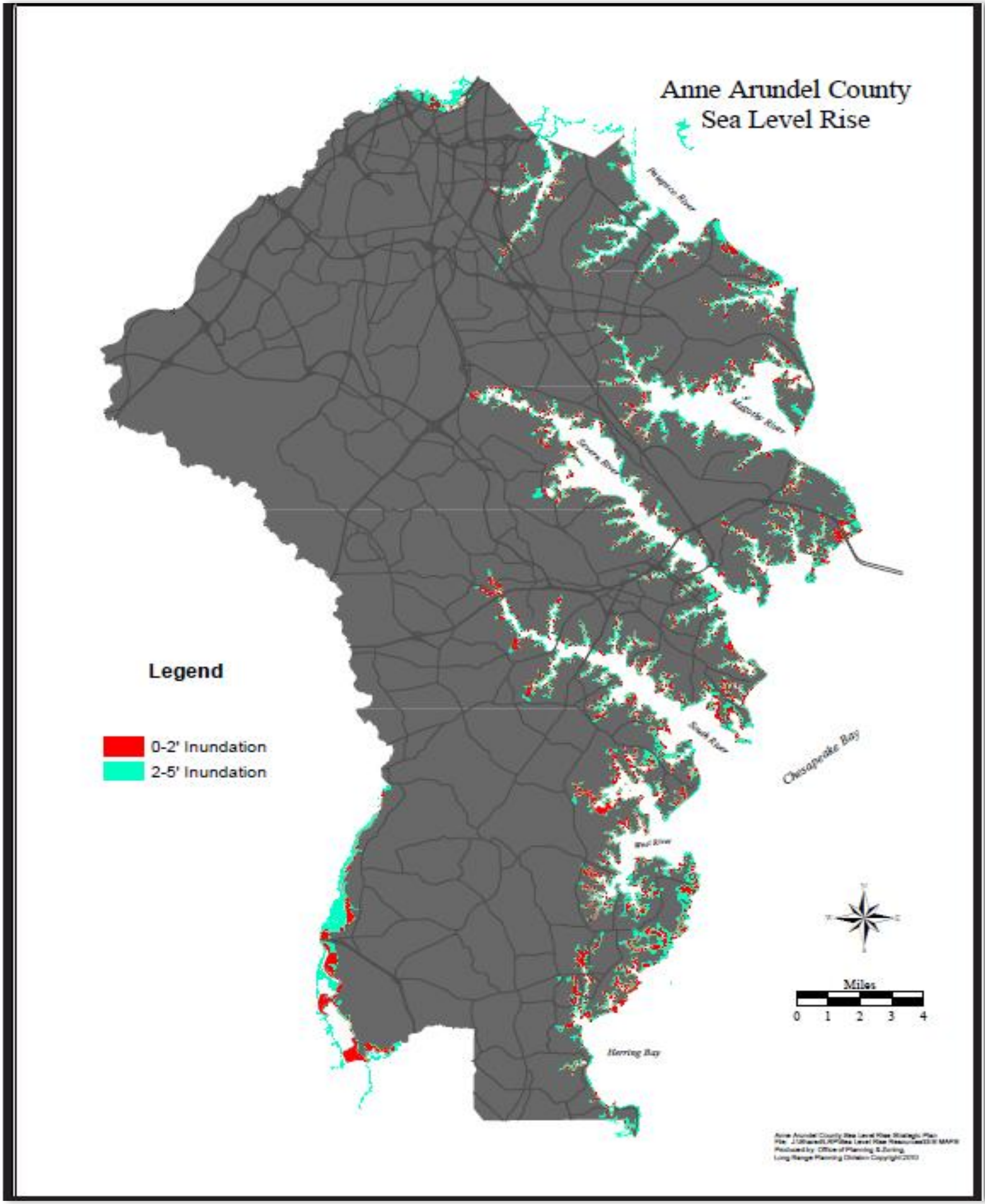


**Figure 5: Mean Annual Sales Price**

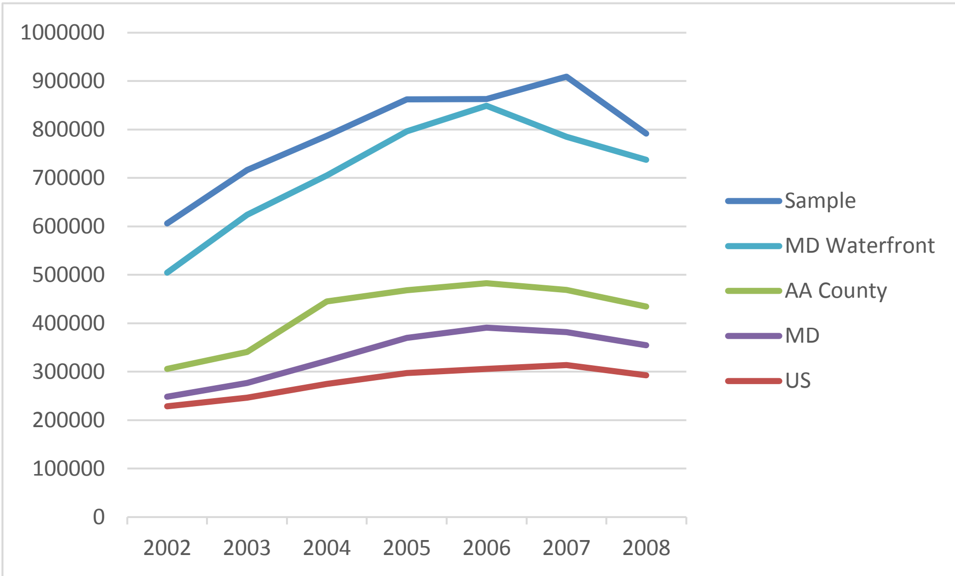



**Figure 6: % of Total Anne Arundel Sales Vacant**

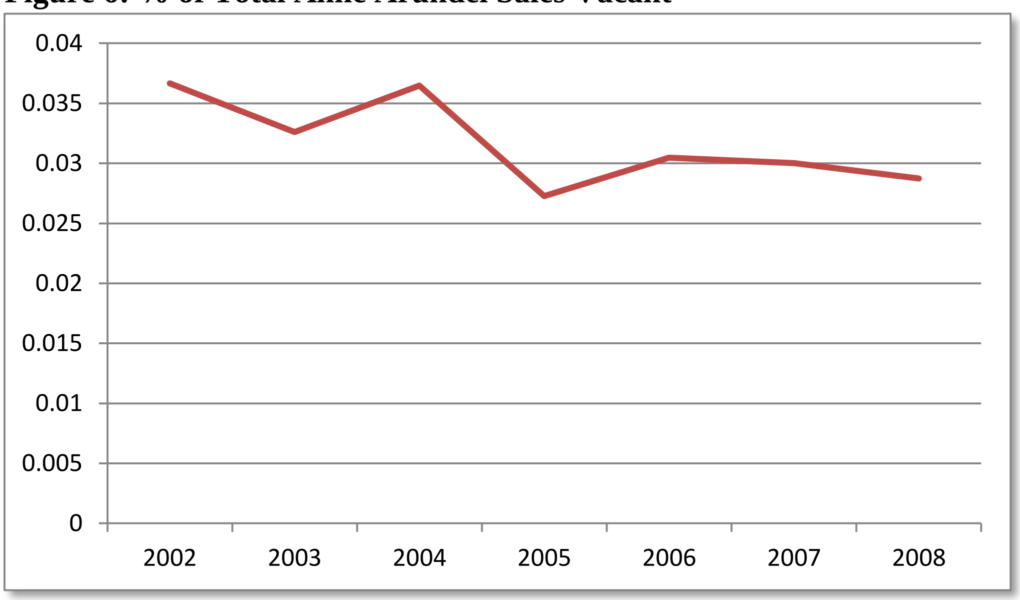


**Table 1: Descriptive Statistics**

| Variable | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| price | 817,392.900 | 651,179.500 | 42,066.920 | 3,996,358.000 |
| SLR Zone 0-2 | 0.041 | 0.198 | 0 | 1 |
| SLR Zone 2-5 | 0.095 | 0.294 | 0 | 1 |
| Breakwater (offensive) | 0.002 | 0.042 | 0 | 1 |
| Bulkhead (defensive) | 0.352 | 0.478 | 0 | 1 |
| GroinField (offensive) | 0.052 | 0.223 | 0 | 1 |
| RipRap (defensive) | 0.234 | 0.424 | 0 | 1 |
| Bulkhead Neighbor | 0.201 | 0.401 | 0 | 1 |
| Riprap Neighbor | 0.259 | 0.438 | 0 | 1 |
| High Density Res | 0.086 | 0.281 | 0 | 1 |
| Med Density Res | 0.625 | 0.484 | 0 | 1 |
| Forest | 0.054 | 0.226 | 0 | 1 |
| Dist Primary Road | 6,753.146 | 6,140.838 | 0.188 | 27,374.780 |
| Water Depth | 1.685 | 1.230 | 0.5 | 6.5 |
| Dist to WWTP | 5,286.220 | 3,445.880 | 340.863 | 13,458.690 |
| BG % High Res | 0.046 | 0.097 | 0 | 0.630 |
| BG % Ind | 0.003 | 0.008 | 0 | 0.066 |
| BG % Urban OS | 0.012 | 0.032 | 0 | 0.207 |
| BG % Ag | 0.052 | 0.092 | 0 | 0.508 |
| BG % Animal Ag | 0.000 | 0.003 | 0 | 0.020 |
| BG % Forest | 0.283 | 0.197 | 0 | 0.726 |
| BG % Wetland | 0.007 | 0.016 | 0 | 0.127 |
| BG % Beach | 0.000 | 0.002 | 0 | 0.017 |
| Dist to Baltimore | 30,177.260 | 13,469.000 | 6,115.065 | 64,474.620 |
| Dist to DC | 48,898.270 | 4,285.271 | 31,186.800 | 57,624.150 |
| $ on Improvements | 147,287 | 149,014.600 | 0 | 2,396,310 |
| Improvement $ Miss | 0.063 | 0.243 | 0 | 1 |
| Age | 34.770 | 27.576 | 0 | 207 |
| Age Sq | 1,969.127 | 2,632.383 | 0 | 42849 |
| Sq ft. Structure | 1,787.124 | 1,097.221 | 0 | 8566 |
| Sq ft. Miss | 0.030 | 0.171 | 0 | 1 |
| Lot Size (Acres) | 0.593 | 1.802 | 0.018 | 64.990 |
| Townhouse | 0.106 | 0.308 | 0 | 1 |
| Basement | 0.482 | 0.500 | 0 | 1 |
| Bathrooms | 1.861 | 1.068 | 0 | 10.500 |
| Attached Garage | 0.279 | 0.449 | 0 | 1 |
| Pool | 0.037 | 0.188 | 0 | 1 |
| Pier | 0.243 | 0.429 | 0 | 1 |
| AC | 0.673 | 0.469 | 0 | 1 |
| Flood Zone | 0.282 | 0.450 | 0 | 1 |
| y03 | 0.194 | 0.396 | 0 | 1 |
| y04 | 0.209 | 0.407 | 0 | 1 |
| y05 | 0.196 | 0.397 | 0 | 1 |
| y06 | 0.168 | 0.374 | 0 | 1 |

| | | | | |
|---|---|---|---|---|
| y07 | 0.133 | 0.340 | 0 | 1 |
| y08 | 0.099 | 0.298 | 0 | 1 |

**Table 2: Property Sales by SLR Zones and Adaptation Structures in Sample**

| | **0-2** | **2-5** | **>5** | **Total** |
|---|---|---|---|---|
| Defensive | 81 | 178 | 1246 | 1505 |
| *Bulkhead* | *49* | *100* | *852* | *1001* |
| *Riprap* | *36* | *105* | *526* | *667* |
| Groinfield | 3 | 5 | 141 | 149 |
| *Groinfield*defnse* | *3* | *5* | *70* | *78* |
| No structure | 35 | 90 | 1140 | 1265 |
| Total | 116 | 268 | 2457 | 2841 |

**Table 3: Hedonic Regression Results**

| | Basic Model | | | Diff-in-Diff | | | Neighbors | | |
|---|---|---|---|---|---|---|---|---|---|
| | Legislative | Tract | Block | Legislative | Tract | Block | Legislative | Tract | Block |
| SLR Zone 0-2 | -0.0646 | -0.0628 | 0.0133 | -0.186** | -0.226** | -0.136 | -0.171* | -0.208** | -0.121 |
| | (0.0481) | (0.0478) | (0.0490) | (0.0949) | (0.0916) | (0.0880) | (0.0942) | (0.0911) | (0.0876) |
| SLR Zone 2-5 | -0.00604 | 0.0108 | 0.0406 | 0.0515 | 0.00734 | 0.0267 | 0.0528 | 0.00589 | 0.0249 |
| | (0.0302) | (0.0301) | (0.0310) | (0.0439) | (0.0446) | (0.0465) | (0.0437) | (0.0442) | (0.0464) |
| GroinField | 0.100** | 0.0193 | 0.216** | 0.104** | 0.0122 | 0.213** | 0.133*** | 0.0349 | 0.214** |
| | (0.0502) | (0.0677) | (0.0846) | (0.0501) | (0.0678) | (0.0850) | (0.0504) | (0.0670) | (0.0849) |
| Bulkhead | 0.141*** | 0.126*** | 0.101*** | 0.132*** | 0.106*** | 0.0846*** | 0.163*** | 0.150*** | 0.122*** |
| | (0.0177) | (0.0174) | (0.0178) | (0.0191) | (0.0187) | (0.0190) | (0.0220) | (0.0215) | (0.0220) |
| RipRap | 0.119*** | 0.138*** | 0.143*** | 0.139*** | 0.145*** | 0.144*** | 0.137*** | 0.144*** | 0.142*** |
| | (0.0197) | (0.0193) | (0.0197) | (0.0214) | (0.0211) | (0.0216) | (0.0220) | (0.0217) | (0.0222) |
| Bulkhead GroinField | -0.159** | -0.111 | -0.269*** | -0.150** | -0.0909 | -0.253*** | -0.180** | -0.113 | -0.257*** |
| | (0.0702) | (0.0832) | (0.0916) | (0.0703) | (0.0835) | (0.0917) | (0.0703) | (0.0824) | (0.0915) |
| RipRap GroinField | 0.128 | 0.121 | -0.0956 | 0.121 | 0.121 | -0.0984 | 0.0924 | 0.0959 | -0.104 |
| | (0.112) | (0.113) | (0.109) | (0.112) | (0.113) | (0.109) | (0.110) | (0.112) | (0.109) |
| Bulkhead Neighbor | | | | | | | 0.0723*** | 0.0973*** | 0.0800*** |
| | | | | | | | (0.0236) | (0.0229) | (0.0229) |
| RipRap Neighbor | | | | | | | -0.0159 | -0.0103 | -0.00971 |
| | | | | | | | (0.0205) | (0.0208) | (0.0213) |
| SLR Zone 0-2* | | | | 0.191* | 0.269*** | 0.195** | 0.168* | 0.245** | 0.175* |
| Bulkhead | | | | (0.0978) | (0.0972) | (0.0934) | (0.0975) | (0.0968) | (0.0930) |
| SLR Zone 2-5* | | | | 0.0176 | 0.0760 | 0.0874* | 0.0154 | 0.0745 | 0.0853 |
| Bulkhead | | | | (0.0509) | (0.0508) | (0.0530) | (0.0506) | (0.0504) | (0.0529) |
| SLR Zone 0-2*RipRap | | | | 0.117 | 0.145 | 0.206* | 0.0955 | 0.118 | 0.185* |
| | | | | (0.117) | (0.115) | (0.112) | (0.116) | (0.114) | (0.111) |
| SLR Zone 2-5*RipRap | | | | -0.183*** | -0.0830 | -0.0701 | -0.186*** | -0.0837 | -0.0704 |
| | | | | (0.0531) | (0.0515) | (0.0538) | (0.0528) | (0.0510) | (0.0536) |
| Flood Zone | 0.0263 | 0.00217 | 0.0142 | 0.0320 | 0.00841 | 0.0188 | 0.0302 | 0.00664 | 0.0177 |
| | (0.0233) | (0.0233) | (0.0237) | (0.0234) | (0.0234) | (0.0238) | (0.0234) | (0.0234) | (0.0238) |
| Observations | 2,841 | 2,841 | 2,841 | 2,841 | 2,841 | 2,841 | 2,841 | 2,841 | 2,841 |
| Number of FEs | 6 | 51 | 131 | 6 | 51 | 131 | 6 | 51 | 131 |
| R-squared | 0.736 | 0.773 | 0.798 | 0.738 | 0.774 | 0.799 | 0.739 | 0.776 | 0.801 |

Standard errors appear in parentheses.

**Table 4: Hazard Zone Variables**

| Hazard Zone | Overall | In SLR 0-2 Zone | Not in SLR 0-2 Zone |
|---|---|---|---|
| 0 | 3,247 | 0 | 3,247 |
| 1 | 802 | 299 | 503 |
| 2 | 909 | 4 | 905 |
| 3 | 1,021 | 5 | 1,016 |
| 4 | 715 | 1 | 714 |

**Table 5: Hazard Zone Regressions**

| | Basic Model | | | Difference-in-Difference | | |
|---|---|---|---|---|---|---|
| | Legislative | Tract | Block Group | Legislative | Tract | Block Group |
| SLR 0-2 | -0.0603 | -0.0612 | 0.0151 | -0.182* | -0.224** | -0.134 |
| | (0.0487) | (0.0484) | (0.0495) | (0.0946) | (0.0912) | (0.0877) |
| SLR 2-5 | -0.00924 | 0.00641 | 0.0358 | 0.0452 | 0.00154 | 0.0201 |
| | (0.0308) | (0.0307) | (0.0316) | (0.0441) | (0.0448) | (0.0467) |
| GroinField | 0.105** | 0.0279 | 0.228*** | 0.108** | 0.0206 | 0.226*** |
| | (0.0510) | (0.0686) | (0.0849) | (0.0509) | (0.0687) | (0.0853) |
| Bulkhead | 0.141*** | 0.127*** | 0.102*** | 0.131*** | 0.107*** | 0.0846*** |
| | (0.0179) | (0.0176) | (0.0179) | (0.0194) | (0.0190) | (0.0191) |
| RipRap | 0.120*** | 0.141*** | 0.145*** | 0.140*** | 0.148*** | 0.147*** |
| | (0.0197) | (0.0194) | (0.0198) | (0.0215) | (0.0212) | (0.0218) |
| Bulk+Groin | -0.157** | -0.112 | -0.273*** | -0.147** | -0.0920 | -0.257*** |
| | (0.0707) | (0.0838) | (0.0917) | (0.0708) | (0.0841) | (0.0919) |
| Rip+Groin | 0.122 | 0.113 | -0.107 | 0.115 | 0.113 | -0.110 |
| | (0.113) | (0.114) | (0.109) | (0.113) | (0.114) | (0.109) |
| SLR 0-2*Bulkhead | | | | 0.193** | 0.270*** | 0.197** |
| | | | | (0.0980) | (0.0972) | (0.0934) |
| SLR 2-5*Bulkhead | | | | 0.0239 | 0.0800 | 0.0926* |
| | | | | (0.0510) | (0.0508) | (0.0529) |
| SLR 0-2*RipRap | | | | 0.115 | 0.142 | 0.200* |
| | | | | (0.117) | (0.115) | (0.112) |
| SLR 2-5*RipRap | | | | -0.183*** | -0.0836 | -0.0714 |
| | | | | (0.0531) | (0.0514) | (0.0536) |
| Flood Zone | 0.0264 | 0.00398 | 0.0161 | 0.0324 | 0.0102 | 0.0208 |
| | (0.0237) | (0.0235) | (0.0239) | (0.0237) | (0.0237) | (0.0240) |
| Hazard Zone | 0.000692 | -0.00149 | -0.00226 | 0.000196 | -0.00159 | -0.00258 |
| | (0.00609) | (0.00585) | (0.00594) | (0.00610) | (0.00584) | (0.00591) |
| Observations | 2,846 | 2,846 | 2,846 | 2,846 | 2,846 | 2,846 |
| R-squared | 0.800 | 0.776 | 0.800 | 0.801 | 0.777 | 0.801 |

Robust standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$

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