Urban Density Changes and Associated Flood Vulnerability in the Halifax River Watershed

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ABSTRACT
The Halifax River urban watershed is undergoing rapid socioeconomic changes that are interacting with natural hazards like coastal flooding driven by sea level rise. We employ a spatially explicit approach to examine changes in past and future land cover, explore the relationship with flooding associated with sea level rise, and discuss possible economic repercussions. We also make use of publicly accessible data related to land cover, population, and sea level rise projections to examine the potential for flooding associated with sea level to drive economic changes in the watershed. We predict significant development of land cover over time with more than 50 percent of the watershed potentially being developed in the next 50 years and about 1 to 13 percent of that development inundated if the current rate of sea level rise continues. When this development interacts with predicted sea level rise, there will be significant economic losses. This work can be leveraged to carry out larger-scale economic assessments in light of rapid urban sprawl and sea level rise.

Keywords: sea level rise, house price, Central Florida, tourism

INTRODUCTION
Background
The banks of the Halifax River are already heavily developed, and new developments are moving inland with an increasing density over time. But even with the new development and increased density, housing prices, fueled by a growing population, are rising rapidly. Increased hazard risk from sea level rise and more powerful hurricanes increase insurance costs, further increasing the cost of home ownership in Florida (Graff Zivin et al., 2020; Barrage and Furst, 2019; Bin et al., 2017). Perhaps surprisingly, the market response to natural disasters only results in temporary declines in housing prices as memories fade, new residents lack information on flood risk,
and damaged houses are replaced with newer, higher-valued construction (Graff Zivin et al., 2020; Bin and Landry, 2013; Hallstrom and Smith, 2005).

As we consider changes to the natural and manmade landscape, housing markets provide an important link between present conditions and the future. Housing accounts for approximately two-thirds of an average person’s wealth while housing investments and services added 17% to the nation’s GDP in 2020 (NAHB, 2022; Iacoviello, 2011). In Florida, housing markets are an important nexus among people, natural amenities, the built environment, jobs, and economic growth, as well as a source of current opportunities and future risks.

**Socioeconomic Conditions and Housing Markets**

With 404,266 net immigrants, more people moved into Florida in 2020-21 than moved away: a number exceeded only twice (1971 and 1972) in its history. Nevertheless, the Demographic Estimating Conference forecasts that Florida’s population will grow more slowly in the future. As the elderly have become a larger share of Florida’s population, natural population growth in the state (births minus deaths) turned negative in 2021 and population growth in Florida has been driven entirely by people moving to the state. The state’s population growth in the future is projected to depend entirely on immigration, and growth rates are projected to fall to approximately half of current rates over the next 15 years, from 1.6% annually to 0.8% (FOEDR, 2022). Immigration thus plays an important role in Florida’s housing market. The University of Florida’s Bureau of Economic and Business Research projects the state’s population will be 27.1 million in 2045, and 33.7 million in 2070, representing population increases of 26% and 53% respectively relative to 2020 (BEBR, 2022).

There is a debate in economics about whether immigrants respond to economic incentives such as wages, economic opportunity, low taxes, or to quality-of-life amenities such as a warm climate, outdoor activities, and inviting environmental features such as rivers and beaches (Partridge 2010). One reason that Florida has high numbers of immigrants is that it offers both economic opportunities and numerous amenities. Natural amenities in the region, in addition to climate, include beaches, rivers, springs, estuaries, forests, and coral reefs that are used by people for a variety of recreational activities including fishing, boating, diving, hunting, riding, hiking, and camping provided by one of the largest state park systems in the nation (Pienaar, 2017). Other important amenities in the region include sporting venues such as the Daytona International Speedway, and a multitude of theme parks (Disney World, Universal Studios, and Sea World among others). Because
many of Florida’s newest residents are retirees, work incentives are likely to play a smaller part in their decision than climate, social networks, and other amenities. In addition, technological and social changes during the Covid pandemic have allowed many workers to telecommute or work from home, which also lessens the role of work incentives in choosing a place to live. We emphasize the role that amenities have in attracting Florida’s record number of immigrants because, without careful land-use planning, high levels of housing growth can degrade the very amenities that attract residents to the region.

While migration patterns can be complex, several studies show Central Florida to be an attractive landing place for new residents – both migrants moving from out of state and in-state residents relocating to less-crowded, more affordable areas (Hauer 2017; Carr and Zwick, 2016). Immigrants are shown to drive up the value of houses not only where they settle but also in surrounding areas as local residents relocate in response to changing housing prices and population demographics (Mussa, 2017; Saiz, 2007). In addition, new residents spur the development of low-density subdivisions of single-family housing. Carr and Zwick (2016), in a study for 1000 Friends of Florida, find that agricultural lands and other green spaces in Central Florida could shrink by over 2.3 million acres by 2070 as half of all green spaces are replaced by developments. Climate change plays an important role in these projections. Hauer (2017) estimates that as many as 250,000 residents from South Florida will relocate to Central Florida due entirely to the impacts of future sea level rise. A separate study assessed Florida as second only to Louisiana in its vulnerability to wetland migration due to sea level rise (Osland et al., 2022). On the Atlantic coast, upland forests and upland croplands are the most vulnerable to urban sprawl, adding to the threats to existing inland natural systems as people have started to develop them (Osland et al., 2022).

**Vulnerability to Coastal Flooding, Land Cover, and Housing Markets**

Vulnerability to climatic hazards such as coastal flooding is generally a product of intensity of exposure to risks such as the extent and frequency of coastal flooding, sensitivity of the social and natural systems of the coast, the strength of the built environment to withstand such shocks, as well as access of the people living in those areas to social and economic resources (Chang and Huang, 2015; Adger, 2006). Flood vulnerability in Florida’s coastal region is the product of rapidly increased coastal flooding driven by sea level rise as well as more frequent hurricanes and a rapid and unsustainable development of coastal regions (Shen et al., 2016). In the US, nearly 41 million people live within the 1% annual exceedance probability floodplain (sometimes called the 100-year
floodplain), with increasing numbers of people moving to flood prone regions (Wing et al., 2018). These changes in land use are exacerbated in Florida because of its rapid population growth rate.

The Halifax watershed is emblematic of Florida’s rapid increase in urban sprawl. Natural areas are rapidly being developed into housing. At the same time, the price of housing has increased, driven by local as well as national demand, and insurance markets are in flux as they seek to assess the effects of increasing flood risk and other hazards from a changing climate. In this article, we aim to establish baseline information related to landcover change, sea level rise, and their interaction with the economic condition of the Halifax watershed. We also aim to explore the temporal dynamics of land cover change, sea level rise, housing prices, and their interaction.

**METHODS**

**Study Area: Halifax River**

The Halifax River lies in the north-eastern part of Volusia County in East-Central Florida. This river, a part of the Atlantic Intracoastal Waterway, is a linear estuary approximately 23 miles long and roughly a half mile wide on average. It flows along the City of Daytona Beach and the eastern coast of Volusia County in Central Florida (Cho and Reiter, 2020). We adopted the watershed approach to this study and included the entire huc10 (Hydrological Unit Code) watershed surrounding the Halifax River within Volusia County (Figure 1). The area next to the Halifax River is heavily urbanized and the areas further inland are being urbanized rapidly.
According to the 2022 census, the total population of the watershed considered for this study is about 250,500. Currently, about 74,000 people live in the City of Daytona Beach, with an increase of about 3.8 percent between 2020 and 2021. According to 2019 national land cover data, this watershed is composed of about 29 percent developed land of various kinds. Forest/shrub covers about 17 percent of this watershed with 22 percent wetlands, and 4 percent of hay/pasture/and herbaceous land cover (MRLC, 2022). The rest of it is open water.

**Data and Analysis**

We carried out population-landcover trend analysis and explored interactions between changing land cover and sea-level-driven coastal inundation. We acquired data and information from the US Census to determine the watershed’s total population and used the population of one of the
major cities in the watershed to explore change in population over time. We then carried out a landcover change analysis using US national land cover data (NLCD) for the years 2001 and 2019 (MRLC, 2022). The multi-resolution land characteristics consortium classifies developed landcover into four different categories: Developed Open Space, Developed Low Intensity, Developed Medium Intensity, and Developed High Intensity. We focused on how different developed land covers have changed over time in the watershed with a special focus on high-density land use. Using ArcGIS Pro 2.8 (ESRI ArcGIS Pro, 2022) we calculated the total area and percentage of various development landcovers from the NLCD dataset. We used Florida 2070 projected developed land cover (Carr and Zwick, 2016) and examined the future change in land cover assumed to be primarily driven by economic development and in-migration to the region. The analysis was performed by calculating the total area as well as the percentage of various developed land cover types in 2001 and 2019 based on NLCD and projected developed landcover in 2070 based on Thousand Friends of Florida’s 2070 (Carr and Zwick, 2016) projected land cover using ArcGIS Pro 2.8.

We then examined the risk of flooding in the watershed based on NOAA’s sea level rise (SLR) projection(s) for 2100 (NOAA SLR Data, 2022) to forecast how current and projected future development interact with the flooding potential in this urban watershed. We extracted the percentage of flooded developed land within 1-ft SLR and 6-ft SLR by 2100 by employing various geospatial analysis tools in ArcGIS Pro. We first used the Extract function by Attributes tool in ArcGIS Pro to extract various developed land cover types from NLCD Datasets. We then aggregated these different landcover types to one “developed” land cover. We used sea level rise polygons from NOAA to extract the developed landcover and calculated the area of the current developed landcover which would be inundated. For future developed land cover projection polygons, we first converted polygons to a raster format of same cell size as of current developed land cover. We then employed the same method as current developed land cover to extract future landcover using NOAA’s SLR projections polygons.

RESULTS AND DISCUSSION

Population and Landcover

The 3.8 percent population increase of Daytona Beach from 2020 to 2021 is significantly higher than both the US national trend (~0.1 %) and Florida trend (1.1%) (US Census Bureau, 2022), suggesting rapid population increase over time in this watershed. As expected, landcover distribution of this watershed has been changing rapidly as well. Our analysis shows that during the
two decades from 2001 to 2019 the area of medium-intensity housing and high-intensity housing almost doubled while the total area of developed open space and low-intensity development remained the same (Figure 2). Developed Open Space is an area with a mixture of constructed materials with predominant coverage of vegetation especially in the form of lawn grasses with less than 20 percent of impervious coverage (MRLC, 2022). Although the area in square kilometers of Developed Open Space and Low Intensity Development remain similar between 2001 and 2019, it does not mean that those are the same locations as in 2001. The Developed Open Space and Low Intensity Development converted to higher intensity development while natural lands were converted to Developed Open Space and Low Intensity Development. That led to areas of lower intensity development in 2001 remaining comparable to 2001 while significantly consuming natural lands and increasing high-density development.

Figure 2: Change in Halifax River watershed landcover between 2001 and 2019. Data source (MRLC, 2022).
The conversion of natural areas into new developments is projected to increase in the future based on the projected trend of population growth and distribution of the population based on our analysis. In 2001 only 237 square kilometers (32%) of the watershed was developed while 273 square kilometers (37%) of the watershed are currently developed, a number projected to increase to about 400 square kilometers (53%) by 2070 (Figure 3).

![Developed Area Coverage in the Halifax River Watershed Over Time](image)

**Figure 3:** Developed area coverage in the Halifax River watershed over time (MRLC, 2022; Carr and Zwick, 2016). Notice that the area of developed land is projected to almost double from 2019 to 2070.

The rapid change in area and density of developed land is attributed to both an increase in economic opportunity and the high level of amenities in the region. Both sides of the Halifax River are filled with housing. The coastal area is also fully developed with single-family housing, condominiums, hotels, and businesses. This area is economically vibrant, with Volusia County hosting more than 10 million tourists in 2018 (Abbott, 2022). An analysis of economic development in the Halifax watershed (Ekanayake et al., 2020) hints at the balance in the region among economic opportunity, natural amenities, and recreational amenities, and finds that the three industries with the best potential for growth are Manufacturing and Construction; Agriculture, Forestry, Fishing, and Hunting; and Accommodation and Food Services. The implication is that each of the factors that makes the Halifax watershed region an attractive area in which to settle are poised for future growth. In addition to the economic opportunity, changes in land cover might also have been driven by the nearest big city, Orlando. Land development in the Halifax watershed accelerated rapidly following the development of Disney World in Orlando in 1971, which is a little over one hour’s
The home of Walt Disney World, Sea World, and Universal Studios, Orlando is one of the most visited cities in Florida, hosting 79.8 million visitors in 2019 (Visit Orlando, 2022).

The Halifax River region is undergoing more rapid change in urban area and density than other parts of Florida. Carr and Zwick (2016), in their analysis of the future of Florida’s land use, point out that the east coast of Florida is one of the regions with dramatic changes in land cover. There is thus an opportunity to conserve land and limit further land development in this watershed in order to maintain biodiversity, ecosystem services, and reduce future flood damage. Urban sprawl can be slowed by setting aside special natural and cultural sites for conservation, supporting greenways and wildlife corridors, incentivizing landowners to conserve important undeveloped or minimally impacted land, and working towards reducing impacts from the new development in the region (Carr and Zwick, 2016). It is possible for the region to increase density in places where development already exists while policymakers attempt to protect undeveloped land.

**Future Flooding Vulnerabilities and Landcover**

Under the assumption that the current map of developed lands will remain unchanged over the period in which sea level rises (SLR) one foot above current levels, we find that about two square kilometers of currently developed area (0.73%) will be inundated. One of the likeliest projections, often used in resilience planning in this region, is for a one meter of sea level rise by 2100 (ECFRRAP, 2018). When our model elevates sea level to the 6-ft NOAA SLR scenario, over 26 square kilometers (~10 %) of currently developed lands will be inundated (Figures 4 and 5).

![Area of developed land inundated by 2100](image)

**Figure 4: Area of current and future vulnerable development in the Halifax River watershed. Data sources: MRLC, 2022; NOAA SLR Data, 2022; Carr and Zwick, 2016**
Several observations can be made from this initial stage in our analysis. First, in addition to the two square kilometers of existing houses that are likely to be flooded in the next 20 years, this model does not include storm surge, so any large storm will compress the time when these houses are inundated and increase the area of flood risk. While two square kilometers represents less than one percent of all development, houses in these areas will either be protected by additional infrastructure, remodeled to be resistant to flooding, or abandoned. Second, a sea level rise of six
feet will flood significantly more developed land and require substantial additional investments in green infrastructure, built infrastructure, flood mitigation remodeling, and policies designed to retreat from these areas to prevent an enormous loss of housing. While there is some time to initiate these more aggressive mitigation and prevention strategies, the amount of time and resources required must not be underestimated. If flood risks and insurance costs increase while associated amenities are degraded (for example, beach erosion accelerated by the construction of protective sea walls), then the immigration that drives higher housing values and a growing tax base could be affected long before houses are physically inundated. These observations are consistent with other analyses. The East Central Florida Planning Council (ECFRPC, 2017) finds that residential housing makes up approximately 90% of the parcels in Volusia County that will be flooded in an SLR analysis with storm surge. It is interesting that, regardless of the scenario, approximately one third of the houses expected to be inundated are more than 50 years old.

Our second analysis uses land cover forecasts by Carr and Zwick (2016) and overlays those developments with 1 ft and 6 ft NOAA SLR forecasts respectively. We find that the area of inundated development increases substantially, with 5.7 square kilometers inundated under 1 ft SLR and 36.41 sq kilometers inundated under 6 ft SLR (Figures 4 and 6). The sea level rise-induced flooding will impact communities mostly along the Halifax River and its tributaries. Figures 5 and 6 show that the land areas next to tributaries on the north and south side of the watershed have the highest likelihood of being impacted by sea level rise-induced flooding. With land use altered to show new development, the share of housing affected by 1 ft of SLR increases to 1.5% of all housing in the Halifax River watershed, while the size of the inundated areas more than doubles from 2 to 5.7 square kilometers. In the 6 ft SLR scenario, the size of inundated areas increases by roughly 40% from 26 to 36.41 square kilometers. Perhaps the most alarming result of the new development model is that the amount of housing affected by 1 ft of SLR more than doubles. Of the 10.4 kilometers of future construction that will be inundated by 6 ft of SLR, over one-third would be flooded by just 1 ft of SLR. The implication is that time for effective land use planning is short.
Figure 6: Interaction between projected developed land (2070) and future sea level rise (2100) in the Halifax River watershed. Data sources: MRLC, 2022; NOAA SLR Data, 2022; Carr and Zwick, 2016.

By preventing the construction of future developments in areas likely to be inundated by an additional 1 ft of SLR, the region potentially can cut the direct damage costs in half over the next 20 to 30 years. However, simply preventing development in vulnerable areas is a costly sledgehammer approach to the problem. It may be far more effective to incorporate green infrastructure in these areas of likely flooding to reduce the effects of flooding beyond these areas. Parks, swales, and green
roofs not only act as storage areas to prevent water from overwhelming storm water drainage systems, they also lower energy costs, increase natural habitats, offer recreational activities, and increase the value of houses located nearby (EPA, 2014). While green infrastructure can improve the livability of neighborhoods during more severe flood events, SLR will require substantial investments to prevent the incursion of the ocean or, most likely, increased flooding from the Halifax River. Eventually, as SLR approaches 6 ft, it may be too costly to fortify and protect the most flood-prone areas or to maintain the infrastructure that supports those areas.

While these decisions and associated behavioral changes may not be made immediately, they will be required in the very near future and will shape communities’ identities in this urban watershed. Will sea walls replace beach activities, resulting in more passive ocean experiences, or will accommodations be put in place to allow beaches to migrate? As infrastructure services in areas that are frequently flooded become increasingly expensive due to frequent upgrades and repairs, how will the community respond? Communities that recognize this reality early can develop a process for temporary use of high-risk areas, combined with a (compensated or uncompensated) planned retreat that fosters natural amenities in flooded areas. These communities will have lower mitigation costs, and will be more attractive to immigrants, residents, and investors looking for a vibrant economy with plentiful amenities to enhance quality of life. Volusia County is aware of this challenge and is actively working on solutions. The County is incorporating climate change effects into its land use planning by prioritizing areas for conservation based on the ecosystem services (natural amenities) offered by different parcels, locations where development could be at high risk of flooding, and areas where green infrastructure could be most effective.

CONCLUSIONS

Global climate change is certainly causing shifts in the tide and storm surge height of the ocean that will directly impact the world’s coasts and result in damage to ecosystems, people, and property. The southeast region of the USA will see about 1 ft to 6 ft SLR by 2100 according to a recent NOAA prediction of future sea level rise in the USA. In our work of assessment of sea level rise and inundation potential by 2100, we report that about 2 to 36 square kilometers of the developed land in the area will be inundated under 1 ft and 6 ft sea level rise scenarios, amounting to about 1 to 13 percent of currently developed land respectively. It is worth mentioning that the area
we analyzed utilizes current and future developed land only and does not include other landcover types.

The Halifax urban watershed is undergoing rapid changes in population and developed land cover driven by economic opportunity locally and regionally. About 37 percent of the watershed is already developed and is further projected to be more than 53 percent developed by 2070. If the trajectory continues, it will significantly reduce natural habitat, biodiversity, and the means for flood control. Sea level rise-induced flooding will significantly impact development and the region’s economy. There is an opportunity to conserve land and control further growth in this watershed in order to maintain biodiversity and ecosystem services and limit future flood damage. The stakeholders in the region can avoid the worst consequences of future SLR by planning for development outside of the flood prone areas, increasing density of the current developed areas to avoid the expansions, and setting area aside for land and water conservation.

LIMITATIONS

In this work we focused on Volusia County rather than the entire watershed of the Halifax River. A small area of the watershed extends into Flagler County as well, but we have not examined new adaptation options and people’s tendency to retreat after the major flooding events there. If new adaptations to sea level rise are applied in this area, the potential loss of developed land could be reduced. This will have major impacts in the new development and housing markets which we did not evaluate because of the lack of anticipatory adaptation data at the watershed scale. We also have not analyzed the economic capacity of the communities in that region. Although we consider housing prices as one of the major factors in relation to new development and sea level rise-induced flooding, in this work we were not able to run direct analysis by relating those variables because of temporal mismatch in the data available in the public domain. Nonetheless, we were able to present empirical evidence of current and future trends of socio-economy driven landcover changes and their interactions with climate change driven coastal flooding in this part of East Central Florida.
REFERENCES


