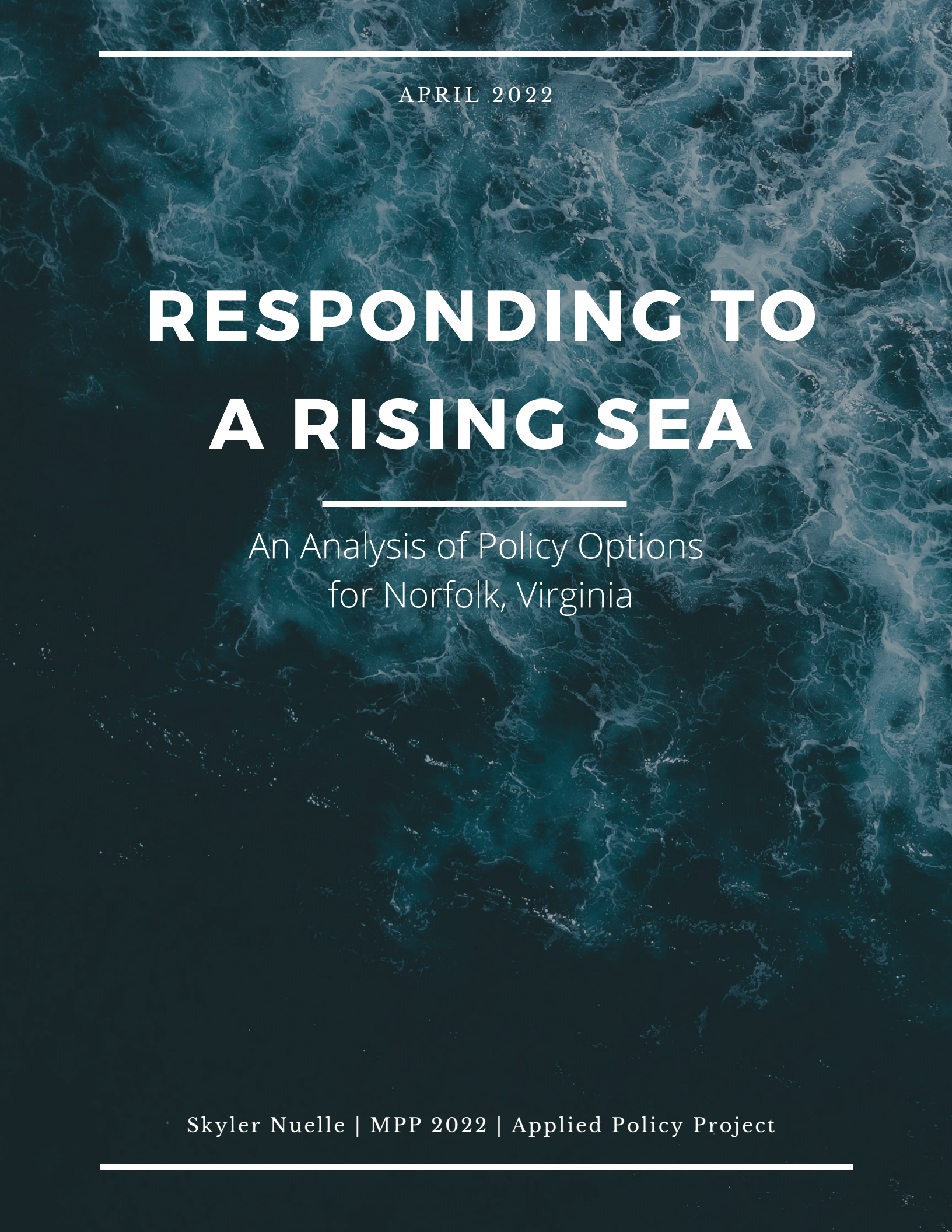

APRIL 2022

RESPONDING TO A RISING SEA

An Analysis of Policy Options for Norfolk, Virginia

Skyler Nuelle | MPP 2022 | Applied Policy Project

Acknowledgments

There are countless people I would like to thank for their support, guidance, and encouragement throughout this process. Thank you firstly to Mary-Carson Stiff and Skip Stiles at Wetlands Watch for working tirelessly every single day to advance coastal resilience and wetlands protection in Virginia. Your work is both impactful and inspiring to so many of us. Thank you also to Wetland Watch for providing me the opportunity to work on a topic that I care so deeply about.

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Thank you to my incredible classmates and the exceptional faculty and staff at the Batten School. Your passions, lessons, and characters continue to push me to be a better friend, student, and citizen. I will be forever grateful to this community of brilliant and inspiring people.

Thank you, finally, to my friends and family that have supported me throughout this process (during both the peaks and the valleys). Simply put, you guys rock.

With gratitude,

On my honor as a student, I have neither given nor received aid on this assignment.

Disclaimer

This study was conducted as part of the program of professional education at the Frank Batten School of Leadership and Public Policy, University of Virginia. This paper is submitted in partial fulfillment of the course requirements for the Master of Public Policy degree. The judgments and conclusions are solely those of the author, and are not necessarily endorsed by the Batten School, by the University of Virginia, by Wetlands Watch, or by any other agency.

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Overview

Introduction

As climate change worsens, Norfolk and its residents will be increasingly jeopardized by rising waters. The following report seeks to identify feasible and effective means of responding to such sea level rise in Norfolk. This analytical report is generally composed of seven general sections that, combined, provide a broad overview of the problem of sea level rise in Norfolk, its magnitude, and its consequences as well as possible responses to it.

Specifically, this report will define the specific problems sea level rise is posing to the city and propose economic estimates of its fiscal scale. It will then summarize relevant context and background on this topic, examining the root drivers of sea level rise, its specific implications on Norfolk, and response strategies that have been used in other contexts. After defining evaluative criteria, this report will propose and analytically compare which alternative is best suited to address sea level rise risks in Norfolk. After defining a specific recommendation, this report overviews the steps and considerations that could guide the recommended approach's implementation.

Client Overview

Wetlands Watch is a Norfolk-based environmental non-profit 5013(c)(3) organization focused on the protection of wetlands and coastal resources in Virginia. Wetlands Watch pursues wetlands protection dimensionally through federal and state policy advocacy, grassroots education and mobilizations, and dynamic regional partnerships. Wetlands Watch has recently focused much of their work on issues related to sea level rise along Virginia's coastline, developing apps, tools, resources, and comprehensive reports that help inform sea level rise planning, adaptation, and decision making in Virginia. Wetlands Watch is a leader in coastal wetlands protection and management policy; as such, they have played essential roles in coastal policy formulation and implementation across the Commonwealth. Most recently, Wetlands Watch has been central in guiding the development of Virginia's Coastal Resilience Master Plan, Virginia's first comprehensive plan to bolster Commonwealth-wide resilience to climate change-induced sea level rise.

This report aims to support Wetlands Watch's mission by identifying creative responses to sea level rise that dually protect Norfolk's coastal communities from flooding and facilitate the flourishing of regional wetland ecosystems. It seeks to advance Wetlands Watch as they help localities plan for sea level rise, advocate for policies that protect Norfolk communities and wetlands, and inform community decisions about sea level rise-related project prioritization and resource allocation.

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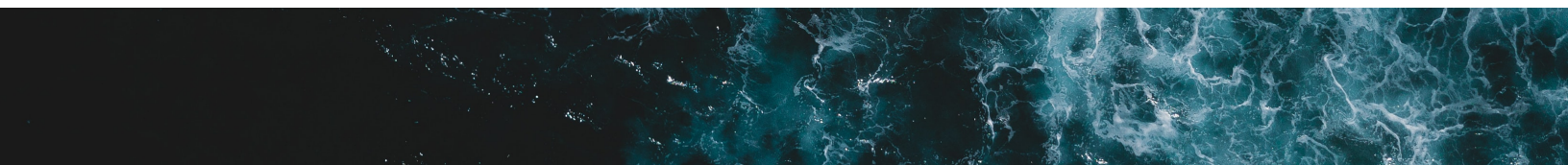
WETLANDS WATCH



Executive Summary

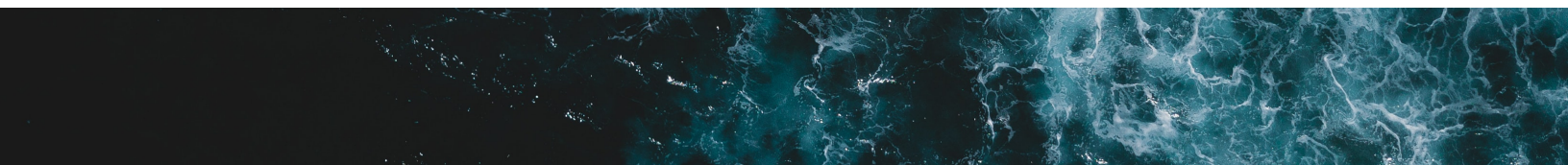
Sea level rise is one of the many impacts of climate change that is threatening populations all around the world. With both rising waters and sinking land, the City of Norfolk, Virginia is exceptionally vulnerable to sea level rise. Currently, the city experiences one of the highest rates of relative sea level rise in the entire United States, and this rate is only expected to increase with time.

Sea level rise poses a threat to the social, economic, and environmental fabric of Norfolk, Virginia. As waters rise, local communities will be increasingly vulnerable to floods and storms, and vital wetland ecosystems will be at risk of inundation and disappearance as they are unable to migrate inland. Without wetland ecosystems, the implications of sea level rise will be exacerbated throughout the city as their flood, storm, and erosion ecosystem services are lost.

This report explores the potential to increase or preserve natural buffer space between rising waters and developed communities in the city to facilitate wetlands migration, preserve their critical ecosystem services, and increase residents' protection from the rising seas. This report examines three potential policy alternatives to respond to sea level rise in the city:

1. Establish a Voluntary Property Buyout Program
2. Develop a Post-Disaster Redevelopment & Acquisition Plan
3. Formalizing a Transfer of Development Rights (TDR) Program with a TDR Bank

Alternatives are evaluated according to cost-effectiveness, administrative complexity, immediacy, and environmental impact criteria. Based on this criteria, this report recommends that Norfolk pursues formalizing a Transfer of Development Rights (TDR) Program with a TDR Bank. Implementation steps and features overviewed include city surveys and market assessments, community engagement and outreach, program proposal recommendations, and evaluation considerations.



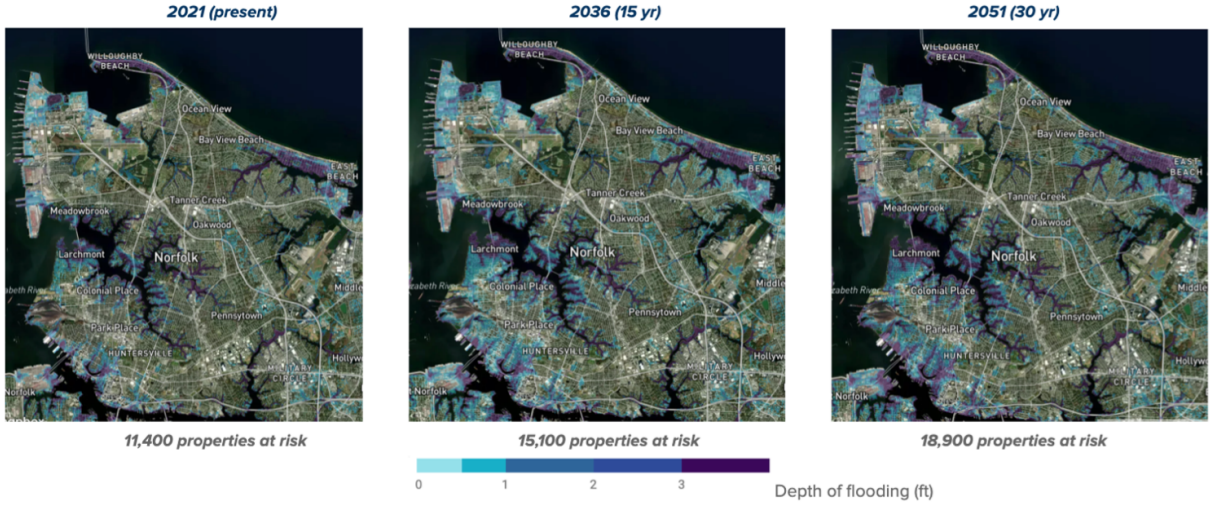
Problem Definition

Everyday, sea level rise threatens global populations, economies, and ecosystems. With about 40% of its population living along coastlines, sea level rise poses an especially salient threat in the United States (NOAA, 2021). With both rising seas and sinking land, the Commonwealth of Virginia is at exceptionally high risk of inundation from climate change-induced sea level rise. This threat is especially mounting in Virginia's coastal city, Norfolk, where sea levels are rising at accelerating rates and residents are becoming increasingly vulnerable as regional wetlands disappear.

With a rate of relative sea level rise more than double the global average, Norfolk, Virginia experiences the fastest rate of relative sea level rise along the United States' entire East Coast. While global communities, on average, have experienced between eight and nine inches of relative sea level rise since 1880, Norfolk has experienced more than 18 inches of rise since 1900 (Connolly, 2015). Sea level rise is accelerating, increasingly jeopardizing Norfolk's economies, communities, infrastructures, and essential ecosystems. Under current projections, it is estimated that more than 15,000 properties will be affected by sea level rise flooding within the next 15 years, and by 2051, such an estimate will surpass 18,500 properties (FloodFactor, 2021). As sea levels rise, Norfolk's coastal developments will prevent wetlands from migrating inland; as a result, these wetlands will be inundated and eventually die. Without these critical ecosystems, regional sea level rise will be exacerbated, leading to more frequent and hazardous flooding, harsher storms, and increasing damages - the costs of which will fall onto society.

Sea level rise is a global problem that will demand global coordination to mitigate. As such, the City of Norfolk, alone, is not able to prevent or mitigate sea level rise; instead, the city must prepare to adapt to the inevitably rising waters. The city has begun implementing a series of coastal resilience measures throughout the city, including novel zoning ordinances, flood-resistant building codes, and participation in resiliency planning initiatives. While many of the implemented measures increase the region's structural flood resiliency, they will not eliminate the city's vulnerability to sea level rise, nor will they increase flood buffer space for wetlands migration. Therefore, the City of Norfolk, Virginia must identify a means of retreating away from flood-prone shorelines to increase natural flood buffer space, allow wetlands migration, and protect Norfolk's communities.

Figure 1. Norfolk Regions at Risk of Flooding Over Time (1% or 100-year floodplain) (*FloodFactor Projection)*



FloodFactor. (2021). Norfolk, Virginia. Flood Factor. https://floodfactor.com/city/norfolk-virginia/5157000_fsid

Cost to Society

With valuable assets, communities, and infrastructure at risk of inundation, sea level rise will be socially, economically, and environmentally destructive in Norfolk, VA. Estimated costs calculated below are not exhaustive and should not be taken as exact values; rather, the following costs serve to demonstrate the magnitude, severity, and urgency of projected sea level rise in Norfolk.

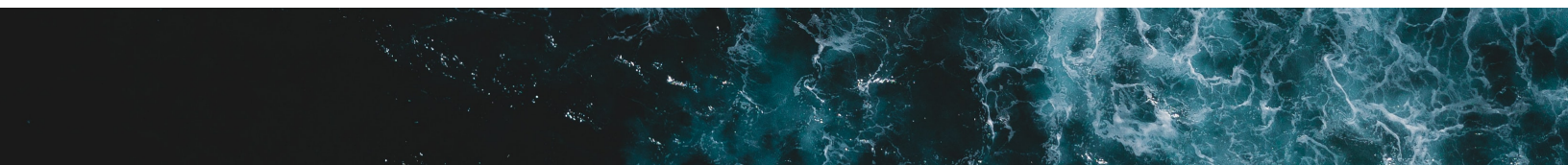
Direct Costs

Direct costs of sea level rise in Norfolk are based on National Flood Insurance Program (NFIP) policies in the city and on the Federal Emergency Management Agency's (FEMA) 2016 flood risk analysis for the city, which drew upon projected models of anticipated flood risk area and flood depths to estimate potential losses that would result from different flood scenarios (FEMA, 2016). Using FEMA estimates of potential flood damages to properties (commercial, residential, other) and the cost of maintaining flood insurance under a 100-year flood scenario in Norfolk, it is estimated that the total direct costs associated with sea level rise in Norfolk is about $306,937,500.

Externalities

The primary externality associated with sea level rise is the drowning and disappearance of wetland ecosystems that provide ecosystem services to human communities (Braun de Torrez, 2021; NOAA, 2021). These ecosystems provide valuable ecosystem services, including storm/erosion protection, recreation, food production, and carbon sequestration amongst others; therefore, sea level rise creates externalities by reducing and/or eliminating these natural ecological processes (Cooley, 2015).

In 2014, Norfolk was reported to have about 777 total acres of wetlands (Berman et al., 2014). In 2021, researchers used NOAA sea level rise projections of the Chesapeake Bay area to estimate the resulting wetlands losses in the region. They estimated that Virginia would lose about 38% of wetlands under a low sea level rise scenario projection of 0.6 meters of rise by 2100; Virginia was estimated to lose about 47% of wetlands under a high sea level rise scenario of 1.8 meters by 2100 (Rezaie et al., 2021). Assuming Norfolk would experience the same rates of wetlands loss, it is estimated that Norfolk would lose between 295-365 acres of tidal wetlands by 2100. Wetland ecosystems have been valued between $2,429-$17,000 per acre in Louisiana (Costanza et al., 1989). Assuming that values are transferable between the states it is estimated that sea level rise could jeopardize between $716,555-$6,205,000 in wetland ecosystem services in Norfolk by 2100.



Background

Background

Climate Change & Sea Level Rise

Climate History

Sea level rise is one of the many implications of global climate change that is threatening communities, economies, and environmental systems across the globe (NASA, 2021; IPCC, 2021). Climate change has driven global sea level rise primarily through thermal expansion, which increases the volume of water in oceans, and through the melting of land ice, which increases the amount of water in oceans (USGCRP, n.d.). Since scientific records began in 1880, global sea levels have increased between eight and nine inches on average, and about 33% of that rise has occurred within the last 25 years, demonstrating the increasing acceleration of rise (Lindsay, 2020). The future severity and rate of sea level rise will depend on greenhouse gas (GHG) emissions, global temperature changes, and emissions mitigation efforts.

Implications of Sea Level Rise in Norfolk, Virginia

Sea level rise represents a socio-ecological issue in Norfolk, Virginia, jeopardizing crucial infrastructure, institutions, and communities while simultaneously threatening invaluable environmental processes (Considine et al., 2017). Norfolk is a low-lying city on Virginia's East Coast, located at the junction of the Chesapeake Bay and the Elizabeth River. Home to more than 240,000 residents, Norfolk is the second largest city in Virginia (Gaberino et al., 2020). The city is part of the greater Hampton Roads metropolitan region, which is recognized as the second largest population center at greatest risk from sea level rise in the U.S. (Considine et al., 2017; Institute for Environmental Negotiation, 2011). The region is especially susceptible to sea level rise because of land subsidence from aquifer compaction (from groundwater pumping) and geological changes, causing an estimated 1.5-3.7 and 0.6-1.8 millimeters of subsistence each year respectively (Eggleston and Pope, 2013; Ezer and Atkinson., 2015).

The City of Norfolk is already confronting the adverse effects of sea level rise. One such effect is *nuisance flooding*, which is minor tidal flooding that can cover roadways and prevent residents from traveling (e.g., to work, school, etc.) or from acquiring important services (e.g., emergency services, hospital, etc.) (Ezar and Atkinson, 2015). With higher seas, nuisance flooding has become more frequent and longer lasting in the city. Prior to 1980, Norfolk experienced only about 30 hours of annual nuisance flooding and 50+ hours of flooding occurred rarely as a result of large storms (once per 10 years); however, since 1990, Norfolk has experienced 100-200 hours of nuisance flooding annually from much smaller weather events (Ezer and Atkinson, 2015). Norfolk experiences between 4.4-5.4 millimeters of sea level rise each year (Eggleston and Pope, 2013; Ezer and Atkinson, 2015; Malmquist, 2020; Kramer, 2016). If Norfolk experienced only 4 millimeters of annual rise, by 2050, the city would face about 500 hours of annual nuisance floods; by comparison, if the city experienced 8 millimeters of rise in the same period, the city would be flooded for about four days a month (about 1,300 hours annually) (Ezer and Atkinson, 2015).

In all cases, Norfolk residents will be less able to access critical roads, infrastructures, and services from nuisance flooding alone. Simultaneously, with storms becoming both more intense and more frequent, the city will likely experience large scale inundation, increasing property damage, threatening residential health and safety, and degrading ecosystems through saltwater intrusion, erosion, habitat loss (e.g., marsh submergence), and pollution contamination (Gornitz, 2019; Nunez, 2019).

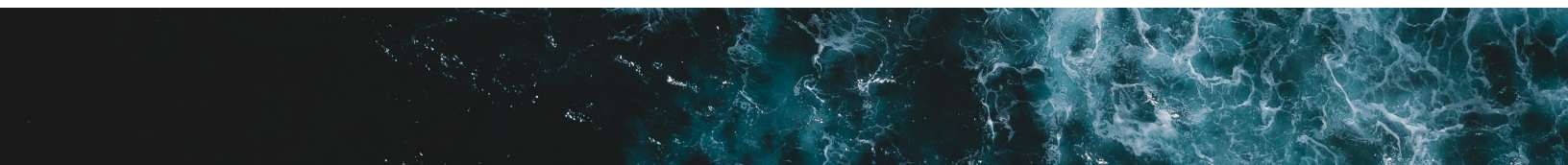


Figure 2. Historic and Projected Nuisance Flooding in Norfolk, VA (Hours Per Year) (*Ezer & Atkinson, 2015*)

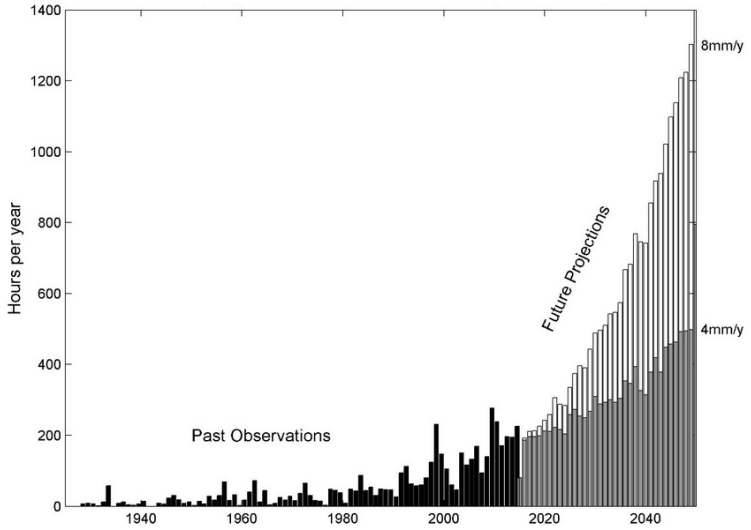


Image Source: Ezer, T., & Atkinson, L. (2015). Ezer, T. and L. Atkinson (2015), Sea level rise in Virginia-causes, effects and response. Virginia Journal of Science, 66(3), 355-359, Publication of the Virginia Academy of Science. Virginia Journal of Science, 66(3), 355–359.

Sea level rise-related flooding will also hinder regional economic activity; in 2018, the city found that the industries that employ the largest number of people in the Virginia Beach-Norfolk-Newport News Metropolitical Statistical Area were the Government, Health Care and Social Assistance, Retail Trade, Accommodation and Food Services, and Manufacturing (City of Norfolk, n.d.). All such industries would be negatively implicated by sea level rise and associated flooding as infrastructure and service/product access would likely be jeopardized by flooding.

Sea Level Rise Projections & Risk

With uncertainty about the amount of GHGs that will be emitted in the future, scientists have developed multiple scenarios of sea level rise, each one varying depending on future emissions rates (Lindsey, 2021). According to a 2019 IPCC report, under a low-, intermediate-, and high-emissions scenarios, global sea levels will rise 0.3, 0.6, and 1.1 meters above 2000 levels by 2100 respectively (NASA, 2021).

Figure 3. NASA Projections of Sea Level Rise under Low-, Intermediate-, and High-Emissions Scenarios

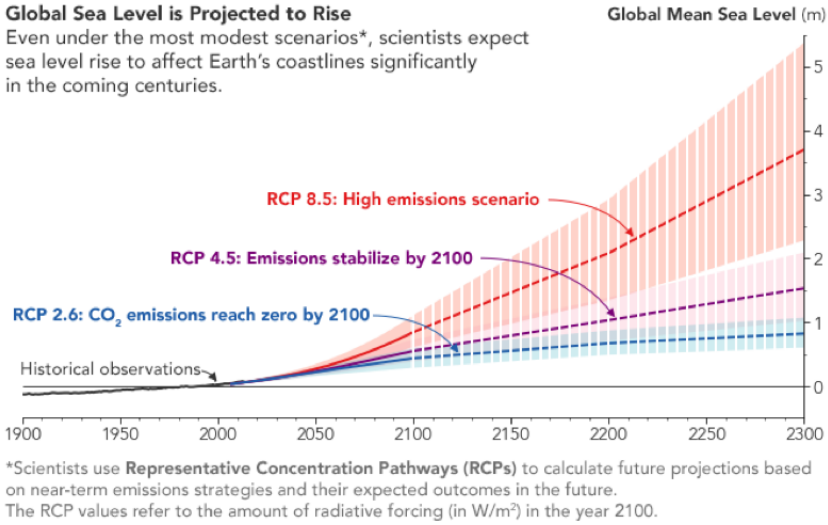
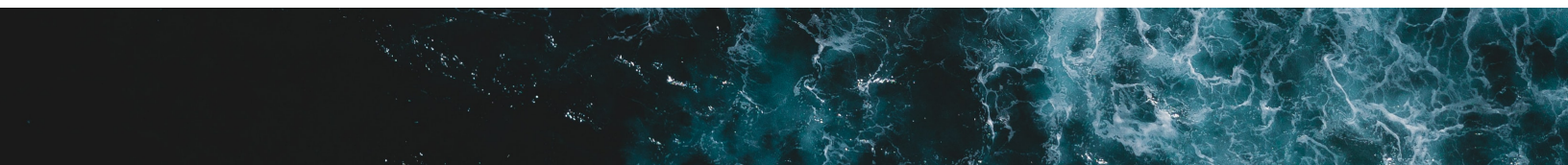


Image Source: NASA. (2021, July 8). Anticipating Future Sea Levels. NASA Earth Observatory. https://earthobservatory.nasa.gov/images/148494/anticipating-future-sea-levels



NOAA's intermediate-high projection scenario serves as the Commonwealth's "standard" for sea level rise planning and has been adopted in the Virginia Coastal Resilience Master Planning Framework (Gaberino et al., 2020; Vogelsong, 2021; Office of the Governor, 2020). Under this projection, sea levels are expected to increase about 6 feet by 2100, about 3.9 feet by 2070, and about 2.2 feet by 2050 relative to 2000 levels in Norfolk, VA (Vogelsong, 2021).

Figure 4. NOAA Sea Level Rise Projection Scenarios at Swells Point Monitoring Station, Norfolk, VA

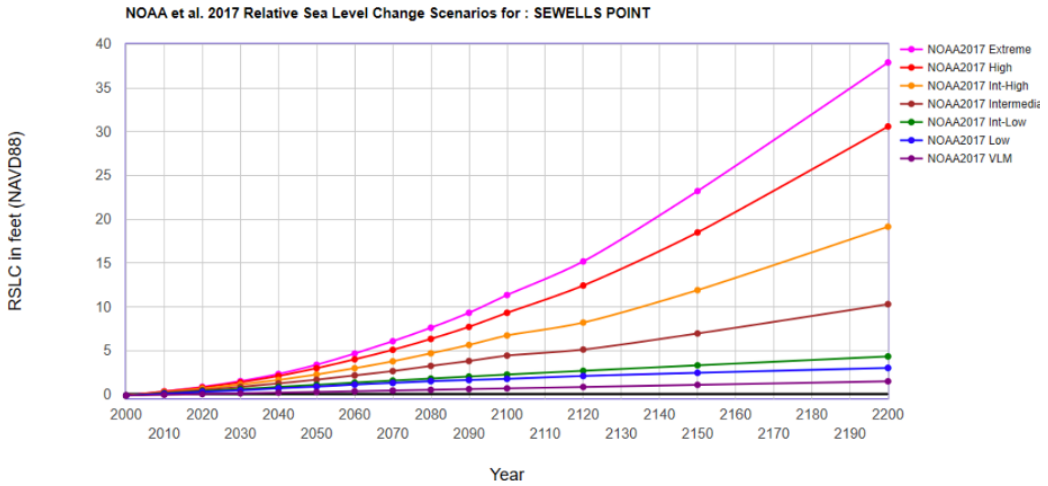


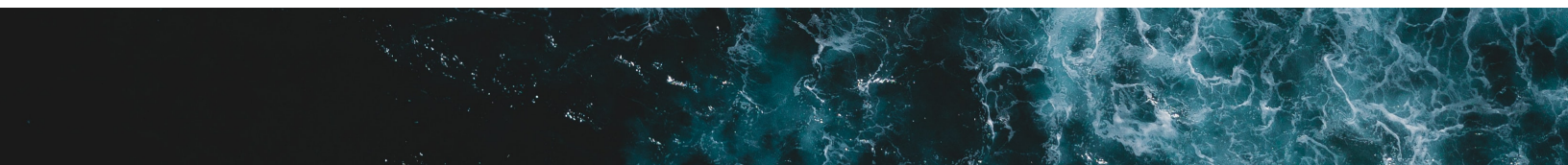
Image Source: Office of Governor Ralph S. Northam. (2020). VIRGINIA COASTAL RESILIENCE MASTER PLANNING FRAMEWORK Principles and Strategies for Coastal Flood Protection and Adaptation. Office of Governor Ralph S. Northam. https://www.governor.virginia.gov/media/governorvirginiagov/governor-of-virginia/pdf/Virginia-Coastal-Resilience-Master-Planning-Framework-October-2020.pdf

Governance

Sea level rise represents a global problem with national, state, and local implications. Planning responses to sea level rise often includes collaboration between multiple levels of government. Federal, state, and local governments are overviewed below to synthesize information regarding funding streams and critical decision-making processes and groups for coastal resilience planning in Norfolk, VA.

Federal Government

The federal government's primary role in responding to sea level rise is in allocating resources, providing technical guidance and/or standards, and providing funding to state and local governments. The federal government supports resilience projects through three primary mechanisms being (1) the National Flood Insurance Program (NFIP), (2) the Federal Emergency Management Agency (FEMA), and (3) the Department of Housing and Urban Development (HUD). Communities that are enrolled in NFIP are required to adopt federally specified floodplain management standards. The program provides additional incentives (e.g., reduced policyholder insurance premiums) for implementing standards above those required by NFIP (DCR, 2021). FEMA has played a central role in coastal resilience and sea level rise response funding. Through their Hazard Mitigation Grant Program (HMGP), FEMA provides funding to local and state governments to finance "sustainable action that reduces or eliminates long-term risk to people and property from future disasters" (FEMA, 2021). In 2020, FEMA awarded the Commonwealth $6.5 million through the HMGP, more than $3.2 million of which was awarded to Norfolk to elevate structures in the city's Special Flood Hazard Area (FEMA, 2020). Finally, HUD has provided funding for sea level rise and environmental resilience projects to local and state governments through their Community Development Block Grant program and their Community Development Block Grant-Disaster Recovery program (HUD, 2020). The National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA) provide further technical advising, scientific funding, and general guidance about sea level rise and potential responses for both states and localities (Folger and Carter, 2016).



State Government: The Commonwealth of Virginia

Virginia's government is responsible for allocating federally acquired funds to specific resilience projects and for designating the specific power of local governments. Virginia has a unique governance structure as the Commonwealth is a "Dillon's Rule" state (Gill, 2013). Dillon's Rule specifies that local governments can only exercise the powers that have been specifically granted to them by the ruling state (Gill, 2013). The Virginian government tends to designate substantial authority to local governments, and the current Virginia Code grants local governments authority in land use planning and development zoning (Gill, 2013). The Code specifies that local governments should consider both the current and future needs of their communities, local natural resources, and make decisions that will best support the "health, safety, [and] general welfare" of their populations (Gill, 2013). In doing so, the broadly defined powers allocated to local governments in the Code allows local governments to account for and plan for projected sea level rise in their planning and decision-making mechanisms.

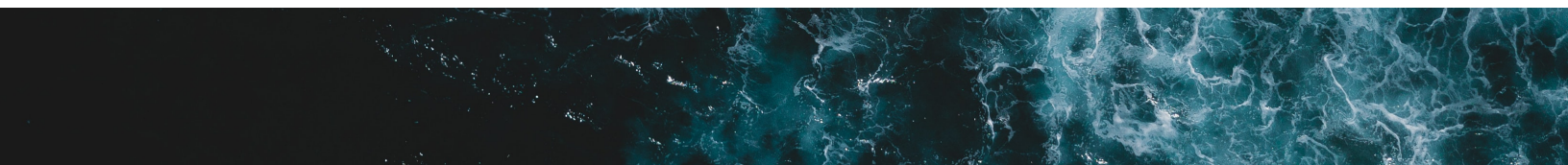
Additionally, the Virginian government has historically set goals for addressing and/or responding to climate change, flooding, and sea level rise issues. In 2018, former Governor Northam signed Executive Order 24 to "increas[e] Virginia's resilience to sea level rise and natural hazards" (EO24, 2018). As a result of the order, the Commonwealth developed a Virginia Coastal Resilience Master Planning Framework in 2020, which specified the Commonwealth's goals, guiding principles, and key objectives/actions to make Virginia more resilient to sea level rise (Office of the Governor, 2020). The framework is divided by region (Norfolk is part of the Hampton Roads Planning District Commissions), and Phase One of the formalized plan for the Commonwealth was released in December of 2021 (Office of the Governor, 2020).

The Commonwealth has historically provided and/or allocated funding to local flood mitigation projects through the Virginia Community Flood Preparedness Fund, a fund established by Governor Northam and the Virginia General Assembly (13News, 2021). The fund was established to bolster community resilience to climate change and its adverse impacts, especially sea level rise (13News, 2021). Funding for the Community Preparedness Fund are from the Regional Greenhouse Gas Initiative's (RGGI) auctions of carbon allowances (DCR, 2021). In October, Governor Northam awarded $7.8 million to 19 different flood mitigation and resilience projects throughout the Commonwealth, more than half of which are in the Hampton Roads region. Amongst its beneficiaries, the City of Norfolk received $900,000 toward the Coastal Storm Risk Management Analysis conducted by the U.S. Army Corps of Engineers and $500,000 for a study of the Lake Whitehurst watershed (13News, 2021; USACE, 2018).

Local Government: The City of Norfolk

Because flooding and sea level rise implicates each region differently depending on local topography, development, and demographic characteristics, local governments in Virginia tend to function as the primary decision makers and project implementers for sea level rise-related issues. With designated authority over land use and planning from the Commonwealth governments, Norfolk has jurisdiction over specific sea level rise responses in the city, though they may be guided by federal or state policies, goals, and funding requirements. Past projects have included a half-mile long floodwall that protects the downtown region from flooding and a $2.4 million investment in elevating a road that connects many residents to a medical center during flood events (City of Norfolk, 2014).

Additionally, Norfolk has developed Norfolk Vision 2100, which defines the city's strategy and goals to increase local coastal resilience (Office of the Governor, 2021). In 2018, the city redesigned its zoning ordinances such that new developments within the 500-year floodplain (0.2% annual flood risk) must be constructed at least three feet above the ground (or 1.5 feet above flood elevation) (Office of the Governor, 2020; Pew, 2019). As part of the re-zoning, the



city redefined the boundaries of flood-prone Coastal Resilience Overlay (CRO) regions, which are areas that are subject to higher flood-resiliency standards (e.g., no basements or electrical system within flood depth zones, higher elevated, etc.) than other building development (Pew, 2019).

The City of Norfolk makes decisions using a Council-Manager government structure (City of Norfolk, n.d.). Under this structure, the Norfolk Mayor, and associated City Council functions as the primary decision-making legislative body; they are responsible for creating policy, approving budgets, levying taxes, and appoint city leaders, including board, committee, and commission members (City of Norfolk, n.d.). The Council is made up of Norfolk's elected Mayor, Kenneth Alexander, and seven elected City Council members, each of which represents a different city ward (Norfolk, n.d.). Norfolk's City Manager, Larry Filer, acts as an intermediary between the city's administrative departments and the City Council. Key offices that direct Norfolk's response to sea level rise include the Norfolk City Office of Resilience and the Department of City Planning. Boards and commissions that have a key interest or relevance to sea level rise responses and planning in Norfolk include the Coastal Management and Review Board, the Erosion Advisory Commission, Norfolk City Planning Commission, the Norfolk Environmental Commission, and the Norfolk Wetland Board. Additionally, the City of Norfolk is also part of the Hampton Roads Planning District Commission (HRPDC), an inter-locality commission that "serves as a forum" to support collaboration between officials from Hampton Roads, Norfolk, and Virginia Beach when making decisions of "regional importance" (VDOT, 2011).

Sea Level Rise Response Strategies [1]

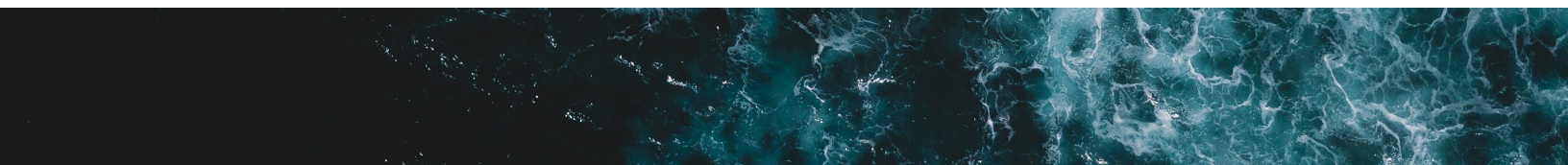
Hard Infrastructure Protection Strategies

Protection responses to sea level rise seek to reduce the impacts of sea level rise on coastal communities by creating physical or structural barriers between the land and water. Protection strategies can stop water from submerging targeted land areas, refunnel water to flood-safe areas, or decrease land erosion and storm surge by minimizing wave strength (Al, 2018). Fortifying shoreline communities from flooding and storm surge, protection responses are typically differentiated as being "hard" or "soft" (Linares, 2012).

"Hard" or "gray" responses to sea level rise include engineered infrastructure such as floodwalls (e.g., seawalls, bulkheads), revetments, or berms (amongst others) (Al, 2018; Betzold and Mohammed, 2017). While effective in preventing flooding in the short term (10-35 years depending on rate of rise), hard infrastructure has been criticized as being unsustainable, mainly on account of negative ecological implications, worsened coastal erosion in adjacent, unfortified communities, and their unaesthetic appearance (Betzold and Mohammad, 2017; Al, 2018; Sadeghi et al, 2018). Hard infrastructure tends to be expensive and relies on frequent maintenance (e.g., sediment replenishment at seawall base) (Sadeghi et al, 2018; Borchers, 2017). Seawall construction is estimated to cost between $150 to $4,000 per linear foot, and levee or dike construction is estimated to cost between $100-$1,500 per linear foot (Eastern Research, 2013). In 2013, Old Dominion University found that gray infrastructure in the Hampton Roads region has likely exacerbated sea level rise and that these built protective measures will likely experience shorter lifespans and reduced flood protection functionality as seas continue to rise.[2]

1 Limitations of evidence and literature cited in the following section can be found in Appendix A.

2 Gray infrastructure has been found to disrupt the migration of ecosystems, flow of sediment, and intensify wave energy on adjacent, unprotected segments of shoreline (Pew, 2021). While the can protect some assets in some areas, this likely comes at the cost of worsening sea level rise, erosion, and vulnerability nearby .



Soft Protection Strategies & Nature Based Solutions

Non-structural or "soft" protection measures reduce sea level rise and flooding by using or enhancing features of the natural environment (Coleman, 2012; Griggs and Reguero, 2021). Soft protection measures include natural based solutions to coastal flooding, such as sediment replenishment, coastal habitat restoration (e.g., oyster reef.), engineered living shorelines, and developing open space that mimic naturally existing ecosystems or flood plains (amongst others) (Griggs and Reguero, 2021).

Most nature-based infrastructures are considered very effective and sustainable. Beach replenishment, however, is one form of nature-based infrastructure that has been criticized as unsustainable and relatively ineffective. Since 1923, more than 1.35 billion cubic meters of sand has been used to replenish beaches and slow erosion; nonetheless, many have short lifespans and must be replenished nearly annually; Palm Beach, FL has been replenished 51 times, and in San Diego, California, a majority of the nearly three million cubic meters of replenished sand eroded or drifted elsewhere within two years (Griggs, and Reguero, 2021). Beach nourishment costs between $300 and $1,000 per linear foot and the process must be repeated frequently (every one to ten years) (Eastern Research, 2013; OCRM, 2000). Such indicates that sediment and beach replenishment alone is unlikely to protect Norfolk against sea level rise and flooding in the long term.

Nonetheless, most nature-based infrastructures, primarily living shorelines (e.g., oyster reefs and wetland marshes), have been very successful in reducing the implications of sea level rise, stabilizing shorelines, and restoring important ecological services (Mitchell and Bilkovic, 2018). Living shorelines reduce wave impacts and erosion rates and are considered a relatively inexpensive and low-maintenance response strategy (i.e., $100-$300 per linear foot of restored oyster or coral reef) (Eastern Research, 2013). NOAA reports that marshes and oyster reefs help to decrease storm surge and wave energy, which cause flooding (NOAA, n.d.); specifically, they report that 15 feet of marsh can absorb up to 50% of wave energy (NOAA, n.d.). Coastal habitats naturally accrete sediment along shorelines that helps to elevate land and reduce the impacts of sea level rise, as compared to hard infrastructure that requires movement and replacement with varying water levels.

How does hard infrastructure compare with nature based solutions?

A University of North Carolina study found that living shorelines (e.g., wetlands) protected land better than hard infrastructure (i.e., bulkheads) during Hurricane Matthew in 2016 and better maintained land elevation without repairs in the post-hurricane period, while 75% of bulkhead hard infrastructure required repairs (Smith et al., 2018). Reinforcing such findings, the San Francisco Bay Living Shorelines Project has recorded a 30-50% reduction in wave energy and a 15-24 centimeters of sediment accumulation as a result of establishing oyster and eelgrass habitats in 150-250 cm of the shoreline (CSCC, 2021). In 2017, researchers found that wetlands in the American Northeast prevented an estimated $625 million in flood damages during Hurricane Sandy alone (Narayan et al., 2017); these wetlands are estimated to reduce annual flood damages in the Northeast by 16% on average, demonstrating the potential benefits of wetlands protection, restoration, and maintenance as a sea level rise protection measure in Norfolk (Narayan et al., 2017).

Accommodation: Resilient Building Codes

Accommodation responses to sea level rise do not prevent or reduce sea level rise, but rather to increase communities' ability to live with it. Accommodation strategies include modifying building codes to restrict development in flood-prone areas, elevating buildings to withstand future flooding, or land use restrictions in floodplains (amongst others). Building codes modifications can be phased in immediately or with flexibility; flexible or dynamic codes do not require formal revision, rather they contain some threshold (e.g., sea level, annual flood hours, etc.) at which point the code changes automatically (EPA, 2017). Dynamic modifications can increase property owners' awareness about how land use regulations may change with time and can allow localities to plan for sea level rise and climate uncertainty (EPA, 2017).

In 2020, the Federal Emergency Management Agency published a study about the impacts of hazard-resistant building codes on disaster damages. FEMA incentivizes flood-resistance building codes through the voluntary National Flood Insurance Program, which discounts insurance premiums for communities that adopt flood-resistance building codes that surpass NFIP requirements (FEMA, 2020). Between 2000-2016, FEMA estimated that there were about 786,000 structures in floodplains, of which about 400,000 had freeboard building codes (additional structural height above flood elevation); FEMA reports that total Average Annual Loses Avoided (AALA) were about $484 million (about $1,200 per structure) (FEMA, 2020). In Virginia, FEMA reported that there were about 464,000 buildings in the floodplain, of which about 4,000 had freeboard codes; total AALA from the freeboard codes in Virginia was estimated at about $5 million (FEMA, 2020). Building code interventions rely on localities' abilities to enforce new codes.

Building Code Modification in Norfolk, VA

In 2019, Norfolk updated building codes to reflect increasing flood vulnerabilities throughout the city; the freeboard code requires that new developments within 100-year and 500-year floodplains be raised 36 inches from the ground as opposed to 16 inches outside of the plains (Pew, 2019). Additionally, the city included new code that requires a 20-foot setback from mean high-water levels for new development, as well as ordinances that increase stormwater infiltration, parking surface permeability, and it added a resilience point system that requires developers to incorporate a certain number of resilient practices in new developments (including flood risk reduction) (Adaptation Clearinghouse, 2018).

Relocation & Managed Retreat

Managed retreat decreases vulnerability to sea level rise by physically moving communities and associated infrastructure away from shorelines and flood prone areas. As infrastructure and development migrates inland, previously occupied land can be converted to flood-mitigating open space that can function as a floodplain during high water events and as a place for marshes and coastal habitats to migrate inland with rising seas (Siders, 2013). Managed retreat strategies allow water to rise and flood unimpeded (Koriam et al., 2011).

Managed retreat can be mandated or voluntary and can draw from several mechanisms, including government buyouts, land acquisitions, disinvestment from flood zones, rolling easements, restricting rebuilding damaged properties, or prohibiting the development of certain lands (EPA, 2017; Dundon and Abkowitz, 2021). Managed retreat strategies can be initiated in response to some threshold (certain level of rise), trigger point (e.g., hurricane, flood, etc.), or in preparation for projected sea level rise. All managed retreat strategies tend to require thorough risk assessments that identify the most vulnerable regions, populations, and infrastructures (Koraim et al., 2011).

Managed retreat strategies are most often implemented through a voluntary property or land acquisition (i.e., buyout) program, in which the government offers to purchase a property in a flood zone from the property owner to be converted into open space or wetland area (Dundon and Abkowitz, 2021). Buyout programs are typically implemented locally and funded primarily through FEMA and Department of Housing and Urban Development (HUD) grants (e.g., Hazard Mitigation Grant Program, Community Development Block Grants) with some local or state contributions (Freundenberg et al., 2016). Some buyout programs include leaseback features, in which government-acquired properties are leased back to their former owners in exchange for rent or for property maintenance (Georgetown, 2019). Leases tend to expire as properties and structures are deemed hazardous by projected sea level rise or damaged by a destructive coastal event, at which point structures are removed and space converted to green buffer space (Revell et al., 2021). Charlotte-Mecklenburg's managed retreat strategy has both buyout and leasebacks features; this program has helped more than 700 families move out of floodplains and has led to the conversion of more than 185 acres of land into open space (Spidalieri et al., 2020).

Buyout Program: Grand Forks, North Dakota

In 1996, Grand Forks, North Dakota successfully implemented a managed retreat strategy in response to excessive flooding in the Red River. The river swelled 5 feet above anticipated levels which overcame regional dikes and flooded 4.5 million acres of land; about 90% of Grand Forks residents were evacuated and about 83% of homes were damaged or washed away, ultimately creating more than $3.5 billion in flood damages (Siders, 2013). In response, President Clinton requested $5.5 billion from Congress to provide 100% of response funding through FEMA (typically only 75%) (Siders, 2013). The City of Grand Forks bought properties at pre-flood fair market values to incentivize relocation and ultimately acquired 802 properties with $171 million they received in HUD block grants. The city successfully removed acquired homes (relocating salvageable properties and destroying damaged ones) and converted the land into 2,200 acres of open, recreational space, called the Greater Grand Forks Greenway (Siders, 2013).

Managed retreat is likely inevitable in some regions of the United States, including in Norfolk, VA, nonetheless, the strategy is associated with certain limitations. While retreat programs themselves can be funded at the local, state, or federal level, they can have negative implications for city property tax revenue if they force residents to a new locality. Additionally, displacement associated with this strategy can be socially and psychologically disruptive, implicating both retreating and receiving communities (Mach et al., 2019). Managed retreat can also exacerbate existing social inequities and vulnerabilities, especially depending on property acquisition prioritization and information transparency (Dundon and Abkowitz, 2021; Siders, 2019).

With effective project design and intense community involvement, however, managed retreat can support and protect vulnerable communities. In the late 1990s, three hurricanes flooded in Kinston, North Carolina; as the primary residents in the floodplains, African American, low-income, and elderly residents were disproportionately affected by the flooding (EPA, 2017). Using FEMA funds, the city offered voluntary buyouts to repetitively flooded property owners, 97% of which accepted the offer (EPA, 2017). A State Acquisition Relocation Fund was established to help renters and property owners move out of the floodplains, where properties were typically more expensive than bought out properties (EPA, 2017). Kinston provides a case study in which a managed retreat strategy helped to protect a vulnerable community from increasing flood risk and damage.

Conclusions from the Literature

The City of Norfolk is lacking a managed retreat plan. Considering the existing evidence, a managed retreat strategy in the city could reduce flood vulnerability throughout the city by increasing space for natural flood buffers and for wetland expansion, restoration, and migration. Doing so will allow the city to protect and increase wetland's naturally occurring flood and storm protection ecosystem services. Managed retreat will increase space for natural infrastructure (i.e., wetlands) to ultimately be far more sustainable than hard infrastructure and more effective than soft infrastructure alone. The following sections of the report will examine creative approaches to managed retreat that increase buffer space for flooding and wetlands available in Norfolk, Virginia.

Criteria

Criteria

The following criteria were used to compare, and analyze, and evaluate policy alternatives. Criteria and their respective weights have been chosen based on the components, objectives, and concerns as they relate to managed retreat strategies that increase natural buffer space and facilitate wetlands migration.

Cost-Effectiveness of Flood Buffer Area (35%)

Cost-effectiveness is defined as the cost of increasing the flood buffer area (i.e., space between shoreline and settlement) over the next ten years divided the number of acres converted to buffer space; cost-effectiveness costs are determined using a 2% inflation rate and the OMB's recommended 7% discount rate for public investment and regulatory analysis.

Costs will include the direct and indirect costs of implementing a policy. Direct costs include operational costs (e.g., cost of acquiring properties) and administrative costs (e.g., personnel, etc.) that are necessary to enact a policy. Indirect costs include opportunity costs incurred from enacting a policy (e.g., forfeited tax revenue). Costs will be discounted over a ten-year period. Effective policies will move people and structures away from shorelines and/or preserve open space to mitigate dangerous implications of sea level rise, such as inundation, storm surge, and wetlands loss. Effectiveness will be measured as the estimated land area (measured in acres) that will be converted or conserved by each policy to serve as flood buffer space. Cost-effective policies will yield large areas of buffer space at low governmental costs.

Data will draw upon estimates of chronically inundated and vulnerable properties in Norfolk (see Appendix B for graphic), average property values and lot sizes, and tax rates, amongst others. Where there is no data specific to the City of Norfolk (e.g., take-up rate), supplemental data will be drawn from case studies of policies implemented in comparable regions in the United States. In some cases, estimates from supplemental data will be transferred and applied to Norfolk, and in others, data will be scaled using population or land area ratios; this process relies on heavy assumptions.

For the purposes of comparison, cost-effectiveness estimates are converted into points; alternatives are allocated one point for every $10,000 it will cost to convert land into buffer space. Specific assumptions and calculations made during the cost-effectiveness analysis can be found in Appendix B.

Administrative Complexity (25%)

Administrative complexity refers to the ease with which each policy can be implemented in Norfolk. Policies will be evaluated on a 1-5 point rubric that accounts for administrative complexity by quantitatively measuring levels of government coordination. The rubric allocates points depending on the levels of government coordination required for the program to be enacted with fewer points indicating more localized government coordination and action. Based on the rubric (outlined below), policies will have low, low-medium, medium, medium-high, or high administrative complexity; policies that score the least points (require the fewest levels of coordination) will be evaluated as having lower administrative complexity and will be considered more favorable.

Policies will receive one point for each level of interaction the City of Norfolk must coordinate; specific points are as follows:

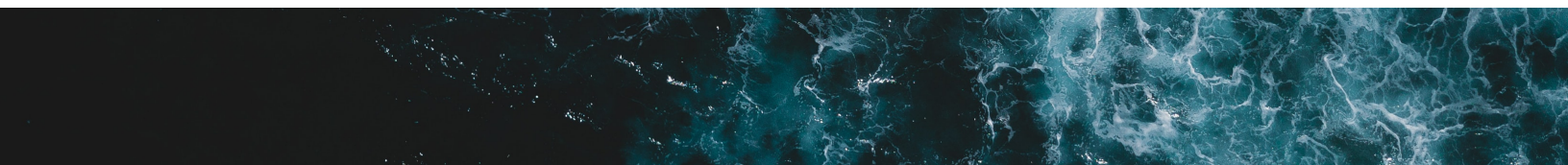
Norfolk coordinates with:	Point Allocation:
Federal government	1
State government	1
Neighboring localities	1
Sub-local communities (e.g., neighborhoods, local organizations, etc)	1
Individual households/property owners	1

All points will be totaled, and the policy with the lowest points total will be evaluated as having lower administrative complexity, and therefore, will be considered easier to implement. Those with the most points will be evaluated as having high administrative complexity, and therefore, will be considered harder to implement.

Evaluation	Low	Medium-Low	Medium	Medium-High	High
Point Total	1 point	2 points	3 points	4 points	5 points

Immediacy (20%)

Sea level is rising especially rapidly in Norfolk, and therefore, policies will be evaluated according to the immediacy with which they can be implemented. Immediacy will measure the number years each option will take to be functionally implemented. When possible, data will be drawn from meta-analysis studies that estimate the time required to implement a policy. When meta-analysis studies are not available, case studies of managed retreat policies in comparable regions will be used to estimate time required for implementation. Policies that can be established and implemented more quickly are more favorable. Policies will be allocated points equal in value to the estimated number of years it would require to be developed and implemented.



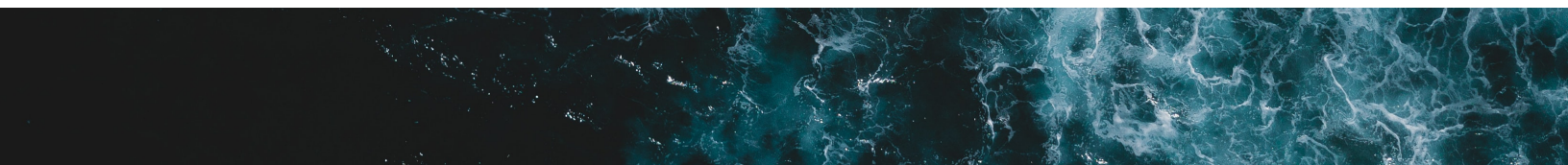
Environmental Impact (20%)

Environmental impact refers to each policy's anticipated effects on Norfolk's surrounding environments. Specifically, policies will be evaluated according to their ability to minimize environmental damage in a flood event by facilitating inland wetlands migration and by minimizing flood-prone environmental pollutants. Pollutants in this context mainly refer to structural pollutants, such as household debris or runoff (e.g., sewage, nutrients) that could pollute coastal ecosystems after flooding events or inundation (Morrison, 2019).

Policies will be evaluated as having low, low-medium, medium-high or high environmental impact (low being most ideal) according to a 1-4 point rubric that considers land uses and features on land affected under each policy. Specifically, the rubric considers whether land affected by the policies have structures that could turn into debris pollution in a flood event, whether measures have been taken to reduce debris in a flood event, and whether land is converted into permanent buffer space prior to a flood event. Policies that permanently remove or prevent structures from shorelines before flood events are most favorable (lower environmental impact) as they facilitate the unhindered inland migration of wetlands, and they permanently remove potential pollutant sources from flood-prone areas. Policies that allow closer proximity of structures to shorelines are less favorable (higher environmental impact) as they could prohibit wetlands migration and will result in coastal pollution as sea levels rise and flooding becomes more frequent.

The rubric is as follows:

Land Use Features:	Point Allocation:	Environmental Impact Evaluation:
No structural demolition needed (no flood debris) Land converted to permanent open space	1	Low
Controlled structural demolition (pre-flooding) to eliminate future flood debris Land converted to permanent open space	2	Low-Medium
Lot with structure Some measures taken to reduce debris in flood event	3	Medium-High
Lot with structure No pre-flood measures taken to reduce debris in flood event	4	HIgh



Alternatives

Alternatives

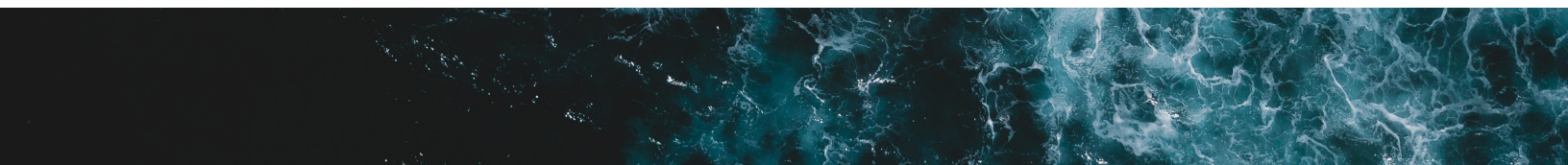
Alternative 1: Voluntary Property Buyout Program

The City of Norfolk could reduce the severity of projected sea level rise by implementing a voluntary property buyout program. In a buyout program, Norfolk would purchase developed properties from willing property owners in targeted, high-flood prone areas within the city (e.g., those within the Coastal Resilience Overlay Zone); purchase price would be determined through an appraisal process. Structures on purchased properties would be immediately demolished so that the property could be converted into open green space to serve as floodplains, protective storm buffers, and community recreation space (Georgetown, n.d.). By providing monetary compensation for flood-prone properties, voluntary buyouts incentivize willing sellers to relocate out of dangerous floodplains and allow for flood-mitigating wetlands to migrate upward as sea levels rise.

Buyout programs can be administered by local agencies, and most are funded through federal, state, and local financing sources. Buyouts have been successfully implemented in both urban and rural settings (Parry et al., 2020). The Federal Emergency Management Agency (FEMA) and the Department of Housing and Urban Development (HUD) provide the majority of federal funding for buyouts (Freudenberg et al., 2016). FEMA provides grant funding for buyouts through the Hazard Mitigation Grant Program (HMGP), which is administered by the state, the Pre-Disaster Mitigation Grant Program (PDM), the Building Resilient Infrastructure and Communities Grant (BRIC), and the Flood Mitigation Assistance Program (FMA), and HUD provides grants through Community Development Block Grants (CDBG) (Freudenberg et al., 2016; Georgetown, n.d.). The Virginia Community Flood Preparedness Fund provides funding for flood preparedness and protection projects, and the Virginia Dam Safety, Flood Prevention, and Protection Assistance Fund provides grants for local relocation and property acquisition projects. Grants from the VA Dam Safety Fund and from FEMA typically require that localities provide a 50% and 25% cost match respectively (Peterson et al., 2020; Parry et al., 2020). While HUD grants can be used for the cost-match requirement, localities can also finance or supplement buyouts through local income or property tax changes. The city of Austin, MN enacted a 0.5% local option sales tax to fund flood mitigation projects; doing so has allowed the city to cover 50% of their buyout costs and has supported their acquisition of 275 properties since 2007 (Peterson et al., 2020).

The voluntary buyout program would require that Norfolk establish a local buyout agency to apply to federal grants, administer the buyout program, and identify target buyout locations. Additionally, the city would need to host community engagement sessions to facilitate community understanding of the program and, if needed, adjust local taxes to finance the program.

Because buyouts are voluntary and not mandated, the success of the program largely depends on take-up. Additionally, a buyout program is limited by funding and may not be able to buy out all of the properties in high-risk flood zones. If the city does require local funding, tax changes would hinge on municipal voter approval.



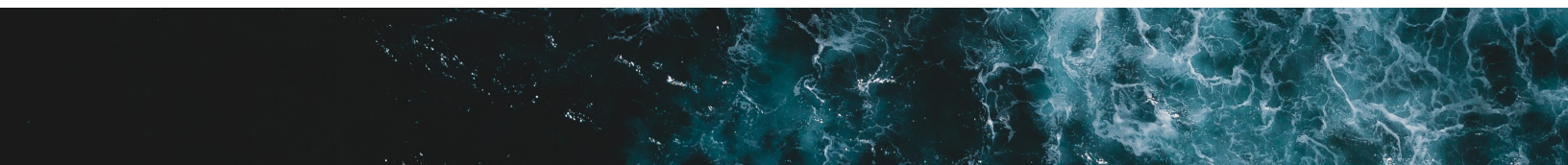
Alternative 2: Post-Disaster Planning with Damaged Property Acquisitions

Norfolk could reduce sea level rise vulnerability in floodplains through the development of a post-disaster redevelopment and acquisition plan. Norfolk would develop a post-disaster redevelopment plan to serve as a blueprint for the city's post-disaster recovery actions (Georgetown, n.d). This option allows Norfolk to increase coastal resilience and buffer space in the period immediately following a disaster event (e.g., flood, hurricane, etc.) through voluntary damaged property acquisitions. Under this alternative, a disaster serves as a trigger event that initiates a property acquisition program for eligible properties (e.g., those that were damaged beyond 50% of their pre-market value during the disaster event). Eligible property owners in designed zones of the city (e.g., floodplains) could opt to sell their property to the city government ; properties could be acquired for the difference between the value of the property owner's flood insurance claim and the pre-disaster fair market value of their home (as determined by pre-disaster appraisals). Remaining structures on acquired properties would be fully demolished and land would be converted into open buffer space for flood drainage and wetlands migration. This post-disaster plan would help the city allocate and prioritize disaster response funding acquired through the state and federal governments to reduce shoreline development and increase natural buffer space through these acquisitions (Georgetown, n.d.).

Pre-disaster redevelopment and recovery plans have been used to improve resilience and advance community safety in other regions, and some states have even mandated that localities develop such plans (FL DEM, 2018). The City of Norfolk's Department of Planning, in coordination with the City Planning Commission and with stakeholder interest groups, would develop the post-disaster redevelopment plan. The development of the plan could be funded through local funding appropriations as an extension of Norfolk's comprehensive planning processes. Alternatively, the plan could be funded through federal (e.g., FEMA, HUD, NOAA) and state (e.g., Emergency Management Performance Grant, VA Community Flood Preparedness Fund) grant programs, which can also provide technical assistance during the plan's development. Between 2015 and 2021, four coastal localities in Georgia developed post-disaster redevelopment and recovery plans using federal grant funding from NOAA's Coastal Resilience Grant Program and with guidance from the state's coastal and emergency management agencies (GADNR, n.d.; Georgetown, n.d.).

Similar to traditional voluntary buyout programs, a post-disaster acquisition program can be administered by local agencies and funded with the same local, state, and federal funding available to voluntary buyout programs (e.g., FEMA, HUD, and VA Dam Safety grants) (Freudenberg et al., 2016; Georgetown, n.d.). In 2012, New Jersey's Woodbridge Township initiated a post-disaster property acquisition program following Hurricane Sandy to accelerate managed retreat out of the floodplains (Spidalieri et al., 2020). Working with the New Jersey Blue Acres Program, Woodbridge acquired about 187 properties that were most affected and/or most damaged by the hurricane; properties have since been converted into open space in the Township (Spidalieri et al., 2020).

This option may be limited in that it requires many levels of government coordination. Additionally, its ability to increase flood buffer space depends on the number and distribution of homes damaged in a disaster event. Additionally, many of Norfolk's properties may already be in immediate danger; in this case, the post-disaster acquisitions plan does not incentivize residents to relocate to safer areas prior to a disaster nor does it offer them protection during or prior to the disaster.



Alternative 3: Transfer of Development Rights Program & TDR Bank

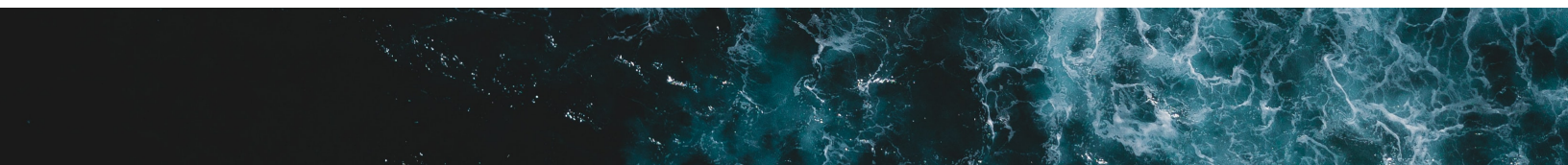
Norfolk could establish a Transfer of Development Rights (TDR) program and TDR Bank to reduce city-wide vulnerability to sea level rise by incentivizing shoreline conservation and steering city growth to flood-resilient zones. TDR programs allow property owners to sever the rights to development on their land from the land itself such that that land's development rights can be bought and sold for development incentives in other parts of the city (Walls and McConnell, 2007; Georgetown, n.d.).

Cities with TDR programs designate two zones within a city through zoning ordinances, being (1) the sending zone, in which the city looks to reduce density, decrease development, and increase preserved open space, and (2) the receiving zone, in which the city looks to steer growth, density, and increased development (Walls and McConnell, 2007; Georgetown, n.d.). In Norfolk, a TDR program could build on existing zoning ordinances that designate a more flood-prone Coastal Resilience Overlay (CRO) zone, which could serve as a TDR sending zone, and a higher-elevated, flood-resilient Upland Resilience Overlay (URO) zone, which could serve as a TDR receiving zone. Steering growth to upland areas and increasing flood buffer space, a TDR program would allow the Norfolk City government to purchase development rights from property owners in the CRO zone (in exchange for conserving land) to be sold to developers in the URO zone. Conserved land could be held as conservation easements and maintained by the city or through a local land trust partnership, and acquired development rights could be held by a city-administered TDR Bank. The Bank would sell these development rights (i.e., credits for increased density, square footage, height, etc.) to developers with projects in the URO receiving zone.

Property owners are compensated for the development rights of their conserved land through direct cash transfer, and they are subsequently eligible for reduced property tax rates. Rights are valued as the difference between the appraised fair market value of a property with and without the conservation easement (Miller & Krieger, 2004). A TDR program has been successfully implemented in King County, WA; between 2000-2019, the TDR program in King County has led to the conservation of more than 144,000 acres of land throughout the county (Spidalieri et al., 2020).

TDR programs can be funded by local sources, including property taxes or through general city budgeting allocations; for example, the TDR program in King County and a similar purchase of development rights program in Virginia Beach are primarily funded through local property taxes (Lung & Killius, 2016; Spidalieri et al., 2020). While TDR programs do require costs associated with administering the program, they are often considered to fund themselves (in part) through the market sale of development rights to developers (Lung & Killius, 2016). Nonetheless, the programs could draw upon state and federal funding sources. At the federal level, FEMA and HUD grants that support managed retreat, land acquisition, and coastal resilience initiatives could support the TDR program. At a state level, Norfolk could receive a grant through the Virginia Land Conservation Fund and/or the Virginia Dam Safety, Flood Prevention, and Protection Assistance Fund, which provide funding for Virginia land conservation initiatives and for coastal relocation/acquisition projects (respectively) (VA DCR, 2021).

Like other options, the participation in this program is voluntary, and therefore, the success of the program largely depends on take-up. This program relies dually on the physical land availability in floodplain and on the existence of a market for development rights (both a supply of land and a demand for development rights). Similar to other programs, if the TDR program does rely on local funding, any tax changes would hinge on municipal voter approval.



Findings

Findings

Alternative 1: Voluntary Property Buyout Program

Cost-Effectiveness

Alternative 1 will convert land into buffer space at an estimated cost of $600,533 per acre. Sea level rise is expected to increase two feet along Virginia's coastline by 2045; under such rise projections, there are 1,001 homes in Norfolk, VA projected to be chronically inundated by 2045 (i.e., flooded at least 26 times) (UCS, 2018; Vakil, 2019). Assuming that 75% of property owners accept buyout offers, as was the case in New Jersey's Blue Acres Buyout Program, it is estimated that about 750 properties would be acquired through voluntary buyouts. Using the average estimated cost of properties projected to experience chronic inundation, and assuming that about 75 homes could be acquired annually over a ten-year period, it is estimated that all 750 homes could be acquired for an estimated cost of $151,964,000. Similarly, it was found that total demolition, tax revenue loss, and personnel costs would total $10,484,626, $1,884,518, and $1,414,063 respectively (using an annual 7% discount rate, 2% inflation rate, and 0.75% salary raise) (UCS, 2018). Using a 7% discount rate and 2% inflation rate over ten-years and using cost estimates of property acquisition, demolition, tax revenue loss, and estimated personnel costs it is estimated that a voluntary buyout program would cost an estimated $600,533 per acre of land converted into flood buffer space.

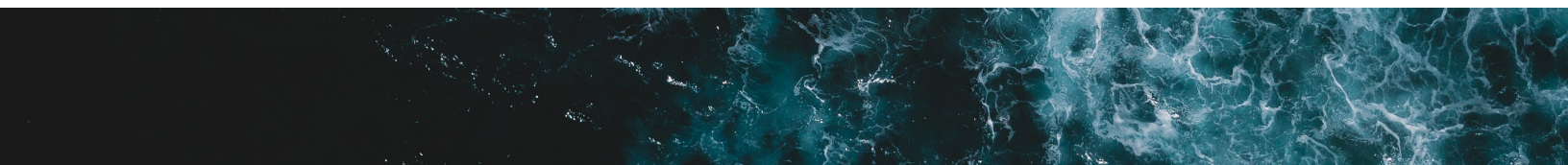
Administrative Complexity

Because voluntary buyouts require administrative coordination between varying government levels and funding streams, Alternative 1 is evaluated as having medium-high administrative complexity. On a scale of 1-5 for administrative complexity, Alternative 1 was found to be a 4.

Voluntary buyouts require that the City of Norfolk first apply to grant programs through federal and state governments and that they have administrators ensuring that the program follows requirements of each funding stream. Additionally, a voluntary buyout program requires that the city establishes close community partners that can help to identify target regions for the buyout program, ensure community needs are met, and to advertise the buyout program to potential participants. Once target regions are identified, the city will have to coordinate transactions between individual households and the city; this will require property appraisals, cash transfers, and subsequent structure demolition for each property. This option requires that Norfolk's local government coordinates with federal and state governments as well as with sub-local communities (i.e., neighborhoods) and with individual property owners; receiving one point for each level of government coordination, Alternative 1 receives 4 points and is rated as having medium-high administrative complexity.

Immediacy

Alternative 1 is estimated to take about 5.7 years to design and implement. Researchers Mach et al. (2019) examined voluntary floodplain buyout programs across the United States. They analyzed more than 40,000 nationwide property buyouts, 94% of which were administered by local governments using federal grants, and they found that the average floodplain "buyout project" took 5.7 years from the project initiation (e.g., disaster event) to the project closeout, at which point some properties had been acquired, some structures had been demolished or relocated, and the land had been converted into open space (Mach et al., 2019). In the case of sea level rise, it is likely that a buyout program would be on-going because, over time, more properties will likely be exposed to chronic inundation. Nonetheless, we can assume that it will take Norfolk 5.7 to initiate a functional buyout program with some amount of land converted into open space.



Environmental Impact

On a scale of 1-4, Alternative 1 was rated as a 2 for environmental impact and is considered to have low-medium environmental impact. Alternative 1 effectively reduces the potential for debris pollution prior to a flood event by removing structures through a controlled demolition; because it requires some form of demolition, it does not satisfy the rubric requirements for "low" environmental impact. Comparatively, because all structures are removed from acquired properties, Alternative 1 also does not meet the rubric's requirements for "medium-high" environmental impact. Alternative 1 requires that acquired land is converted and permanently maintained as open buffer space to facilitate flood prevention and wetlands migration. Therefore, Alternative 1 is allocated 2 points and is considered to have low-medium environmental impact.

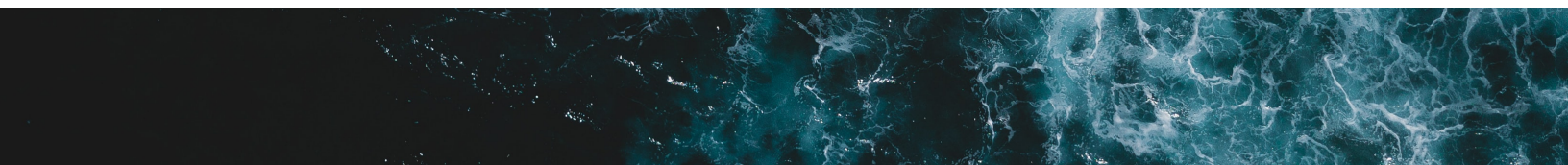
Alternative 2: Post-Disaster Planning with Damaged Property Acquisitions

Cost-Effectiveness

Alternative 2 will convert land into buffer space at an estimated cost of $548,331 per acre. Alternative 2 would offer severely damaged (>50%) property owners the price difference between their relative flood insurance claim and the pre-disaster fair market value of their home; on average, this amount was estimated as $241,892 per property. McNab et al (2019) estimated that 6,321 residential properties would be destroyed (more than 50% home value lost) in the Hamptons Roads regions during a severe hurricane. Scaling such estimates based on relative population densities, it is estimated that Norfolk, VA has 885 properties at risk of destruction. Assuming that 75% of property owners accept compensation offers for destroyed property, it is estimated that 664 properties would be acquired through a post-disaster acquisition program. On average, Virginia experiences at least one hurricane about every two years. Using a 7% discount rate, a 2% inflation rate, and assuming a 0.75% salary raise annually over a ten-year period, in which 133 homes are acquired every hurricane-year and drawing upon cost estimates of flood insurance claims, property acquisition, demolition, tax revenue loss, and estimated personnel costs it is estimated that a post-disaster property acquisition program would cost an estimated $548,331 per acre of land converted into flood buffer space.

Administrative Complexity

On a scale of 1-5, Alternative 2 is scored 5 for administrative complexity, and it is evaluated as having high administrative complexity. Alternative 2 has two administrative processes: (1) the development of the PDRP and (2) the post-disaster property acquisition program. The development of the PDRP will require that Norfolk coordinate with the federal and state government to finance the PDRP (e.g., through NOAA and state-administered FEMA grants). Because disasters typically affect regions as opposed to local areas, the PDRP will require intergovernmental coordination between the City of Norfolk and surrounding localities (Sarasota PDRP, 2010). Additionally, the development of the plan will require a thorough city-wide vulnerability assessment to identify regions that are at risk of severe storm damage; the plan will draw upon issues, concerns, and needs of at-risk communities and therefore, the development of the plan will require intense community engagement and collaborative-decision making at the sub-local level. In the case of a disaster event, Norfolk will again need to coordinate with federal, state, and local governments to secure and distribute post-disaster response funding. Norfolk will have to work with communities and households to ensure community awareness of the program and to coordinate property transactions (including damage assessments, property appraisals, cash transfer, demolition). Receiving 1 point for each level of coordination required, Alternative 2 is allocated 5 points, and therefore, is evaluated as being highly administratively complex.



Immediacy

Alternative 2 is estimated to take about 7.7 years to develop and implement. The State of Florida requires that every county develop a Post Disaster Redevelopment Plan (PDRP); Hillsborough County was one of the first counties enrolled in the state's pilot programs to develop a PDRP. In their 2010 PDRP, Hillsborough reports that the development of the plan took two years to create (Hillsborough County, 2010). Therefore, it is estimated that the City of Norfolk would require at least two years to develop a PDRP. Additionally, because Alternative 2 also requires a form of voluntary property acquisition and cash transfer, it will likely require an additional 5.7 years, as outlined by Mach et al. (2019), after a disaster to establish a functioning property acquisition program. Therefore, Alternative 2 will take an estimated 7.7 years to establish.

Environmental Impact

On a scale of 1-4, Alternative 2 is given a 4 for environmental impact and is evaluated as having a high environmental impact. Alternative 2 does not remove coastal structures from shorelines prior to a flood event. Rather, structures are left in their existing state to be destroyed or damaged by severe flood and/or storm events; resulting destruction will lead to more debris and associated urban runoff pollution in coastal waterways after a flood event. Alternative two does not satisfy the rubric requirements for low and low-medium environmental impact because properties have structures on them prior to and during a flood event. Additionally, Alternative 2 does not satisfy the requirements for medium-high environmental impact because Alternative 2 does not require that any pre-flood measures are taken to reduce debris pollution in the case of a future flood nor does it secure permanent open buffer land space prior to a flood event. Therefore, Alternative 2 is allocated 4 points and evaluated as having a high environmental impact.

Alternative 3: Transfer of Development Rights Program & TDR Bank

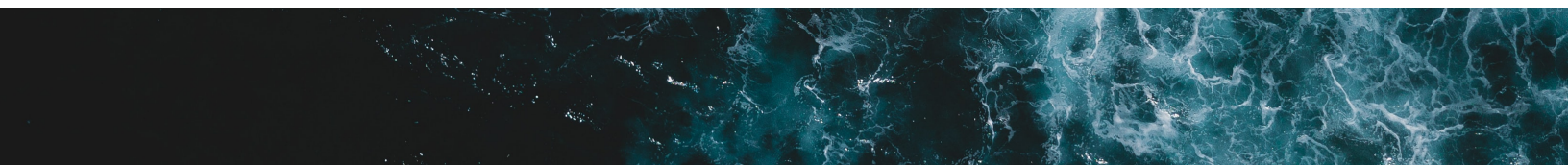
Cost-Effectiveness

Alternative 3 will convert land into buffer space at an estimated cost of $12,190 per acre. Alternative 3 would formalize a Transfer of Development Rights program in Norfolk with the establishment of a TDR Bank; through the program, the Norfolk government would purchase development rights from willing and eligible property owners and hold land in conservation easements. This alternative builds on existing ordinances in the city, which steer development toward higher elevated ground through designated Upland Resilience and Coastal Resilience Overlay zones. Drawing upon the outcomes estimated from a similar program functioning in neighboring locality, Virginia Beach, it is estimated that a development right could be acquired, on average, for an estimated $8,635 per acre. Using a 7% discount rate, a 2% inflation rate, and assuming a 0.75% salary raise annually over a ten-year period, in which about 50 acres are acquired every year (scaled estimate from Virginia Beach case) and drawing upon cost estimates of tax revenue loss and estimated personnel costs it is estimated that establishing a Transfer of Development Rights program with a TDR Bank would cost an estimated $6,131,961 (net present value), or about $12,190 per acre of land converted into flood buffer space.

Administrative Complexity

On a scale of 1-5, Alternative 3 is scored 3 points for administrative complexity and is considered to have medium administrative complexity.

TDR programs can be developed, implemented, and managed entirely by municipal governments in Virginia (Georgetown, n.d.; Frederick County, n.d.). In 2018, the City of Norfolk released new zoning ordinances, which designated the Coastal Resilience Overlay (CRO) zone and the Upland Resilience Overlay (URO) zone (City of Norfolk, 2021; Georgetown, 2018). The existing zoning ordinances incentivize growth in upland areas by subjecting development to lesser restrictions and regulations. Alternative 3 builds on these existing zoning ordinances to



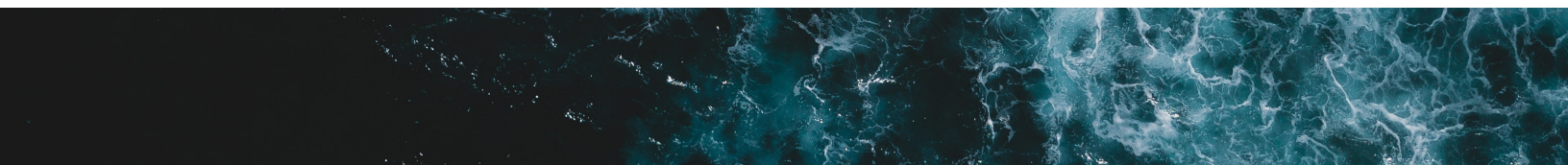
formalize a TDR program in the city. In this sense, Norfolk already has much of the city level ordinances in place to formalize a TDR program. Because establishing a city-level TDR program is within the powers of the Norfolk municipal government, Alternative 3 does not require the city government to coordinate with federal, state, or inter-locality governments; nonetheless, Norfolk could pursue state administered grants (e.g., via Virginia Land Conservation Fund, Office of Farmland Preservation, etc.), which would require state-level coordination. In this case, establishing a TDR program and TDR Bank would require that Norfolk's municipal government coordinates with state government agencies, sub-local communities - being neighborhoods and TDR stakeholder groups (e.g., developers) - as well as with individual landowners that would participate in the program. Therefore, Alternative 3 receives 3 points in the administrative complexity rubric and is evaluated as having medium administrative complexity.

Immediacy

Alternative 3 is estimated to take about 3 years to implement functionally. Alternative 3 is considered easier to implement as compared to Alternatives 1 and 2 because the City of Norfolk already has zoning ordinances in place that are supportive of the formalization of a TDR program. Nonetheless, the program will require the establishment of a TDR Bank and substantial community engagement to increase stakeholder (i.e., landowner and developer) awareness and participation in the program. The successful TDR and TDR Banking program in King County underwent a three-year initial pilot and development period before being formally adopted into the County Code (Spidalieri et al., 2020). Norfolk is smaller than King County and already has city ordinances supportive of a TDR program; nonetheless, it is conservatively estimated that a TDR program could take up to three-years for the City to develop, fund, and implement with some success. While the TDR program does require the acquisition of development rights, it does not require the acquisition and subsequent coordination and demolition of structures, which reduces the immediacy of Alternatives 1 and 2.

Environmental Impact

On a scale of 1-4, Alternative 3 is scored a 1 for environmental impact and is considered to have low environmental impact. A TDR program would permanently conserve open space and land in Norfolk to serve as long-term buffer space. As sea levels rise, this conserved space will facilitate the inland migration of wetlands and increase natural, flood mitigating buffer space throughout the city. Because the land conserved in a TDR program is already open and/or natural, it does not require any form of structural demolition nor does it have any form of structure on it that could turn into pollution during a flood event. As a result, Alternative 3 does not satisfy the requirements of medium-low, medium-high, nor high environmental impact. It is allocated 1 point in the rubric and evaluated as having a low environmental impact.



Outcomes Matrix

	Cost-Effectiveness (35%) *(pts in 10,000s)*	**Administrative Complexity** (25%) *1 (low) - 5 (high)*	**Immediacy** (20%) *(pts in years)*	**Environmental Impact** (20%) *1 (low) - 4 (high)*	Average *(lowest point value is most favorable)*
Alternative 1: Voluntary Buyouts	**$600,533/acre** 60.0533 pts	**Medium-High** 4 pts	**5.7 years** 5.7 pts	**Medium-Low** 2 pts	23.56 pts
Alternative 2: Post-Disaster Plan with Property Acquisitions	**$548,331/acre** 54.8331 pts	**High** 5 pts	**7.7 years** 7.7 pts	**High** 4 pts	22.78 pts
Alternative 3: Transfer of Development Rights Program	**$12,190/acre** 1.2190 pts	**Medium** 3 pts	**3 years** 3 pts	**Low** 1 pt	1.98 pts

Recommendation

After evaluating each alternative according to their relative cost-effectiveness, administrative complexity, immediacy, and environmental impact, I recommend that the City of Norfolk pursue Alternative 3, establishing a transfer of development rights program and TDR bank in the city. A TDR program would effectively provide incentives for property owners to conserve land that can serve as flood buffer and marsh migration space, while at the same time, providing developers tools to increase density and development in safer, higher elevation regions in the city (Walls and McConnell, 2007; Georgetown, n.d.). After reviewing the outcomes matrix, it is evident that Alternative 3 is the most cost-effective, least administratively complex, most timely, and least environmentally destructive. Because the City of Norfolk already has existing zoning ordinances supportive of a TDR program, this option will be easier to implement as compared to Alternatives 1 and 2. Alternative 3 allows Norfolk the most autonomy in the development and administration of the proposed managed retreat strategies. Additionally, it is the only alternative that uses conservation, as opposed to demolition, to increase natural buffer space and flood protection throughout the city.

In order to see a significant change in the recommendation, large assumptions about the cost of acquiring development rights from property owners would have to be made. While there may be some variation in this cost in actuality, it is extremely unlikely that we would find a change to the degree necessary to change this recommendation; therefore, under projected outcomes, the recommendation to establish a TDR program is considered relatively sound and robust.

2 Discussion about the sensitivity of this recommendation can be found in Appendix B.

Implementation Considerations

Implementation Considerations

In 2006, the Virginia General Assembly adopted legislation that allowed local governments to adopt and implement TDRs without state interference (Mullen, 2012). Therefore, the development, implementation, and administration of the program will fall under the purview of the Norfolk Department of City Planning and the City Planning Commission with the authorization of the Norfolk City Council. The establishment of a Transfer of Development Rights program in Norfolk will build on existing land use zoning ordinances enacted in 2018 in the form of an amendment that will be formally established after being passed by the Norfolk City Council. The implementation of the TDR program will require multiple steps and processes, which have been organized and outlined below.

I. Conduct City Survey

Norfolk city planners need to first survey the city to determine whether the existing Upland Resilience Overlay (URO) zone and the Coastal Resilience Overlay (CRO) zone are sufficient and suitable for the TDR program. This data collection process could be done internally, conducted by staff in the Department of City Planning, or it could be done externally, by hiring city external consultants. The URO and CRO zones are already formally recognized in city ordinances, insinuating that the city has already determined that these regions are suitable for changing development patterns (increasing density in the URO and decreasing density in the CRO). Nonetheless, surveying the city will be important for planners to demonstrate the amount of land available for development in the receiving (URO) and sending (CRO) zones. While the URO and CRO zones have already been established, conducting a city-wide survey could help to identify additional regions in the city that should be included in the URO and CRO zones. Regions that are found to be at high risk from sea level rise and projected flooding could be added to the existing CRO, while those that are found to have higher elevations and opportunity for increased development and density could be added to the URO.

This survey will provide data to planners and to the Council about the flood risk, land features, density, and development opportunities available throughout the city. This information will be critical for land-use decision making as the city plans for sea level rise, resilience, and managed retreat. Because of the importance of the survey, it is possible that some stakeholders who oppose the establishment of a TDR program (e.g., if there is a City Council member opposed) will question the validity of the survey if it is conducted by city planners. If this is the case, it may be favorable to hire an external, third-party consultant whose information will be viewed as more objective. This is not considered to be a large concern as the Norfolk City Council and the City Planning Commission (part of the Department of City Planning) has been reported as being amicable and trusting (NOAA, 2021).

II. Community Engagement & Market Assessment

To implement the TDR program, Norfolk city planners need to ensure that there exists a both a demand for development rights and a supply of land available. Surveying the city will determine the physical land availability, while stakeholder engagement with landowners in sending zones and land developers in the city will determine the potential size of the TDR market and the specific incentives that will best support the needs of developers. City planners should plan to host focus groups, open forums, public meetings, and stakeholder interviews with landowners in the CRO zone and with developers in and around Norfolk.

The TDR program will be jeopardized if community stakeholders from either the sending or receiving zones object to the program. Therefore, it is imperative that the Department of City Planning involve these communities in every step of the TDR program's development, decision-making, and monitoring processes. Such involvement should engage stakeholders in conversations through open houses, accessible and advertised public meetings, focus groups, and one-on-one interviews. Community members must be made aware of such engagement opportunities by posters, community partners (e.g., churches) that can disseminate information, and through mail services (postal and email). Meetings should focus on educating community members about the program and the reasoning for it (e.g., sea level rise, projections, etc.); specific questions should be prepared and asked that focus on attendee's perception of the program, concerns they have about it, and why they would or would not participate in it. Hosting smaller focus groups and one-on-one interviews will help the city connect with underrepresented and vulnerable populations in the city, which could bring to light equity concerns or unintended issues that might arise out of the program. In this way, engaging communities will help the Planning Department get feedback from members during the development of the TDR program and identify challenges to the program before they arise; ultimately, this will help the city better meet the needs of its residents through the TDR program and will help to avoid future oppositions or unintended consequences from the program.

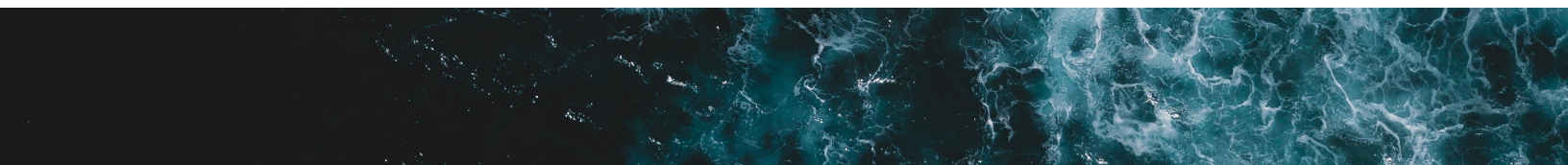
III. Defining Procedures & Transfer Right Ratios

The implementation of TDR program in Norfolk will require that city planners define the legal processes and standards involved in transferring development rights. Procedures to be defined include how development rights will be held, tracked, and transferred, whether there will be a minimum parcel size eligible for the TDR program, what formal processes must be undergone before a development project begins, and how developers will access development rights (e.g., auction or direct exchange with TDR Bank) (PA Land Trust, 2019). Importantly, city planners will have to determine how the city will determine the ratio between land acquired and development rights (i.e., credits) (UWOS, 2005). Specifically, this will require that planners determine the how many development rights will be received for land acquired (e.g., per acre acquired) and how those rights will function in developments (e.g., increased building density). Such procedures will be deliberated and decided by city planners in the Department of City Planning; their final determinations will be included in their formal proposal to amend the zoning ordinance. Additionally, city planners will decide whether land acquired through the TDR program will be managed by the city (e.g., Department of Parks and Recreation) or via partnership with a land trust. The Living River Restoration Trust is a land trust operating in Norfolk, VA, which could serve as a land trust partner. If planners elect to partner with the Living River Restoration Trust, representatives of the land trust will be included in the development of TDR development right transfer procedures and post-acquisition land maintenance procedures.

To avoid complicated and ineffective procedures during this step, planners should pursue interviews and meeting with other localities that have implemented TDR programs successfully. Doing so will help Norfolk anticipate and mitigate challenges during procedural development, which will support the program's efficiency.

IV. Proposing the Program as a Zoning Ordinance Amendment

Planners will have to propose the TDR program as an amendment to the existing zoning ordinances in the city. The amendment will both provide residents the voluntary option of utilizing TDR and it will set administrative processes (e.g., who administers the program, what processes are required to transfer rights, what exchange rates will be used). Setting administrative provisions, this amendment would establish a TDR Bank to be administered by the Department of City Planning. This bank would serve as a market for development right acquisition (from property owners) and sale or auction (to developers). The proposed amendment will build upon existing regulations.



Specifically, this will designate the Upland Resilience Overlay (URO) zone as the receiving zone and the Coastal Resilience Overlay zone as the sending zone. The proposal will go through the City Planning Commission, who will make recommendations to the City Council about the proposal's consistency with Norfolk's future plans, policies, and objectives (City of Norfolk, n.d.). The City Council will then decide whether the TDR program will be adopted in the zoning codes (City of Norfolk, n.d.).

To mitigate opposition to the program that could arise in the City Council, city planners drafting the TDR amendment should partner and/or engage with members of both the Planning Commission (who are within the planning department) and with members of the City Council. Engaging with these decision makers could help foresee constraints and barriers to the program, and it could provide planners the opportunity to demonstrate the potential effectiveness of TDR program in preparing Norfolk for sea level rise. If the TDR program is met with resistance and hesitation from the Council, the TDR amendment could be instead proposed as a pilot program that could be implemented only after proving successful and cost effective (McConnell and Walls, 2007). King County, WA implemented their TDR program after an initial three-year pilot program, which allowed administrators to modify the program as needed and to address challenges before expanding the program across the entire locality (Spidalieri et al., 2020).

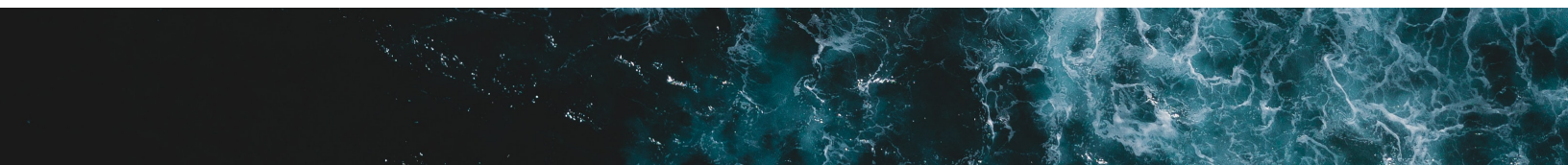
V. Information & Education Dissemination

The Department of City Planning will administer the TDR program. Therefore, they will be responsible for educating community members, stakeholder groups, and sending/receiving communities of the program. Specifically, staff will be responsible for informing residents in both the URO and CRO zones about the program, its purpose, and the incentives it provides. They could accomplish this through the same information dissemination streams used during community engagement sessions (meetings, hearings, public spaces, community centers, postal services, and email).

Additionally, they will be responsible for ensuring that participants in the program are full informed about the program, its procedures, and its implications on their properties/developments. Staff will have to negotiate transactions between landowners, the TDR Bank, and developers (UWPS, 2005). This will include coordinating land appraisals with landowners, and subsequently, coordinating land maintenance and/or restoration with the determined party (e.g., Department of Parks and Recreation, Living River Land Trust, other). The Department of City Planning will be responsible for providing full information about the TDR program, procedures, land maintenance and management to landowners participating in the program. Similarly, the city planners will be responsible for providing and ensuring that developers purchasing development rights are fully aware of where development may take place and how purchased development rights implicate a development. In doing so, the department will ensure full information and disclosure before, during, and after a TDR transaction. Fully informing participants and surrounding stakeholders about the program will help mitigate litigation risks and complaints against the program.

VI. Evaluation & Monitoring

It is imperative that the city continue to engage with various stakeholders after the program is implemented. This means that the city will need to establish and/or promote accessible channels of communication between program stakeholders (i.e., developers, landowners, receiving community members, sending community members, etc.) and program administrators. Doing so will help the city identify flaws, unintended consequences, and opportunities for



program improvement. In the past, Norfolk has benefitted from engaging with stakeholders after program implementation. For example, maintaining conversations and open dialogue with city stakeholders, especially with developers, helped the Planning Commission identify features of the 2018 resilience zoning systems that were hindering developers from incorporating resilient features into their buildings (NOAA, 2021). In an interview with NOAA, one zoning administrator in Norfolk's Planning Department reported that their continued engagement with stakeholders, especially developers, has helped Norfolk identify opportunities for improvement within the code that will increase the code's effectiveness and the city's overall resilience (NOAA, 2021).

Planners should evaluate the cost-effectiveness of the program according to both the amount of space acquired through the TDR program and the distribution of it annually. The city should map areas in which land had been acquired and converted into buffer space. Doing so will allow city planners to evaluate how the program is functioning within the city and whether it is effectively increasing buffer space in preparation for worsened sea level rise. Mapping acquired space may show where people are receptive to the program and where they are not. Additionally, mapping will inform the city as to where there are larger flood buffers and where populations may be more vulnerable to sea level rise; this information could point to underlying or systemic equity issues between those regions that are benefiting from the TDR program (in the form of increased flood protection) and those that are not (vulnerable). Regions with little or no flood buffer should be targeted for increased community engagement and partnership that will help the city better meet their sea level rise and flooding needs.

Conclusions

Sea level rise represents one of the most pressing issues facing Norfolk today. Under current projections of future sea level rise, Norfolk is expected to experience unprecedented flooding, storms, displacement, and ecological degradation. Nonetheless, Norfolk's residents are already facing its immense challenges today. By establishing a transfer of development rights program in the city, Norfolk can protect open flood buffer space, facilitate wetlands migration and preservation, and steer future development to flood-resilient areas to become an even more resilient city.

With a TDR program, the City of Norfolk could work with nature, not against it, to better protect both its human and ecological communities from the mounting threats posed by sea level rise.

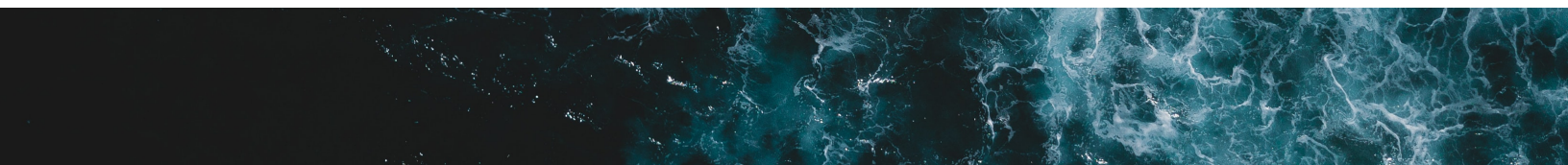
Appendix

Appendix A: Limitations of Literature

Literature is primarily drawn from academic journals, research organizations, and government agencies, and supplemental information is drawn from university and NGO reports, working papers, and city pilot projects. As a result of the nature of sea level rise and coastal flooding, the causal effect of certain programs is often ambiguous as researchers are (sometimes) unable to isolate the effects of interventions as opposed to other natural processes and factors (e.g., land shape, current, wind, etc.).

Additionally, each locality experiences flooding and sea level rise differently depending on their local morphologic, hydraulic, and geological characteristics, therefore, "control" (those that get a certain intervention) and "treated" groups (those that do not) will, in most cases, be systematically different (e.g., land shape, land use, level of development). As a result, literature is limited in that it tends to indicate whether a certain intervention is or is not effective in reducing flood risk and sea level rise as opposed to estimating an exact "treatment effect." Additionally, literature is limited in that many researchers measure the effectiveness of different interventions using varying metrics.

Research is primarily drawn from case studies with some similarities as Norfolk (e.g., metropolitan, coastal, or geographic); such sources shed light on how interventions function in differing contexts (social, geographic, and environmental), which will be useful in evaluating which interventions are most likely to succeed in Norfolk. Nonetheless, results from case studies are not perfectly generalizable as characteristics of sea level rise, flooding, damages, and vulnerabilities vary by region.



Appendix B: Cost-Effectiveness

I. Visualization of Chronic Inundation

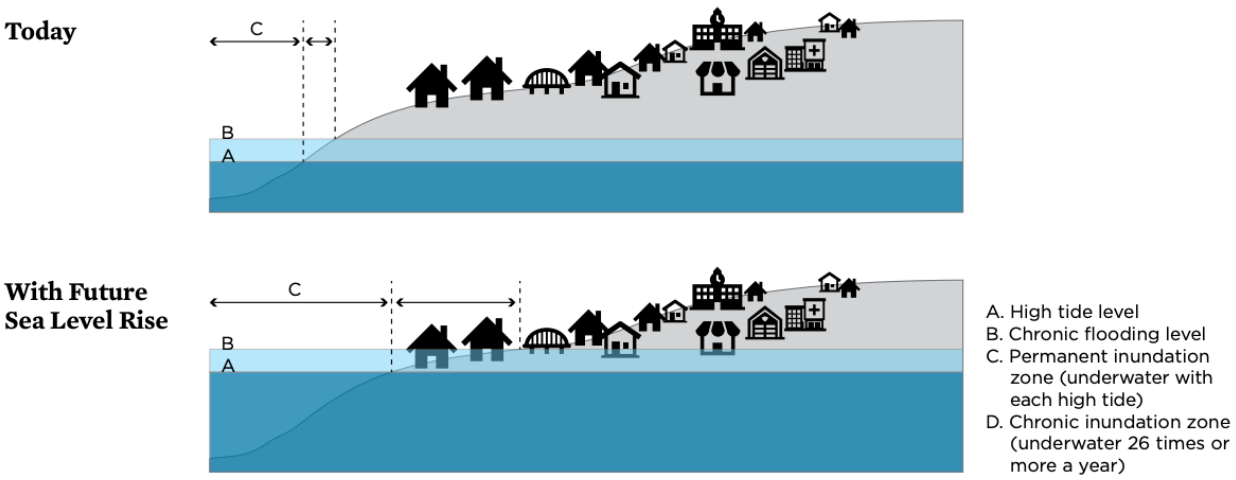


Image Source: Union of Concerned Scientists. (2018). Underwater: Rising Seas, Chronic Floods, and the Implications for US Coastal Real Estate (pp. 1–24). https://www.ucsusa.org/sites/default/files/attach/2018/06/underwater-analysis-full-report.pdf

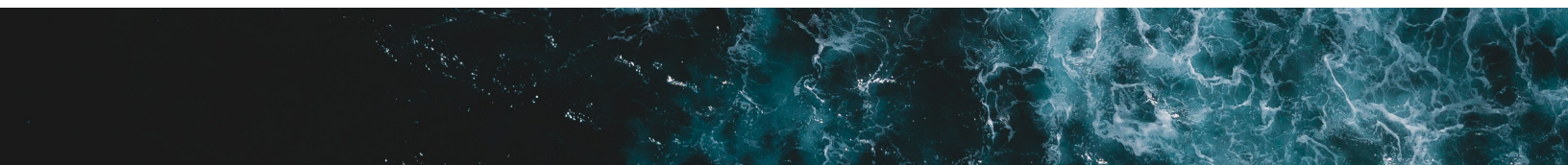
In 2018, the Union of Concerned Scientists (UCS) used property and sea level rise data to project the chronic flooding/inundation risk for coastal properties across the United States. UCS developed both a report and an interactive mapping tool that identifies the number of residential homes, current property values, estimated population, and estimated tax base at risk of chronic inundation from sea level rise by 2045. A home is considered chronically inundated if it experiences flooding at least 26 times annually. (UCS, 2018).

II. Alternative 1, *Cost-Effectiveness*

UCS estimates of chronic inundation in Norfolk, VA were used in this paper to estimate cost-effectiveness. According to UCS, there are 1,001 residential properties at risk of chronic inundation by 2045 in the City of Norfolk, VA (UCS, 2018). Using the property data from the real estate company, Zillow, UCS estimated that properties at risk of chronic inundation by 2045 are worth an estimated $261,152,600, which is the estimated cost acquiring all properties at risk of chronically inundation (100% take-up rate). UCS estimated that these properties house an estimated 2,211 people and contribute an estimated $3,238,575 in local property taxes (UCS, 2018). Nonetheless, it is unlikely that 100% of residents will accept the buyout offer; assuming a 75% the take-up rate, as observed in New Jersey's Blue Acres Buyout Program, it is estimated that about 750 homes would be acquired at an acquisition cost of $260,892 per home and a total tax revenue loss of $3,235 per home (NJDEP, 2015).

HomeAdvisor estimates that the average cost of a house demolition is $18,000 (HomeAdvisor, 2021). Assuming about 75 homes are acquired annually for 10 years, it was found that total acquisition costs would be $151,964,000, total demolition costs would be $10,484,626, total tax base loss would be $1,884,518, and total personnel costs would be $1,414,063 (using 7% discount rate, 2% inflation rate, and 0.75% salary raise rate).

The average acreage of a property in Virginia, as reported by HomeAdvisor in 2018, was used to estimate projected buffer space. According to HomeAdvisor, the average lot in Virginia is 16,834 square feet, or 0.386 acres (HomeAdvisor, 2018). Therefore, the 750 properties of interest were estimated to cover 276 acres of land.



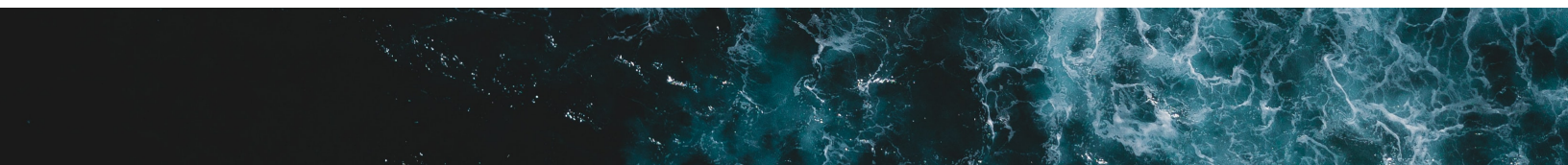
II. Alternative 2, *Cost-Effectiveness*

Norfolk, VA's formal weather records began in 1871 when the National Weather Service was established in the downtown area (NOAA, n.d.; ODU, 2019). NOAA found that, on average, Virginia tropical storms yearly and hurricanes once every 2.3 years (NOAA, n.d.). In 2016, coastal Virginia experienced a category 5 hurricane, Hurricane Matthew. Hurricane Mathew caused significant damage across the state - destroying more than 2000 homes, and in 2018, the commonwealth experienced the category 4 Hurricane Florence - causing flooding, extreme winds, storm surge, and infrastructure to collapse across the Hampton Roads region (Stewart, 2017).

In 2019, researchers at Old Dominion University's Dragas Center for Economic Analysis and Policy created a model to estimate damage that could be expected from another Florence-type hurricane in the Hampton Roads region. In another Florence-type hurricane, they find that more than 33% of all buildings at risk of flooding would be damaged and 6,321 (33%) residences would be completely destroyed (destroyed being that more than 50% of the home is damaged) (McNab et al., 2019). Norfolk (pop 244,601) is estimated to compose about 14% of the Hampton Roads population (1.729 million) (US Census Bureau, 2019). Assuming that property damage is comparable to population distribution, it is estimated that a Florence-like hurricane would destroy an estimated 885 residences in Norfolk. Assuming 75% take-up, it is estimated that 664 property owners would accept post-disaster compensation for their property. I assume the same average value of flood-prone properties ($260,892), demolition ($18,000), and tax revenue loss ($3,235) as calculated in Alternative 1 using the 2018 UCS report. The average lot size estimate (0.386 acres) is used in Alternative 2.

FEMA reports that the average NFIP flood insurance claim in Virginia is $19,000 (FEMA, 2019). To estimate the average cost of property acquisition in Alternative 2, I took the average value of flood-prone properties ($260,892) and subtracted the average NFIP claim as reported from FEMA ($19,000). Therefore, the average estimated cost for each property acquisition in Alternative 2 is $241,892. Category 4 hurricanes are relatively rare in VA; however, the state has experienced two since 2016, and the frequency of such storms are likely to increase. Nonetheless, for this analysis, I assume that Norfolk will be affected by smaller hurricanes every two years and that 133 (20%) of the 664 properties likely to be destroyed in a severe hurricane will be affected in each. Alternative 2 requires that city planners both develop a post-disaster redevelopment plan and that they administer the program after a disaster. Therefore, there are two types of personnel costs (1) plan building and (2) post-disaster compensation administration; because both developing the plan and administering/maintaining the program are expected to be labor intensive, they are estimated to require equal hours annually.

Over a ten-year period, it was found that total acquisition costs would be $121,818,186, total demolition costs would be $9,064,902, total tax base loss would be $1,629,164, and total personnel costs would be $1,414,063 (using 7% discount rate, 2% inflation rate, and 0.75% salary raise rate).



III. Alternative 3, *Cost-Effectiveness*

Because TDR programs are a relatively new tool for coastal managed retreat, I use data from case studies and estimates of PDR and TDR programs in other contexts and regions to estimate cost-effectiveness of a TDR program in Norfolk (Lung and Killius, 2016). Land availability, participation, and the extent to which the upland overlay zone can be developed are potential dissimilarities between these cases that could result in varied results in Norfolk.

Estimated costs and projected effectiveness for Alternative 3 were based on the costs and outcomes of the City of Virginia Beach's Purchase of Development Rights (PDR) program. In a PDR program, the local government buys the development rights to eligible land from willing sellers as a conservation easement; the land is then held as permanent open, conserved space. The proposed TDR program in Norfolk mirrors this program, with the exception that development rights can then be sold via the TDR Bank to developers. By using estimates from the Virginia Beach case, I conservatively estimate the cost of a TDR program in Norfolk. I demonstrate the full potential cost of a TDR program in Norfolk (i.e., costs before being offset by developers purchasing rights) by assuming that no developers purchase development rights from the local government. This is unlikely to occur in practice, and therefore, cost estimates of land acquisition estimate worst-case-scenario costs.

Between 1995 and 2015, the City of Virginia Beach conserved 9,265 acres of land through their PDR program (Lung and Killius, 2016). Therefore, it is estimated that the program conserves about 463.25 acres annually on average. Virginia Beach encompasses 497.3 square miles of land; while Norfolk covers only 54 miles of land (Gore, Lam, & Vargas-Castro, 2011; Whitney and Sharp, 2022). Scaling Virginia Beach's program outcome in proportion with the relative land areas, it is estimated that a TDR Bank in Norfolk could acquire about 50 acres of land annually (assuming same land composition, availability, and participation).

The City of Virginia Beach spends an estimated $4 million each year on the PDR program, or an estimated $8,635 per acre conserved (Hankerson, 2018). The Virginia Land Conservation Tax Credit (LPTC) grants property owners a tax credit for 40% of the value of the land they donate or conserve in conservation easements. Therefore, if it is assumed each conservation easement is worth an estimated $8,635 per acre conserved, then it is estimated that for every acre conserved the government loses about $3,454 in tax revenue, or about $173,738 per year. Additionally, estimating that the program would result in 50 acres a year at an estimated $8,635 cost of acquiring development rights, it is estimated that it would cost an estimated $434,346 annually for the government to purchase the development rights for 50 acres of land. Projected over ten-years and including estimated annual personnel costs (600 hours for nine people annually), it is estimated that the net present value of a TDR program would be about $6,131,961. This estimate breaks down into an estimated cost-effectiveness of about $12,190 per acre conserved as buffer space.

In summary, over a ten-year period, it was found that total easement acquisition costs would be $3,369,928, total tax base loss would be $1,347,971, and total personnel costs would be $1,414,063 (using 7% discount rate, 2% inflation rate, and 0.75% salary raise rate).

IV. Personnel Costs, *Cost-Effectiveness*

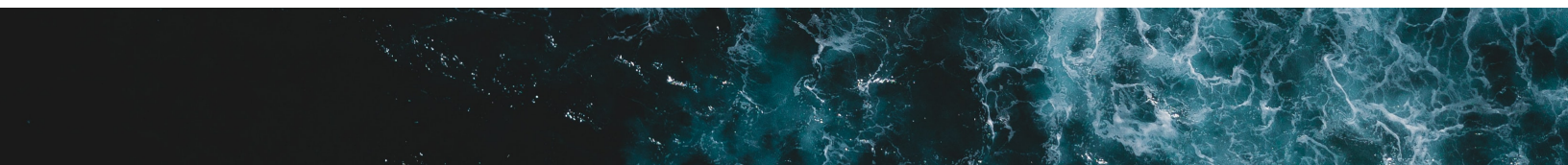
It is assumed that each policy will require local government staff to administer and implement the policies. Therefore, each policy assumes there will be a cost of employment. The average salary for a Norfolk City Planner ($69,687) was broken into an hourly wage (assuming 40 hour work week) of $33.50 (Indeed, 2021). It is assumed that the average salary includes employee benefits; in addition, a 0.75% salary raise is accounted for in personnel cost estimates. There are nine members of the Norfolk City Planning Department listed as staff in the city's staff directory They are responsible for making land use and management decisions, for developing city-wide plans, and for advising the City Council and Planning Commission on planning matters for the City (City of Norfolk, n.d.). Depending on the size and administrative complexity of each policy, I make assumptions about the number of hours each member will allocate to the development of the policy. It is assumed that administrative processes that coordinate with larger governments (e.g., federal, state) will require more time.

Hourly Wage of Planner	$33.50
Number Norfolk City Planners	9
Estimated Hours of Participation (per person per year)	Variable

V. Sensitivity Analysis

Alternative 3 scored the lowest (most favorably) in all four criteria considered in this analysis. Most notably, a TDR program scored significantly lower in the cost-effectiveness criteria than the post-disaster property acquisition program and the voluntary buyout program. In order for this outcome to change, the TDR program would have to cost about at least $536,141 more per acre than it is currently evaluated to cost. This analysis already made a conservative assumption that no developers would purchase any development rights from the city, therefore, the program's estimated cost-effectiveness assumes that the program does not generate any revenue from the sale of development rights. In order to see a significant change in the cost-effectiveness of the program, large assumptions about the cost of acquiring development and rights from property owners would have to be made. While there may be some variation in this cost in actuality, it is extremely unlikely that we would find a change to the degree necessary to change this recommendation; therefore, under projected outcomes, the recommendation to establish a TDR program is considered relatively sound and robust.

It is possible, however, that a survey of land availability in the city and engagement with property owners could show that there is less land available for conservation and development right transfer than assumed in this report (e.g., because of lacking physical land space, land distribution, or lack of landowner willingness to participate). In this case, the city would have to create open space for wetlands migration out of currently occupied land plots via acquisition and demolition. Depending on the aforementioned factors (e.g., land availability, stakeholder participation willingness, etc.), the recommendation could flip to Alternatives 1 or 2. In all proposed alternatives, a survey and community engagement, especially with property owners, vulnerable communities, and developers, will be critical for Norfolk to implement a managed retreat strategy effectively.



VI. Cost Tables & Assumptions, *Alternative 1*

Voluntary Buyouts (Assumptions)

Analysis Period	10 years
Discount Rate	7%
Inflation Rate	2%
Annual Salary Raise	0.75%
Estimated Homes Destroyed in Hurricane (75% Take-up)	1001 (750.75)
Cost Acquisition (per property)	$260,892
Local Tac Contributions (per property)	$3,235
Demolition Cost (per home)	$18,000
Avg Lot Size (acre)	0.368

Cost - Voluntary Buyouts (2023-2027)

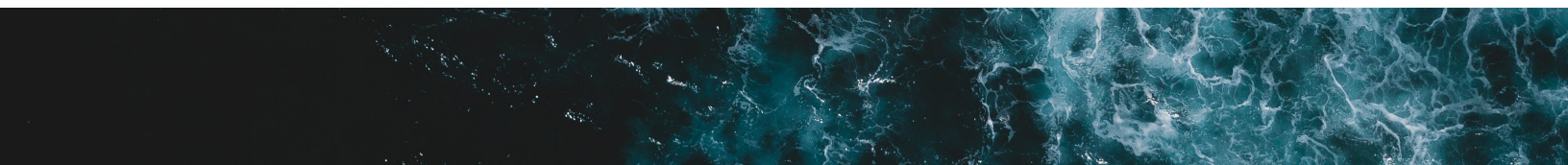
YEAR	2023	2024	2025	2026	2027
Estimated Cost Acquisitions	$18,671,190.56	$17,798,705.02	$16,966,989.83	$16,174,139.84	$15,418,338.91
Estimated Cost of Demolitions	$1,288,202.80	$1,228,006.41	$1,170,622.93	$1,115,920.93	$1,063,775.09
Estimated Tax Revenue Loss	$231,542.98	$220,723.21	$210,409.04	$200,576.85	$191,204.10
Estimated Personnel Cost	$173,740.08	$165,621.38	$157,882.07	$150,504.40	$143,471.48
Annual Total	$20,364,676.42	$19,413,056.03	$18,505,903.88	$17,641,142.01	$16,816,789.58

Cost - Voluntary Buyouts (2028-2032)

YEAR	2028	2029	2030	2031	2032
Estimated Cost of Acquisitions	$14,697,855.79	$14,011,040.10	$13,356,318.60	$12,732,191.56	$12,137,229.34
Estimated Cost of Demolitions	$1,014,065.97	$966,679.71	$921,507.76	$878,446.65	$837,397.74
Estimated Tax Revenue Loss	$182,269.33	$173,752.07	$165,632.81	$157,892.96	$150,514.79
Estimated Personnel Cost	$136,767.21	$130,376.22	$124,283.87	$118,476.21	$112,939.94
Annual Total	$16,030,958.30	$15,281,848.09	$14,567,743.04	$13,887,007.39	$13,238,081.81

Cost - Voluntary Buyouts (Total 10 years)

TOTAL	
Estimated Cost of Acquisitions	$151,964,000
Estimated Cost of Demolitions	$10,484,626
Estimated Tax Revenue Loss	$1,884,518.13
Estimated Personnel Cost	$1,414,062.87
Total (10 yr)	$165,747,206.56



VII. Cost Tables & Assumptions, *Alternative 2*

Post-Disaster Plan & Acquisitions (Assumptions)

Analysis Period	10 years
Discount Rate	7%
Inflation Rate	2%
Annual Salary Raise	0.75%
Estimated Homes Destroyed in Hurricane (75% Take-up)	885 664
Number Homes Acquired (every other year)	133
Cost Acquisition (per property)	$260,892
Local Tac Contributions (per property)	$3,235
Demolition Cost (per home)	$18,000
Avg NFIP Award in VA (per property)	$19,000
Avg Lot Size (acre)	0.368

Cost - Post-Disaster Plan & Acquisitions (2023-2027)

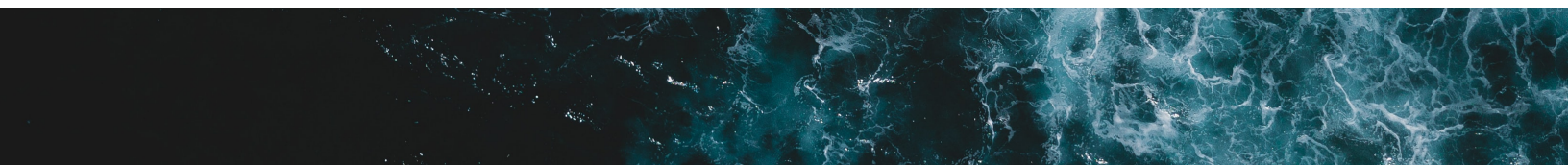
YEAR	2023	2024	2025	2026	2027
Estimated Cost Acquisitions	$0	$29,455,004	$0	$26,766,518	$0
Estimated Cost of Demolitions	$0	$2,191,846	$0	$1,991,787	$0
Estimated Tax Revenue Loss	$0	$441,048	$0	$400,792	$0
Estimated Personnel Cost	$173,740	$165,621	$157,882	$150,504	$143,471
Annual Total	$173,740	$32,253,520	$157,882	$29,309,601	$143,471

Cost - Post-Disaster Plan & Acquisitions (2028-2032)

YEAR	2028	2029	2030	2031	2032
Estimated Cost of Acquisitions	$24,323,422	$0	$22,103,317	$0	$20,085,851
Estimated Cost of Demolitions	$1,809,988	$0	$1,644,782	$0	$1,494,656
Estimated Tax Revenue Loss	$364,210	$0	$330,967	$0	$300,758
Estimated Personnel Cost	$136,767	$130,376	$124,284	$118,476	$112,940
Annual Total	$26,634,387	$130,376	$24,203,350	$118,476	$21,994,205

Cost - Post-Disaster Plan & Acquisitions (Total 10 year)

TOTAL	
Estimated Cost of Acquisitions	$122,734,113
Estimated Cost of Demolitions	$9,133,059
Estimated Tax Revenue Loss	$1,837,775
Estimated Personnel Cost	$1,414,063
Total (10 yr)	$135,119,010



VII. Cost Tables & Assumptions, *Alternative 3*

Transfer of Development Rights (Assumptions)

Analysis Period	10 years
Discount Rate	7%
Inflation Rate	2%
Annual Salary Raise	0.75%
Estimated Acreage Conserved (annually)	50.3
Estimated Rights Acquisitions Cost (per acre)	$8,635
Land Conservation Tax Credit (LPTC)	40% easemt. val.
Estimated Tax Revenue Lost from Conservation (per acre)	$3,454

Cost - Transfer of Development Rights (2023-2027)

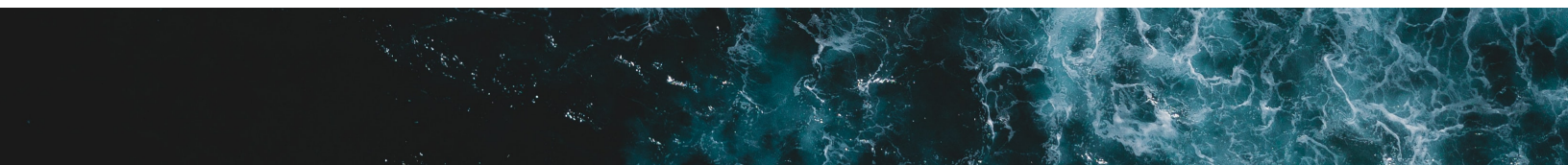
YEAR	2023	2024	2025	2026	2027
Estimated Cost of Rights Acquisitions	$414,049.12	$394,701.03	$376,257.05	$358,674.95	$341,914.44
Estimated Tax Revenue Loss	$165,619.65	$157,880.41	$150,502.82	$143,469.98	$136,765.77
Estimated Personnel Cost	$173,740.08	$165,621.38	$157,882.07	$150,504.40	$143,471.48
Annual Total	$753,408.84	$718,202.82	$684,641.94	$652,649.33	$622,151.69

Cost - Transfer of Development Rights (2028-2032)

YEAR	2028	2029	2030	2031	2032
Estimated Cost of Rights Acquisitions	$325,937.13	$310,706.42	$296,187.43	$282,346.89	$269,153.11
Estimated Tax Revenue Loss	$130,374.85	$124,282.57	$118,474.97	$112,938.76	$107,661.25
Estimated Personnel Cost	$136,767.21	$130,376.22	$124,283.87	$118,476.21	$112,939.94
Annual Total	$593,079.19	$565,365.20	$538,946.27	$513,761.87	$489,754.30

Cost - Transfer of Development Rights (Total 10 years)

TOTAL	
Estimated Cost of Rights Acquisitions	$3,369,927.56
Estimated Tax Revenue Loss	$1,347,971.02
Estimated Personnel Cost	$1,414,062.87
Total (10 yr)	$6,131,961.45



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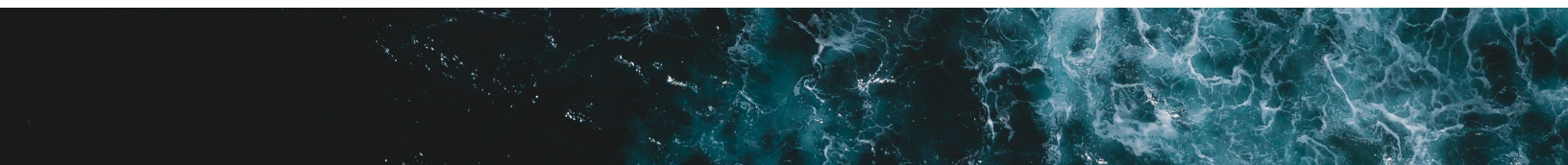

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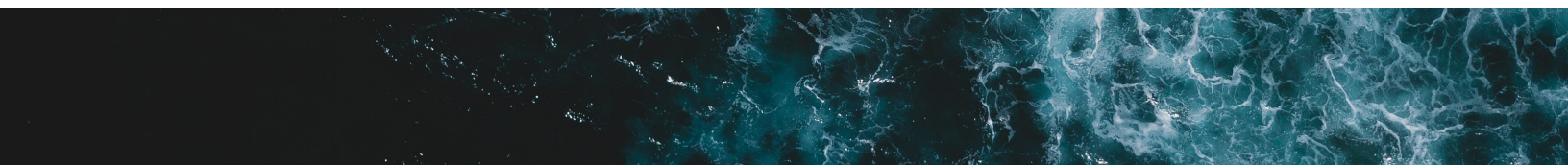

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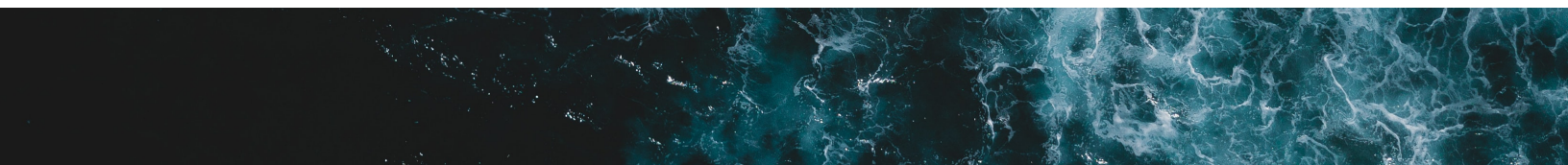

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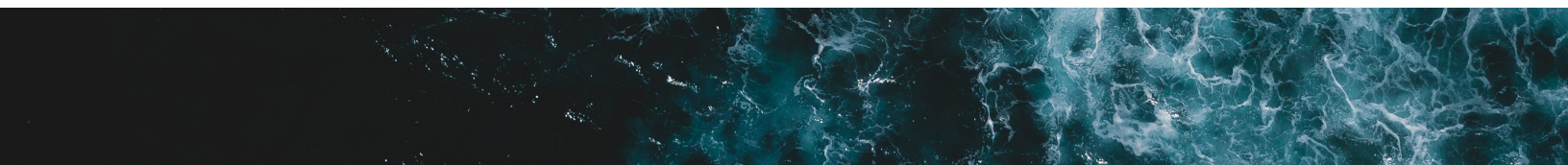

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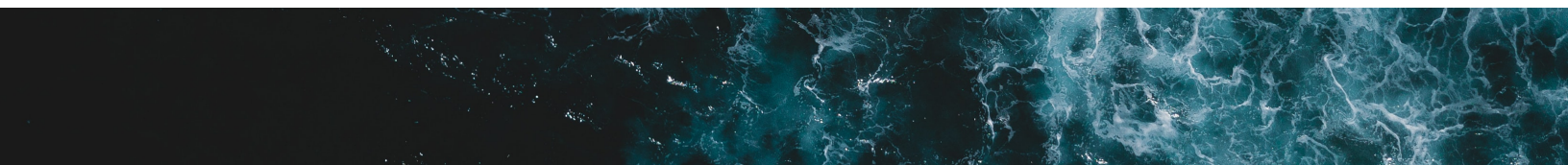

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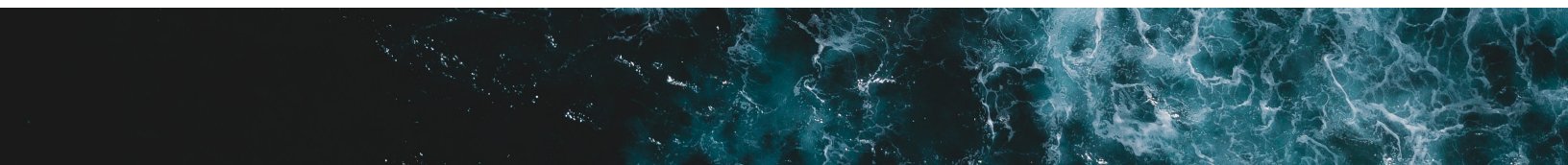

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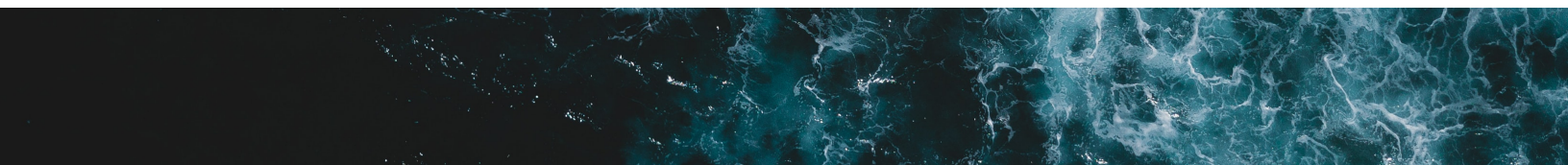

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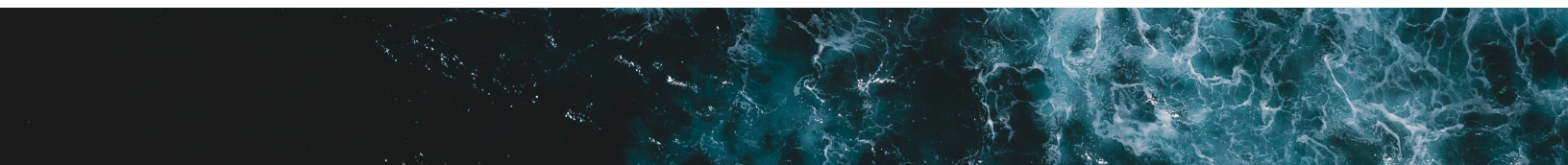

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