Estimating the contribution of vacant land in mitigating flooding in the Neuse Basin

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Abstract

Flooding in the United States results in economic losses amounting to tens of billions of dollars annually, with urbanization and development in floodplains serving as key drivers of increased flood risk. This study explores the flood retention potential of vacant lands within current and projected landcover scenarios in the Neuse River Basin, a rapidly urbanizing region prone to significant flooding challenges. Using InVEST, a GIS-based modeling suite for ecosystem service valuation, we integrated land use/land cover (LULC) data with hydrological modeling to quantify flood mitigation capacity. Our findings indicate an 8.1% increase in floodplain land development from 2020 to 2060, with an additional 10% rise projected from 2060 to 2100. Despite these trends, vacant floodplain land parcels demonstrate significant potential for floodwater retention, with a one-square-foot increase in vacant land corresponding to a 1.65 m^3 rise in runoff retention capacity. Results underscore the sensitivity of flood storage capacity to landcover changes and highlight the importance of preserving vacant lands in floodplain management. The results also point to the importance of river basin management plans running parallel with local development policies. This study offers a practical framework for assessing ecosystem-based flood mitigation services and provides actionable insights for urban planners and policymakers.

Introduction

Flooding in the United States results in tens of billions of dollars in monetary damages every year (1,2). The susceptibility to urban flooding is rising due to climate change and rapid urbanization (3). Climate change has exacerbated the frequency and magnitude of inland and coastal flooding, causing damage nation-wide (4). Moreover, studies have confirmed a significant association between land development, urbanization, and erratic rainfall in urban areas (5–7). Precipitation rapidly changes to runoff due to impervious surfaces, reduced green spaces, and inadequate stormwater infrastructures in the urban areas (8–10).

Studies in various contexts have projected increasing inland flood damages in the future (1,11,12). For example, in a study by Federal Emergency Management Agency (FEMA) on climate change impacts, the nation's flood-prone area will likely increase by 40-45 percent over the next 90 years (13). Major catastrophic flooding events in North Carolina have caused damage to properties and death (14–16), altering water quality and fisheries habitat (17), especially in the coastal communities. Also, excessive rainfall leads to inland riverine flooding (18,19). The North Carolina Climate Risk Assessment and Resilience Plan predict an increase in frequent riverine flooding due to the rise in the intensity and frequency of extreme precipitation (20). Consequently, flood managers have started to pay attention to green space on an urban and regional scale (21).

In the past, flood mitigation in the United States was implemented using structural and technocratic approaches to reduce flood risk. However, in recent times, mitigation approaches have been geared towards nonstructural mitigation practices, including zoning, education, flood insurance, and regulation (22). In addition, recent research and land policies have demonstrated the potential of open spaces as a flood mitigation strategy by reducing runoff and storing floodwaters in flood plains (7,23,24). Acquiring damaged properties and restoring them to open spaces after severe storm impact has gained recognition as a role in the local floodplain management (22,25–27). However, most homeowners are unwilling to participate in these buyout programs due to their reluctance to leave (7). One study examined the potential of private vacant land at multiple spatial scales instead of focusing on the existing open space restoration approach (28,29). Vacant lands provide the opportunity for protecting wetlands and flood plains. Newman, Smith, and Brody (2017) developed a framework to identify vacant lands with high potential for maintaining ecological services in a flood-prone area in Houston. Previous studies have looked at the economic cost and benefits of conserving open spaces in floodplains while accounting for future developments in the United States (29,31) but did not quantify the amount of floodwater retained in vacant lands with projected future land development. Kousky and Walls (2014) estimated the benefits of open space conservation but did not account for future development projections.

Quantifying flood retention and the damage avoided by green spaces is essential to improving flood mitigation strategies. Flood depth and inundations are mostly mapped using hydrological models (33–35). These models require sophisticated data inputs and are expensive to use, which becomes challenging for policymakers to interpret. However, simple empirical statistics and models with high spatial resolutions can supplement these hydrological models with limited data availability (3,36). The InVEST model is an open-source tool that promotes natural capital valuation and policy planning. The application of the model for urban flood mitigation is designed to include hydrological information for an easy explanation of policy research (37,38). This study utilized the InVEST model to quantify flood retention potential in the Neuse River Basin.

The study aims to quantify vacant lands' flood retention potential within the Neuse watershed's floodplain and future project developments in 2040, 2060, 2080, and 2010, assuming vacant lands remain the same. The novelty of this study is forecasting the extent to which vacant land can serve as a flood mitigation strategy using land-use projection data from the USGS. This study will contribute to scientific knowledge and inform policymakers about the potential of vacant lands for flood mitigation. The results from this research would be beneficial in answering the questions: 1) What is the current flood retention potential of vacant lands in the floodplain within the Neuse River Basin, 2) What will be the flood retention potential of vacant lands under projected land development? 3) What is the difference in flood retention of vacant lands compared to the current and future developments?

Materials and Methods

Study area

The Neuse River Basin covers about 16000 km^2 of eastern North Carolina in the USA. The river flows towards the southeast United States from Northern Piedmont west to Pamlico Sound (39). The river basin climate is humid and has minor variations in temperature since it stretches from the inland Piedmont region to the Atlantic Ocean. The basin is identified with an 8-digit Hydrologic Unit Code (HUC) number 03020201 (40). The river flows through several cities, including through the Raleigh-Durham corridor. Precipitation has shown an increasing trend from the early 1990s through to 2016 at the lower coastal stations, with an estimated 0.05 inches per year, accounting for about 5 inches on average over the 20th century (41). The cities within the watershed experience significant flooding due to climate change. In addition, the towns within the basin have suffered hurricanes in the past, including Floyd, Matthew, Fran, etc.(42). The watershed is predominantly forest land, cropland, and urban land; however, rapid urbanization and population growth have occurred in the basin over the past years. The upper Neuse River Basin population is projected to increase by 53% in the next 25 years. This will increase water pollution from stormwater, which is a significant concern for the city and flood planners in the region (40).

InVEST Model set-up

This study uses the Integrated Valuation of Ecosystem Services and Tradeoff (InVEST), an open-source software used to map and value natural goods and services. The model operates on the premise that natural infrastructure functions to reduce runoff production by slowing surface flows and directing flow into drainage basins or floodplains. By focusing on the extent of the watershed, InVEST calculates the amount of runoff retained per pixel compared to the storm volume. For each sub watershed, it also calculates the potential economic damage by overlaying data on flood extent and building footprints. Runoff retention is estimated using the Curve Number (CN)-based approach (43). The curve number is a simple way of capturing these hydrologic soil group and land use/ land cover properties—higher values of CN have higher runoff potential (for example, clay soils and low vegetation cover), lower values are more likely to infiltrate (for example, sandy soils and dense vegetation cover). This study employed the Urban Flood Risk Mitigation module of InVEST to quantify flood volume and runoff production based on equation (1). Potential runoff retention (in mm) was calculated as a function of the curve number, CN. The empirical relationship between $S_{max,i}$ and CN_i is shown in equation (2). The model further calculates the runoff retention index for each pixel, as a function of the total precipitation (equation 3).

$$Q_{p,i} = \frac{(P - \lambda S_{max,i})^2}{P + (1-\lambda)S_{max,i}} \quad \text{if } P > \lambda S_{max,i} \quad \text{otherwise } Q_{p,i} = 0 \tag{1}$$

$$S_{max,i} = \frac{25400}{CN_i} - 254 \tag{2}$$

$$R_i = 1 - \frac{Q_{p,i}}{P} \tag{3}$$

where;

$Q_{p,i}$ is the total runoff from precipitation

P is the design storm depth in mm

$S_{max,i}$ is the potential retention in mm

λS_{max} is the rainfall depth needed to initiate runoff i.e., the initial abstraction adapted for the model, where $\lambda = 0.2$

CN_i is curve number

R_i is runoff retention per pixel

Data inputs for InVEST model

Land use and land cover

The study used the 2019 National Land Cover Database (NLCD), which is a satellite-based land cover mapping of all states in the US (44). The data is presented as 30-meter-square pixels that have been classified using 16 standard land cover classification schemes. The database also includes information on impervious urban surfaces. NLCD is a product created by the Multi-Resolution Land Characteristics (MRLC) Consortium, a partnership of federal agencies led by the U.S. Geological Survey (USGS). Future land cover projections were also obtained from the USGS. The dataset includes annual land cover maps from 2006 to 2100 (45). This dataset is characterized by a 250-meter spatial resolution (250-m pixels), 17 land cover classes, similar to classes from NLCD, with a spatial coverage for the entire conterminous United States. This study included projected map layers for the years 2040, 2060, 2080 and 2100.

Vacant land parcels

The geocoded parcel data used was a statewide standardized parcel resource available in NC OneMap website. This dataset includes attributes such as ownership, area in acres, assessed value, and other core cadastral attributes. Web services have both polygons (parcel boundaries) and points representing each property, placed at or near the geometric center, with the same set of attributes. Each cl;ounty uploads an Esri shapefile with agreed-upon state attributes to the NC Parcels Transformer, a cloud-based application. When the county translates their parcel attributes to the state schema there may not be a match for the attribute transformation, therefore some attributes may be blank. In this current study, only 9 out of 23 counties had parcel descriptions. The analysis conducted for this study does not include the counties with missing parcel descriptions. The aggregated cadastral dataset was last updated in 2016.

Watershed and sub-basins

The watershed and sub-basin data were obtained from the NC (North Carolina) Department of Environmental Quality Online Geographic Information Systems. The watershed data includes a delineated vector layer of the river basin. The HUs are delineated at 1:24,000-scale in the conterminous United States consistent with the national criteria for delineation and resolution. For this dataset, the hydrologic units are given a Hydrologic Unit Code (HUC) of 12 digits describing where the unit is in the country and the level of the unit. This current study selected a 12-unit HUC polygon to achieve the greater analytical detail. Attributes of this dataset include HUCs, size of sub watershed (in the form of acres and square kilometers), type of watershed, non-contributing areas, and flow modifications.

Soil hydrologic groups

Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms. Hydrological studies in the United States have historically classified soils into four primary groups (A, B, C, and D) and three dual classes (A/D, B/D, and C/D), based on the categories established by the United States Department of Agriculture (USDA). This current study obtained soil hydrological group information from the Gridded Soil Survey Geographic Database (gSSURGO). gSSURGO is derived from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database. Statewide rasters were derived by converting to state boundaries from the traditional conterminous United States 30-meter raster database. This current study focused on a 10-meter raster (MapunitRaster_10m) of the map unit soil polygons feature class, which provides statewide coverage in a single layer. This resolution was chosen to maintain the extent of the polygons without sacrificing display performance.

Curve numbers and rainfall depth

The Simple Curve Numbers Method (SCN) uses curve numbers to calculate the volume of stormwater runoff that is generated from a given amount of rainfall. Curve number describe the characteristics of the drainage area that determine the amount of runoff generated by a given storm based on hydrologic soil group and land cover. The SCS runoff equation is given below:

$$Q^* = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (4)$$

Where;

Q^* = Runoff depth (in)

P = Rainfall depth (in)

S = Potential maximum retention after rainfall begins (in)

S is related to the soil and surface characteristics of the drainage area through the curve number (CN) by the following equation:

$$S = \frac{100}{CN} - 10 \quad \text{where CN is the curve number (no units)} \qquad (5)$$

In the current study, curve numbers for North Carolina soils were derived from various literature sources as shown in Table 1. The study adapted a rainfall depth of 3.10 inches, which corresponds to a 24-hour, 1-year return rainfall event, and is an average across all counties in Neuse River Basin (refer to supplementary materials for details). Estimates of county-level rainfall amounts for the selected storm design were based on the National Oceanic and Atmospheric Administration (NOAA) Atlas 14-point precipitation frequency estimates. Curve numbers were further adjusted to account for temporal variations in land development (46,47). A graphical representation of datasets used in the model are illustrated in the supplementary materials.

Table 1: Soil-water balance model lookup table values and citations for runoff curve numbers

Land Cover		**Curve Number by HSG**			
Description	**Land use code**	**A**	**B**	**C**	**D**
Open water	11	99	99	99	99
Perennial snow/ice	12	40	40	40	40
Developed, Open space	21	39	61	74	80
Developed, Low intensity	22	51	68	79	84
Developed, Medium intensity	23	61	75	83	87
Developed, High intensity	24	89	92	94	95
Barren Land	31	63	77	85	88
Deciduous forest	41	36	60	73	79
Evergreen forest	42	30	55	70	77
Mixed forest	43	36	60	73	79

Shrub/scrub	52	35	56	70	77
Grassland/herbaceous arid	71	49	69	79	84
Pasture/hay fair	81	39	61	74	77
Cultivated crops	82	64	75	82	85
Woody wetland	90	36	60	73	79
Emergent herbaceous wetland	95	72	80	87	93

Adapted from (41,48) and North Carolina Department of Environmental Quality Stormwater Design Manual (2017). NLCD stands for National Land Cover Data; HSG stands for Hydrological Soil Group

Scenario building

Using land cover data from USGS, we designed plausible scenarios of how the future may develop and assessed their precipitation patterns and runoff retention. We used future land use projections for the years 2040, 2060, 2080 and 2100 as different future scenario input for InVEST. Each of these datasets formed the counterfactual scenario for the respective years. In comparison, runoff retention was modeled for each projected year, simulating all land parcels that were vacant in 2019 to remain undeveloped in each respective year. A linear regression was conducted to evaluate the relationship between vacant space and amount of runoff retention produced by the InVEST model. The dependent variable was amount of runoff retention (m^3) and the explanatory variable was the total acreage of vacant spaces (sq ft) in a sub-watershed.

Results

Projected future land development

Results show that between 2020 and 2100, the Neuse River Watershed is likely to see an increase in developed areas (Figure 1). There will be an 8.1% and 10% increase in undeveloped land in 40-year increments between 2020-2060 and 2060-2100, respectively. The hotspots representing projected future development areas intersect with known urban and metropolitan administrative areas. For example, there is a concentration of projected future development along the urbanized Durham-Raleigh corridor. Changes in land cover types are key in how effectively a sub-watershed's hydrology responds to flooding.

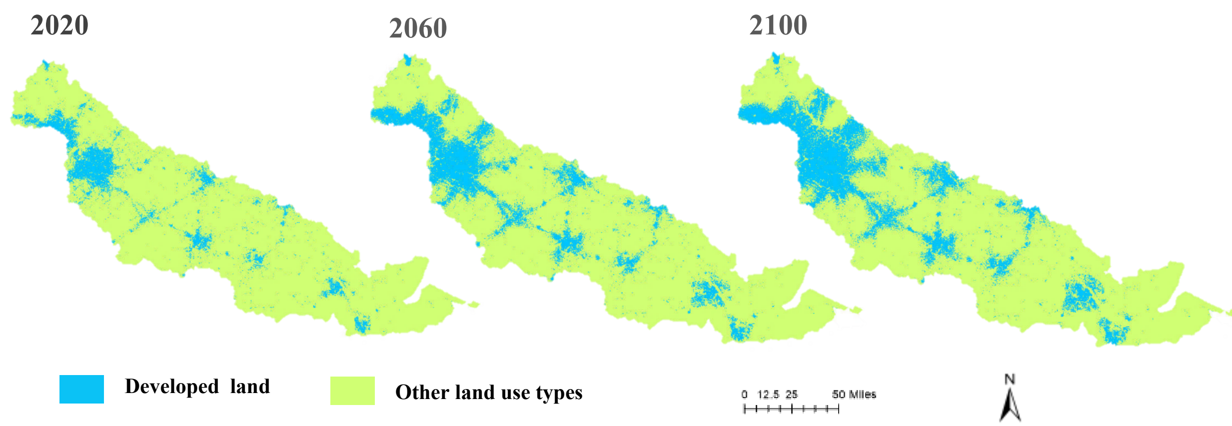

Figure 1: Change in developed land cover type in Neuse Basin. The left map shows the distribution of developed land (blue) and other land uses (green) in 2020. The middle and right maps show the distribution of developed versus other land uses in 2060 and 2100, respectively.

Runoff retention in vacant land

The findings reveal that the Neuse River Basin encompasses 850,000 land parcels across 23 counties. However, only 9 of these counties provided descriptions for their county-level data, and were therefore included in the analysis. Among these counties, the study identified a total of 91,000 vacant land parcels. The analysis found 16,000 vacant parcels within the floodplain, covering a total area of 541,398 square feet. The estimated volume of runoff retention for vacant land at the baseline scenario (year 2020) was 41,943,030.58 m^3 (Figure 2). The projected analysis showed an increase in flood retention for vacant lands compared to developed lands, with the exception of 2040. This discrepancy may be attributed to the projected land cover classes in that scenario being more effective at conserving floodwaters. Notable changes in runoff retention were observed, with a 1.90% difference between vacant and developed lands in 2060, and smaller changes of 0.10% and 0.12% in 2080 and 2100, respectively. Additional summary statistics from the InVEST model are available in the supplementary information.

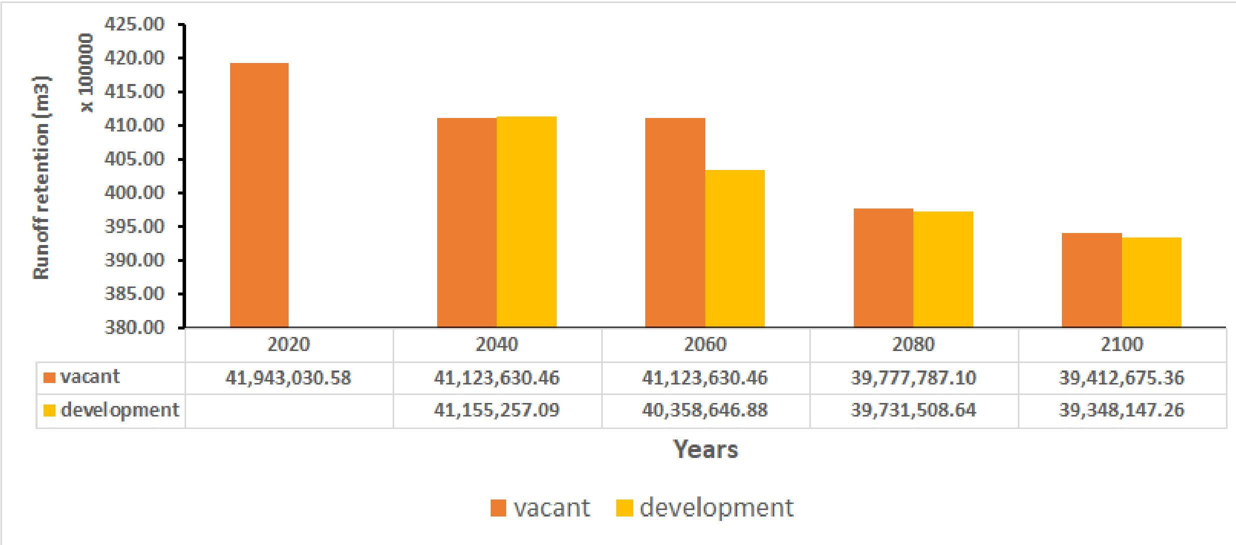

Figure 2: Estimated runoff retention of vacant and development land at baseline and projected scenarios. The y-axis shows the runoff retention index (measured in m³) of the watershed, plotted against time periods on the x-axis (2020, 2040, 2060, 2080, and 2100), comparing vacant land versus developed land within the Neuse River Basin.

Figure 3 illustrates the runoff retention index for the Neuse River Basin across different temporal scenarios. The basin consists of 192 sub-watersheds, each identified by a 12-digit hydrologic unit code. The runoff retention index represents the proportion of runoff retained after a rainfall event, relative to the total runoff generated in a sub-watershed. In the baseline year of 2020, the average runoff retention index (Ri) across all sub-watersheds was 0.65. For the years 2040-2100, the average Ri for the vacant land scenarios was 0.67, while the average Ri for the developed land scenarios was 0.64, suggesting that preserving vacant land in the floodplain may provide greater flood risk protection. Notably, sub-watersheds located in the upper Neuse Basin demonstrated higher runoff retention.

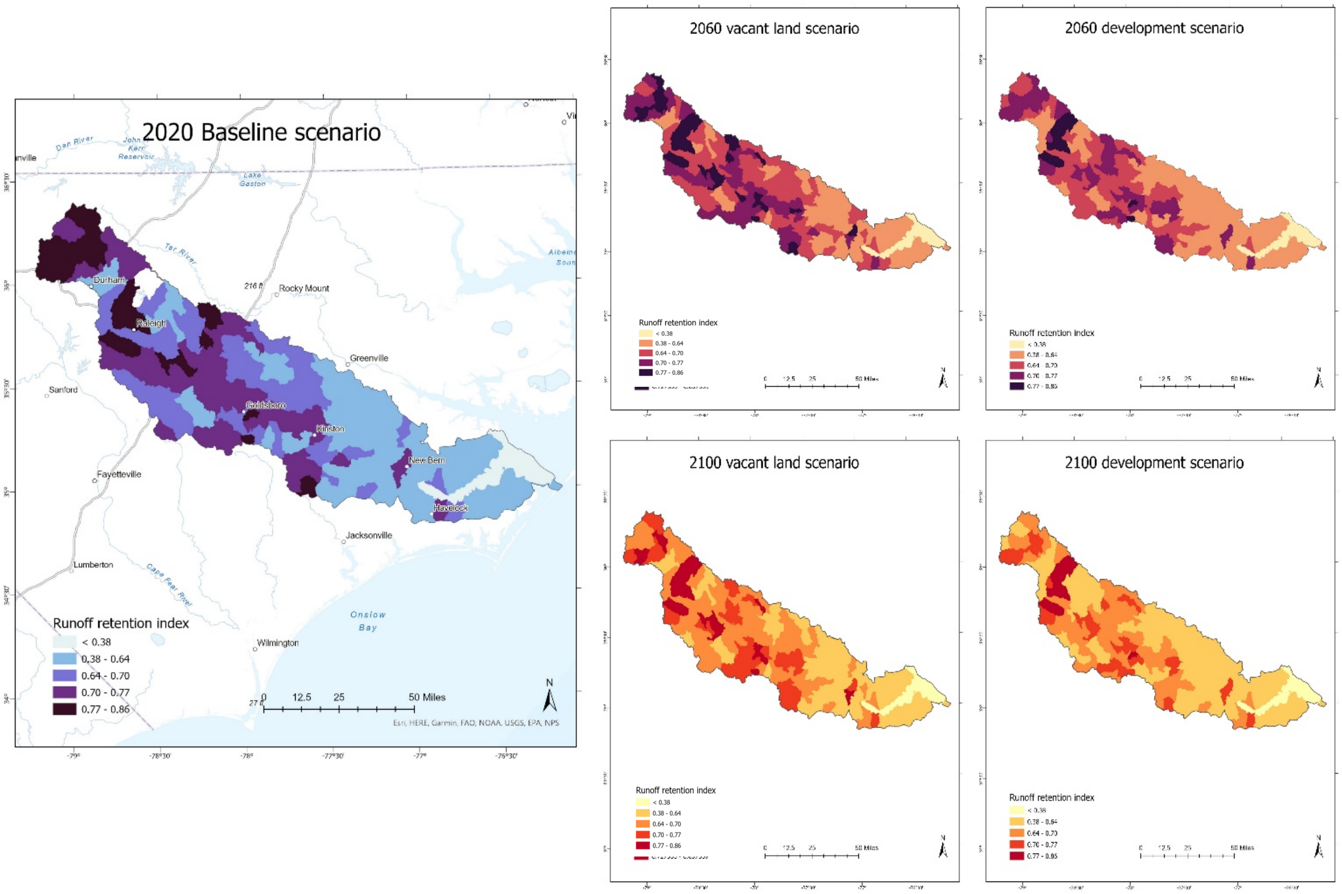

Figure 3: Modeled change in amount of runoff retention in Neuse Basin over time. The maps show the runoff retention index of the Neuse River Basin, defined as the proportion of runoff retained after a rainfall event, relative to the total runoff generated in a sub-watershed. The map on the left represents analysis for the year 2020, while the maps on the right depict projections for 2020 through 2100 in 20-year increments. In each map, darker hues indicate higher runoff retention, while lighter hues represent lower runoff retention. Higher runoff retention indexes are a proxy for greater capacity to mitigate flood risk.

Discussion

This study provides information on the precipitation pattern and runoff infiltration in the Neuse Basin following a 24-hour, 1-year return rainfall design with an estimated rainfall depth of 3.10 inches. The findings suggest that maintaining a significant proportion of undeveloped vacant land can help mitigate flood impacts. Additionally, the analysis of runoff retention in the basin for the 2060, 2080, and 2100 future scenarios supports our hypothesis, showing that this relationship holds true under projected future development.

Our findings align with those of Kelleher et al. (49), who investigated stormwater infiltration performance on vacant lots in Buffalo, New York. Their study demonstrated that 500 vacant lots infiltrated between 15.5 and 83.9 m^3 of runoff volume during a one-hour storm event modeled on a 21-year storm design. The study also found that demolishing buildings increased rainfall detention. This suggests that the infiltration rate into the ground is substantially impeded when precipitation interacts with impervious surfaces, highlighting the role ofbuilt environment characteristics in influencing stormwater dynamics. Extensive studies, both within and outside the United States, have supported this concept (7,29,50–54). However, an unexpected finding in our study was that the runoff retention in the projected 2040 development scenario exceeded that of the vacant land scenario. This result may be attributed to the anticipated land cover types in 2040 being better suited to enhancing stormwater infiltration compared to vacant land.

Several studies have established that floodplain development and urbanization are primary drivers of increased flood risk (52,55–59). Consistent with these findings, our results reveal a projected upward trend in land development within the Neuse River Basin over the next 80 years, highlighting the growing pressure of urbanization on hydrological systems and its potential to exacerbate flood risks by increasing impervious surfaces and disrupting natural water flow pathways. A study by Carrell (60) examined changes in urban development over the past 30 years within the Walnut Creek Watershed, a sub-basin of the Neuse River Basin, and concluded that increased development in the watershed disproportionately impacted at-risk communities in its southeastern region.

Our study indicates that increasing land developments serves as a proxy for higher potential runoff within the basin, a finding consistent with Lin et al. (52), who explored the implications of future land-use changes in the Pearl River Delta, China. Using a future land-use simulation model for flood risk assessment, their study projected a significant increase in a built-up areas in 2030 and 2050 compared to the 2015, correlating with a marked rise in flooding risk. Similarly, understanding changes in land development within the flood plains of the Neuse River Basin is critical due to the potential consequences of flooding.

As development intensifies in these areas, the proliferation of impervious surfaces reduces infiltration capacity, resulting in higher runoff volumes (61,62). This runoff not only strains stormwater infrastructure (Shariat et al., 2019) but also disproportionately impacts minority communities, who often face greater vulnerability to flooding events (64). Johnson et al. (31) further emphasize the growing risks, reporting that by 2050, an estimated 141,449 km^2 and 127,928 km^2 of land within U.S. floodplains are projected to be developed under two population and development scenarios based on the Integrated Climate and Land Use Scenarios (ICLUS). Such developments within floodplains significantly increase the risks to property and human life during flood events, underscoring the need for proactive land-use planning and floodplain management.

As with all aspects of the hydrological cycle, the interaction between precipitation and surface runoff varies temporally and spatially. Our analysis revealed that some counties within the Neuse Basin managed runoff more effectively, optimizing the natural capacity to mitigate flood risk. In contrast, a negative association between vacant land and runoff retention was observed for Franklin and Nash counties. This discrepancy may be attributed to the relatively small total acreage of vacant land in these counties, which accounted for only 1.5% and 0.6%, respectively, of the basin's total vacant land. The limited data points for these counties likely lacked the statistical power needed to robustly detect trends, emphasizing the importance of scale in analyzing the relationship between vacant land and flood risk. This finding highlights the need to investigate vacant land and flooding dynamics at appropriate spatial scales. While InVEST software is designed to model these relationships at the sub-watershed level, finer-scale studies could provide more actionable insights for planners, real estate developers, and water authorities. Future research should consider conducting analyses at smaller scales, such as parcel or neighborhood levels, as well as broader basin-wide assessments for comprehensive planning.

Previous studies have similarly identified urban corridors in North Carolina as flood-prone hotspots. Consistent with our findings, the literature reports an increase in flood extent in Kinston, where much of the population resides along the Neuse River and faces heightened vulnerability to flood hazards (17,42). Moreover, North Carolina has experienced more than three severe hurricanes in recent decades, leading to catastrophic flooding and extensive damage to infrastructure. These recurring flood events underscore the urgency of integrating adaptive land-use planning and flood mitigation strategies to enhance resilience across the region.

Implications for flood risk management

Vacant lands have been recognized as valuable assets in reducing flood damages, particularly in floodplains, by storing floodwaters and enhancing runoff retention. Our findings support this concept, showing that preserving vacant lands within floodplains can significantly improve flood retention compared to developed areas. The increase in runoff retention in vacant lands over time aligns with previous studies that have quantified the flood mitigation services of urban green spaces and open lands. These spaces have demonstrated substantial runoff retention capacities, further emphasizing their potential in managing flood risks.

This study highlights the importance of acquiring and protecting vacant lands within floodplains as a strategy to reduce flood volumes, both in current and future development scenarios. It reinforces the need to integrate nature-based solutions, such as the preservation of open urban green and blue spaces, into flood resilience planning. Beyond flood mitigation, preserved vacant lands can offer additional environmental benefits, including habitat protection, recreational opportunities, and improvements in water quality.

The positive correlation between vacant lands and runoff retention observed in our study suggests a valuable policy opportunity to use vacant lands as a tool for flood mitigation in the Neuse River Basin. Counties with significant increases in runoff retention linked to vacant land should prioritize planning buyouts or land acquisition to prevent future development in these areas. This approach can help protect floodplains and reduce flood risk to surrounding communities.

While this study provides important insights, further research is needed to address its limitations. Future studies should consider conducting a benefit-cost analysis to evaluate the trade-offs between preserving vacant lands and developing them, taking into account both flood risk reduction and economic factors. Additionally, integrating hydrological models to project future flood risks in the context of climate change and increasing precipitation will provide more comprehensive guidance for flood management strategies.

Limitations

This study has several limitations that must be considered. First, the InVEST Model simulation introduced potential uncertainty in the analysis. While the simulation was based on the physical properties of the hydrological cycle, it gave limited consideration to meteorological inputs such as the directional flow of runoff and ocean-related flooding. Additionally, the land use and land cover data used in the modeling process had a spatial resolution of 250m, which did not allow for precise modeling of runoff distribution at the land parcel level.

A key assumption of this study is that preserving and maintaining vacant land within floodplains will reduce future flood risk. However, the study does not account for the potential impacts of development outside the floodplain that could result from the proposed preservation policy, particularly in upstream areas. Such development may lead to increased flooding downstream over the long term. Consequently, more sophisticated techniques are needed to identify areas that may be more susceptible to future development and flooding as a result of preserving vacant land in the floodplain.

Another limitation was the lack of comprehensive land parcel data. More than half of the counties included in the study had missing land parcel data, which could have introduced bias into the model outputs and affected the accuracy of estimates regarding the impact of vacant land on flood risk reduction. Despite these limitations, the study provides valuable evidence on the role of vacant land in mitigating stormwater runoff and contributing to flood risk management

Conclusion

Over the years, extreme rainfall events have caused extensive and sometimes devastating flooding near rivers and coastal areas in North Carolina. Communities living with the Neuse River Basin catchment have been reported to have suffered significant economic flood-related losses. Flood mitigation by the vacant land in Neuse Basin was quantified in terms of runoff retention and the volume of runoff retained at each pixel during a 2-year design precipitation. Analysis results indicate that having a higher portion of undeveloped space can reduce the effect on flooding risk. The study provides a practical approach for estimating potential runoff retention service offered by the ecosystem. The results may serve as guidelines for city planners and policymakers for sustainable land use and planning.

Acknowledgments

We would like to acknowledge the support of Clark L. Gray from The Department of Geography and Environment, and Antonia Sebastian from The Department of Earth, Marine and Environmental Sciences | Environment, Ecology, and Energy Program (E3P) at the University of North Carolina at Chapel Hill for their contributions to this research.

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Supporting information

Supporting information detailing additional steps for data processing in the InVEST Model, historical rainfall estimates for the Neuse River Basin, maps illustrating input modeling data, and summary statistics of the model output.

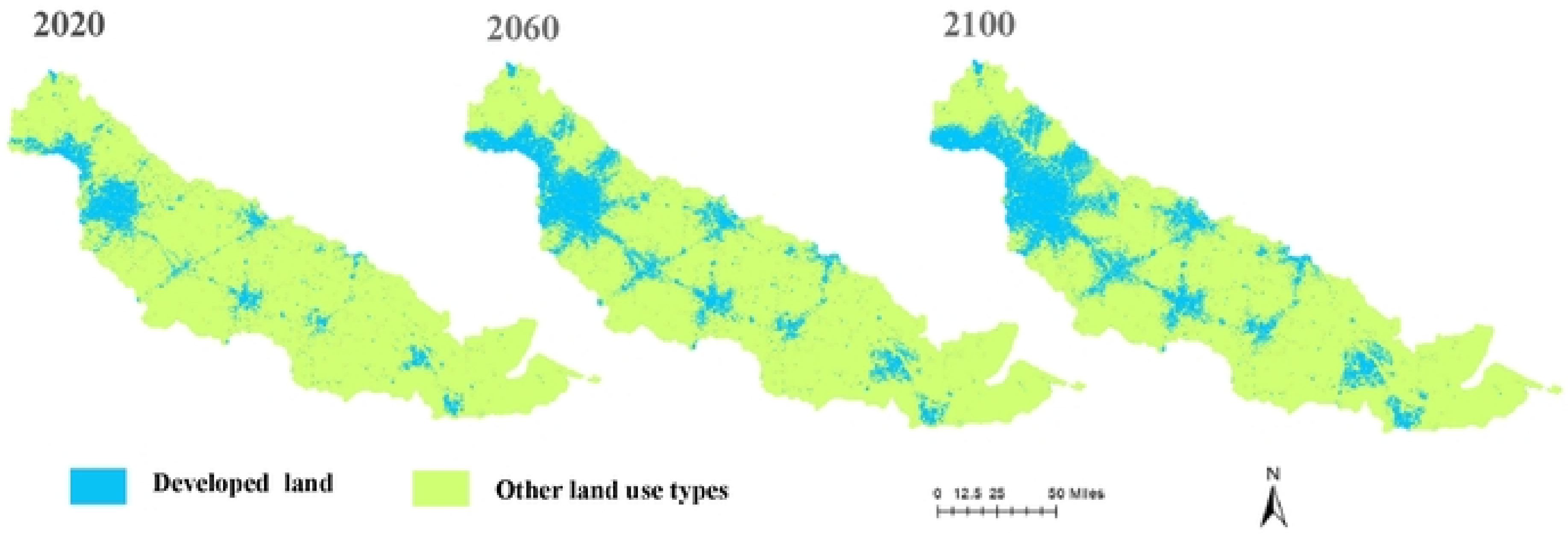
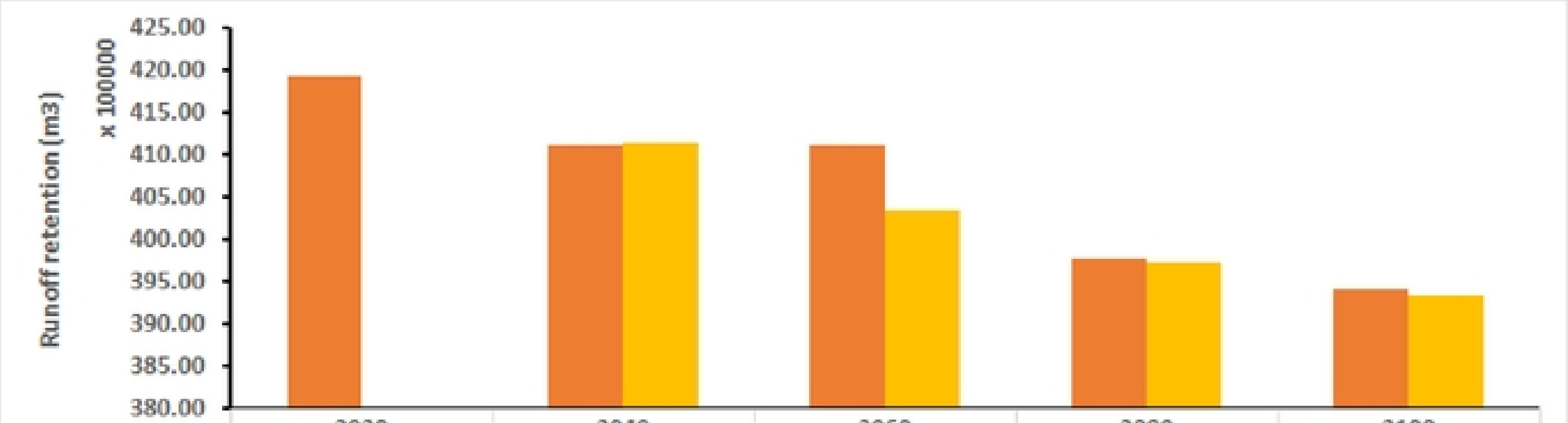

2020
2060
2100
Developed land
Other land use types
0 12.5 25 50 Miles
N

Figure 1



	2020	2040	2060	2080	2100
vacant	41,943,030.58	41,123,630.46	41,123,630.46	39,777,787.10	39,412,675.36
development		41,155,257.09	40,358,646.88	39,731,508.64	39,348,147.26

Figure 2

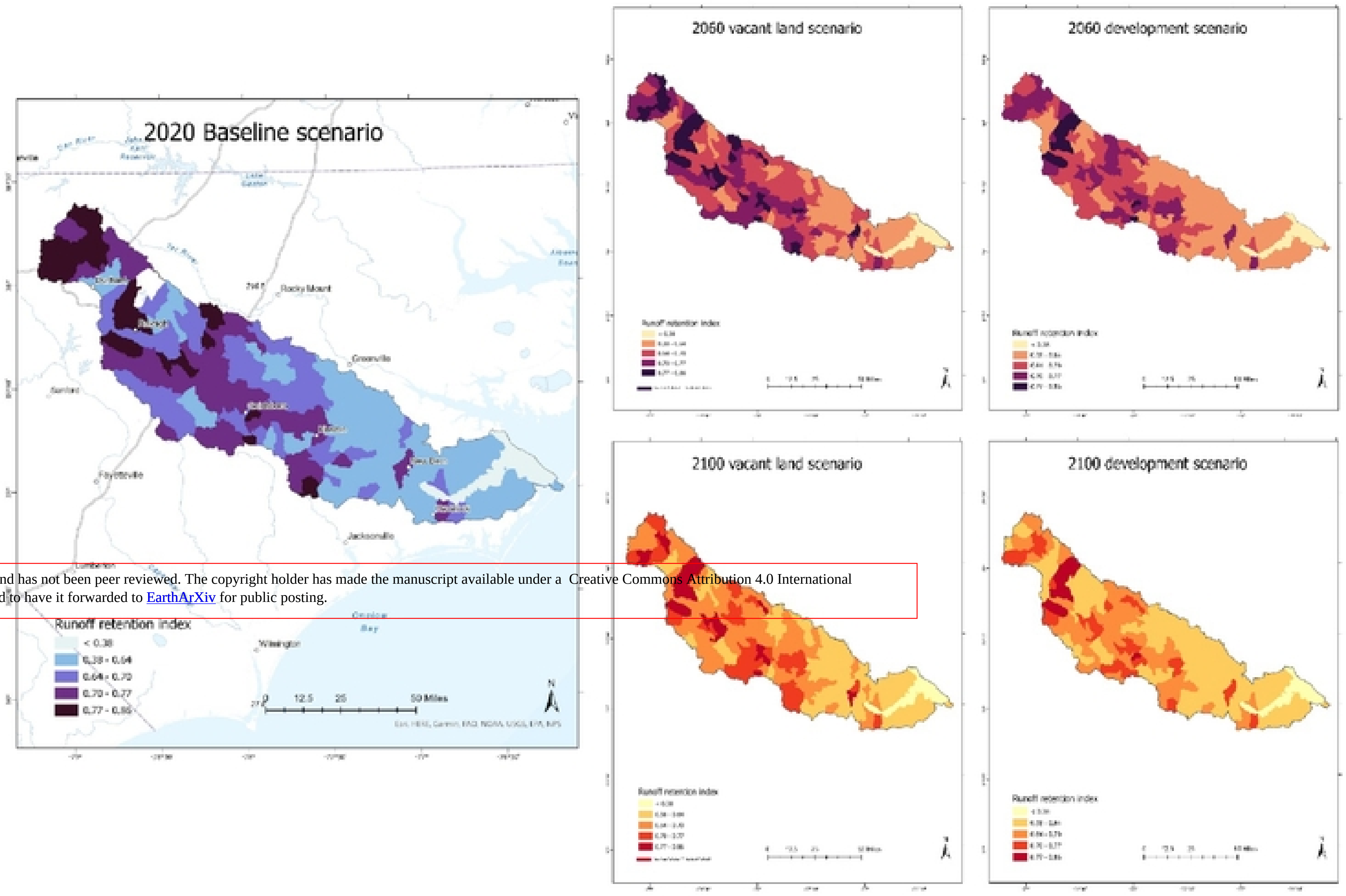

2020 Baseline scenario
Rocky Mount
Greenville
Sanford
Fayetteville
Jacksonville
Wilmington
Runoff retention index
< 0.38
0 12.5 25 50 Miles
2060 vacant land scenario
2060 development scenario
2100 vacant land scenario
2100 development scenario

Figure 3