AN ANALYSIS OF ECOSYSTEM SERVICES AND BENEFITS TO GUIDE CONSERVATION IN THE CHESAPEAKE BAY WATERSHED

By

Students: Chuqi Cai, Ardath Dixon, Cate Jaffe, Erik Rieger
Advisor: Dr. Elizabeth Albright

April 30, 2021

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Chesapeake Bay Watershed drains approximately 64,000 square miles of farms, cities, and forests into the largest estuary in the United States. The watershed crosses five state boundaries and the District of Columbia, and is home to over 18 million people. Our client, the Chesapeake Conservancy, is a long-standing contributor to conservation and restoration efforts throughout this complex watershed. Recently, the Conservancy and its regional partners have adopted a framework to conserve 30% of the watershed by 2030 and 50% by 2050. Our research aims to advance the scientific and economic case for this ambitious 30 by 30 land protection goal. Using a case study approach, we apply geospatial and economic analyses to examine and communicate the key ecological and economic benefits these lands provide to both people and nature. Our process is couched in a multi-criteria, ecosystem services framework.

The first section of this report introduces the Chesapeake Bay watershed, our client and actions made towards the 30 by 30 land protection goal. Our research goal was to identify, quantify, and map the ecological and economic benefits of additionally conserved lands for (a) water quality from nutrient retention, (b) runoff attenuation for flood mitigation, (c) biodiversity conservation and habitat connectivity, and (d) human access to public open spaces. We also included two additional valued criteria: (e) development vulnerability and (f) benefits to traditionally underserved communities. In this section we also introduced the rationale behind these chosen criteria.

The second section describes our methodology to identify priority lands for conservation based on their provision of selected criteria and to demonstrate the benefits of potential conservation with quantitative facts, figures, and economic valuation. We start with our site selection, parcel data processing and then detail the analytic steps we used in the multicriteria analysis. We explain the steps of the multicriteria analysis we used to create conservation prioritization scenarios and identify parcels that provide co-benefits. We also describe the steps in the value estimation of ecosystem services.

The third section of this report details the results of our analyses. We describe the distribution of parcel scores for each of the conservation criteria, the results of the economic valuation, and the distribution of conservation prioritization scenarios from our multicriteria analysis. Finally, we discuss the final distribution of parcels that provide co-benefits. We present multiple maps, tables, and figures that convey our scenario results, alongside the written descriptions. Overall, our results show hotspots of unprotected lands along the eastern and western shores of the Bay with multiple co-benefits projected to increase in economic value over time. Targeting 30 by 30 conservation actions to these lands will likely maximize regional conservation benefits.

In the fourth and final section we discuss our central findings based on the results in section three. We provide recommendations, list the limitations of our analysis, and suggest avenues for future research and application of our results. The overarching limitation of this analysis is that data produced here are principally for landscape-scale assessment of ecosystem services, not a localized site-specific evaluation or application. These data should not be used for individual parcel selection or as a proxy for on-the-ground conditions in a specific location.

Our analysis shows that the coastal reaches of the Chesapeake Bay's western shore, which includes portions of the Paxtuent and Severn Watersheds, are a hotspot for co-benefits relative to the study area used in this case study. Ecosystem services provided by lands on the Delmarva Peninsula (Chester-Sassafras Watershed) and western shore are projected to increase in monetary value over time. For some HUC 12 watershed boundaries, this increase in value exceeds $4 million dollars. This increase is principally driven by the expected increase in wetland area and the limited decrease in forest and farmland area. Significantly, watersheds in the southernmost regions of the study area currently provide a high density of co-benefits with some projected to increase in their ecosystem service value. Collectively there are 90,500 acres of unprotected co-benefit priority parcels in this region. These are the highest priority conservation areas for protection in terms of the current provision of ecosystem services and benefits.

Based on the above findings, we find that conservation actions in the southernmost regions of the study area would likely minimize potential tradeoffs between ecosystem services. Conservation targeted in the Paxtuent and Severn Watersheds is more likely to protect lands that could provide critical co-benefits such as flood mitigation, nutrient retention, human access to open space, and habitat connectivity. Conservation in the Chester-Sassafras Watershed and eastern shore may be cost-effective because it preserves lands which, without additional restoration or management, will provide ecosystem services that increase in value over time. Watersheds in the northern part of the study area (the Lower Susquehanna Watershed) have some localized hotspots of co-benefits. However, based on projected land use change, the economic value of those services is projected to decrease over time without conservation action. Conservation in these regions would be most effective in providing ecosystem services and benefits when paired with restoration activities targeted towards working forests, farms, and riparian corridors, as the Chesapeake Conservancy and its regional partners have been implementing and facilitating.

A final takeaway from this research is that the quantification of co-benefits, as shown in this analysis, is likely to play an increasingly important role in future conservation efforts. While our specific recommendations are for our study area, they provide a blueprint for how to implement these ambitious conservation goals in the larger Chesapeake Bay Watershed. The current political momentum behind 30 by 30 supports this mission. By considering and quantifying key ecosystem services, decision makers and community partners can provide defensible evidence for land protection goals.

1. INTRODUCTION

1.1. The Chesapeake Bay Watershed

The Chesapeake Bay Watershed feeds into the largest estuary in the United States and has a land to water ratio of 14:1, stretching from central New York state to the southern coastline of Virginia (Figure 1). This watershed is distributed across five state boundaries and Washington D.C., and drains approximately 64,000 square miles of farms, cities, and forests which are home to over 18 million people (Chesapeake Conservation Partnership, 2019). The watershed is valuable for its fishing industry, agriculture, heritage, and recreation assets.

Figure 1. The Chesapeake Bay Watershed.

This watershed is experiencing several environmental threats. With a diversity of land uses, the Chesapeake Bay and its associated watershed have for decades struggled with water pollution caused by runoff carrying sediment, excess nutrients, and other pollutants. Sea-level rise induced by climate change is expected to inundate coastal areas (Najjar et al., 2020; Li et al., 2020). The frequency of 100-year floods have been increasing, yielding greater risk to communities and infrastructure (Wright et al., 2019). Increasing development pressure is causing the loss of critical habitat needed to protect regional biodiversity.

Historically, water quality has been the primary ecosystem service used to promote conservation in the Chesapeake Bay Watershed. In 2010, after years of insufficient restoration efforts and persistent poor water quality in the Bay, the U.S Environmental Protection Agency (EPA) established the nation's largest Total Maximum Daily Load (TMDL) pollution limits (EPA, 2016). TMDLs—a kind of "pollution diet"—establish specific pollution reductions necessary to meet water quality standards in the Bay. The current Bay TMDL calls for a 25% reduction in nitrogen, a 24% reduction in phosphorus, and a 20% reduction in sediment within the Bay (EPA, 2016). This landmark 2010 rule was further supported by President Obama's 2009 Executive Order 13508, which called on federal agencies to work with regional and local partners to address critical restoration needs in the watershed. Since the TMDL and Executive Order, a diverse network of governments, cities, non-profits, private companies, federal agencies, and regional partnerships have collaborated on restoration, conservation, and management in the watershed. For instance, the 2014 Chesapeake Bay Watershed Agreement explicitly incorporated conservation as a critical tool for meeting the agreement's goals. This agreement set goals to meet the TMDL with signatories at the federal, state, and local scales. It advances goals for water quality beyond the TMDL to include criteria such as vital habitat (e.g. stream health, wetlands, and forest buffers), land conservation, public access, and climate resiliency.

1.2. The Client & The Global Deal for Nature

Our client, the Chesapeake Conservancy, has been a significant contributor to meeting the TMDL with restoration and conservation efforts throughout the Chesapeake Bay Watershed over the last decade. A non-profit organization based in Annapolis, Maryland, the Conservancy leverages public-private partnerships, regional collaborations, and technological innovations to drive effective conservation across the Chesapeake Bay Watershed.

Recently, the Conservancy and its regional partners adopted the “Global Deal for Nature” framework to guide conservation efforts. This momentum was inspired by E.O. Wilson’s *Half-Earth* theory of island biogeography, which posits that protecting 50% of Earth’s surface can protect 85% of its biodiversity (Pimm et al. 2018). The “Global Deal for Nature” includes more short-term goals, advocating to protect 30% of the world's native ecosystems by 2030 and 50% by 2050 (Dinerstien et al., 2019). Beyond the preservation of biodiversity, the Global Deal for Nature has the potential to protect and enhance a wide variety of ecosystem services that provide critical support to human communities, infrastructure, and livelihoods.

The federal government recently adopted 30 by 30 into its climate policy, bringing this framework to the national scale. President Biden’s January 2021 Executive Order 14008 committed the U.S. to conserving 30% or more of its land and oceans by 2030 (The White House, 2021). This aligns directly with the Chesapeake Conservancy and CCP’s existing goals, and these organizations will play a key role in coordinating regional partners to implement the new mandate.

1.3. Ecosystem Services

Protecting lands such as productive agricultural fields, intact wetlands, and forested riparian buffers can have wider societal benefits such as enhancement of food security, water purification, human health, and carbon storage (Watson et al., 2014, Dirzo et al., 2014). For example, up to a third of the world’s largest cities rely upon protected areas for their drinking water (Watson et al., 2014). While a frequent hurdle for conservation is lack of funding for implementation and monitoring, others have demonstrated that the economic net benefit from maintaining ecosystem services is worth up to $33 trillion per year (Watson et al., 2014; CCP 2019; Costanza et al., 1997).

While conservation and restoration in the watershed have until now primarily focused on water quality, the.Chesapeake Conservancy is particularly interested in showing: (a) how these land protection goals can be achieved in concert with the delivery of vital ecosystem services, (b) how additional land protection benefits underserved communities and improves climate resilience—from services such as improved access to recreational open space, flood mitigation, and water purification, and (c) how supply and demand for ecosystem services is affected by the distribution of farms, forests, habitat, and lands critical to human health and heritage.

Current scientific underpinning and modelling of land management in the watershed are notoriously complex, and the opacity of these technological tools have been identified as a barrier to future stakeholder engagement with conservation and restoration efforts in the watershed (Sterner et al., 2015; Paolisso et al., 2013). Thus, by addressing pressing conservation needs through the lens of ecosystem services and building approachable analyses, it may be possible to garner greater support for land protection.

1.4. Research Goals

The central mission of this research is to help advance the scientific and economic case for land protection goals in the Chesapeake Bay Watershed at the parcel scale. The 2030 goal necessitates the conservation of more than 3.1 million acres by 2030. To reach the 2050 goal, an additional 8.2 million acres would need to be conserved on top of the 3.1 million by 2030 (CCP, 2019). Despite growing enthusiasm for these ambitious conservation goals, many stakeholders, policy makers, and researchers working in the Chesapeake Bay Watershed are just beginning to envision how conservation in pursuit of 30 by 30 and 50 by 50 can look. Given that over 65% of the watershed remains unprotected, where these crucial conservation activities should be targeted remains an open question. Likewise, research could better quantify the potential benefits of such conservation, and how best to target conservation efforts to maximize these co-benefits.

We aimed to identify, quantify, and map the key ecological and economic benefits of additionally conserved lands on (a) water quality from nutrient retention, (b) runoff attenuation for flood mitigation, (c) biodiversity conservation and habitat connectivity, and (d) human access to public open spaces. These ecosystem services were examined alongside two additional valued criteria: (e) development vulnerability and (f) benefits to traditionally underserved communities. We focused these efforts on a sub-area of the central Chesapeake Bay Watershed by mapping these ecosystem services for unprotected lands through various scenarios (Figure 1). Our case study approach can be used to communicate and determine regional conservation priorities, and the process was designed to be adaptable and scalable for use by the client, Chesapeake Conservancy, and their regional affiliates.

1.5. Conservation Criteria Considered for this Research

1.5.1. Biodiversity and Habitat Connectivity

The Chesapeake Bay itself has over 3,600 species of plants, fish, and animals, making it North America's largest and most biodiverse estuary (Claggett et al., 2004). Intentionally conserving particularly biodiverse regions can prevent extinctions, and thus contribute to global conservation efforts (Pimm et al., 2018). Much biodiversity loss has been attributed to habitat loss, climate change, disease, fragmentation, and land-use changes (Dirzo et al., 2014). Conserving 30% of the Chesapeake Bay Watershed by 2030 and 50% by 2050 provides a venue to intentionally protect this region's rich biodiversity. Without this intentionality, the current trends of human-caused animal extinction are likely to continue (Dirzo et al., 2014).

1.5.2. Development Vulnerability

Land conservation provides the means to actively prevent ecosystem destruction from development, enabling a more intentional pathway for expansion. Infrastructure development and land use changes are major threats to ecosystem protection (Dinerstein et al. 2019). The Chesapeake Bay Watershed is currently home to over 18 million residents. With projected growth expected to reach about 20 million by 2030 (Chesapeake Bay Program, 2021), this region provides an opportunity to analyze the means to incorporate population growth alongside land protection goals. By raising conservation urgency for regions with high development vulnerability, land protection can mitigate conversion of critical ecosystems to developed areas. Such direction enables ecosystem protection to coexist with infrastructure development.

1.5.3. Human Access to Open Spaces

Outdoor recreation space provides direct benefits to human health and can mitigate urban heat island effects (Jennings, 2015; Plumer, 2020). Specifically, exposure to protected and undeveloped land areas has been linked with stress reduction, psychological restoration, social cohesion, space for physical activity, reducing exposure to harmful environmental conditions, and immune system modulation (Mears et al., 2019; Boone et al., 2009).

Dialogue on social inequalities increased throughout 2020, inspiring greater integration of justice initiatives with environmental conservation work (Lee, 2021). Likewise, historic red-lining practices are being more openly discussed (Plumer, 2020). In 1933, the Home Owners' Loan Corporation was established in each state, and they produced regional studies for housing markets throughout America. These reports classified neighborhoods as green, blue, yellow, or red for their financial risk-level regarding private mortgages. Typically, neighborhoods with any Black residents meant an automatic red classification, and therefore low likelihood for financial assistance (Rae, 2003). This unequal distribution of loans to promote home ownership and investments is a central cause of imbalanced distribution seen today. Lower home ownership typically meant less agency for neighborhood upkeep and improvement, resulting in the frequent correlation between communities of color and areas with urban heat island effects and in cities today.

Open space accessibility is one measurable characteristic that can quantify social imbalances, highlighting those areas lacking green areas. The 30 by 30 conservation goals set by the Chesapeake Conservation Partnership provide the opportunity to complement this dire need for public green space with conservation and restoration. Increased access to trails, forests, waterways, and vistas can improve nearby residents' physical and mental health (Mears et al., 2019; Plumer, 2020). Protecting ecosystems intentionally provides an opportunity for simultaneous ecological and social benefits.

1.5.4. Benefits to Underserved Communities

Both the climate crisis and the COVID-19 pandemic have shown disproportionate impacts on people of color, low-income, and/or indigenous communities (Lee, 2021; Plumber, 2020). In 1994, President Clinton issued Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations (Lee, 2021). Since then, environmental justice has been incorporated into governmental affairs. For example, the Environmental Protection Agency created the EJSCREEN online tool to visualize environmental justice mapping at the census block group level. They began developing this nation-wide visualization in 2010, made it publicly accessible in 2015, and published the most recent update in 2020 (EJSCREEN, 2016; EJSCREEN, 2020). This display provides resources to mathematically and scientifically quantify disproportionate impacts and systemic racism throughout the United States (Lee, 2021).

EJSCREEN offers three visualization options: environmental indicators (e.g. pollution and contamination levels), demographic indicators, and EJ indices as a combination of the previous two (EJSCREEN, 2020). Therefore, integrating demographic data into environmental analyses can highlight focus areas with dual benefits. Large-scale conservation initiatives such as this project across the Chesapeake Bay Watershed provide the opportunity to incorporate environmental justice into the planning process for land conservation efforts.

1.5.5. Flood Risk Mitigation

The Chesapeake Bay and its associated watershed are projected to experience a variety of climate change impacts as the 21st century progresses. One of the most concerning predictions for the Bay and watershed is an increase in damaging flood events, exacerbated by sea level rise, submergence of flood mitigating coastal ecosystems (marshes, wetlands, eelgrass), and rising hurricane frequency in the Atlantic (Najjar et al., 2020; Li et al., 2020). Some of the most damaging flood events in the watershed are caused by high-precipitation tropical storms which create substantial, stormwater runoff-driven flooding in cities, towns, and farms (York County Planning Commission, 2019). Ellicott City, Maryland experienced three 100-year (or 1% annual chance storms) in the span of ten years: once in 2011, 2016, and 2018. The 2016 storm killed two people and caused $22 million in damages and $42 million in lost economic activity (Poon, 2019). These flood events are only increasing in frequency. 100 year flood events have historically been defined by a 1% chance of occurrence in a given year. However, climate change is driving an increase in the frequency of extreme rainfall events in the United States, making the “100-year” flood increasingly common and straining aging flood infrastructure (Wright et al., 2019).

Conserving and managing wetlands, riparian forests, and other flood-mitigating lands can prevent damage to communities and infrastructure, yielding immediate and long-term economic benefits (Johnson et al., 2020). These “nature-based” approaches to mitigating flood risk and damages are becoming increasingly common-place in city, county and state planning for storm events as a cost-effective way to lower flood risk. A recent report in Nature Sustainability found that by 2070, the cumulative avoided damages would exceed the costs of land acquisition for more than 1/3 of unprotected natural lands in the 100-year floodplain (Johnson et al., 2020). While nature-based approaches to flood mitigation are being adopted at many scales, land conservation and restoration for flood mitigation is most effective when planned and implemented at large spatial scales (The World Bank, 2017). Thus, this case study takes a landscape scale approach to it’s assessment of conservation opportunities for flood mitigation and co-benefits.

1.5.6. Nutrient Retention

Forest and farmland are estimated to be the largest contributors of ecosystem service value in landscapes dominated by piedmont and coastal plains (YuAn et al., 2012), such as the Chesapeake Bay Watershed. Together, forest land and agriculture represent the number one and two land uses by area in the watershed (USDA NRCS, 2018). However, these lands are often at a high risk of conversion to development—be it urban, suburban, industrial—which can dramatically impact the filtration of pollutants, transport of sediment, and generate new carbon dioxide emissions while limiting the future potential of natural ecosystems. With development, these landscapes can permanently lose ecosystem services and with significant consequence. Already protected farmlands in the Chesapeake Bay Watershed are valued in the billions of dollars for their ecosystem services (Schwartz and Kocian, 2015).

With specific regard to water purification, additional conservation of these lands can provide the nutrient retention service needed to meet total maximum daily load (TMDL) requirements in the watershed whilst also providing the terrestrial area and support for other ecosystem services required by the 30 by 30 and 50 by 50 goals. Nutrient retention varies spatially such that a geospatial framework can help to identify hot spots, which are lands with the highest supply of and/or demand for this service (Egoh et al., 2008; Qiu and Turner, 2013). In combination with measures of vulnerability and land use change, it is possible to prioritize farm and forest conservation such that water quality, flood mitigation, habitat connectivity, and economic benefits are maximized according to diverse needs. This data is essential to both private and public entities that face constraints to land protection and must justify the high costs of conservation (Liu et al., 2017) relative to other water-quality enhancing practices.

1.6. Valuation of Ecosystem Services

The natural resources from the Chesapeake Bay Watershed create considerable economic value for the region. Besides the employment related to the watershed and the value created by economic activities such as recreation, hunting, fishing, agriculture, forest, and parks, the watershed also provides tremendous ecosystem service value to the related regions, including but not limited to the value of carbon sequestration, water and soil conservation (Kauffman, 2011). Quantifying the economic benefits of conservation can make planning processes more robust and improve cost-effective decision making. When focusing on the overall economic benefits of Chesapeake Bay conservation, Phillipe (2014) concluded that the total economic benefit of the Chesapeake Clean Water Blueprint is estimated at $22.5 billion (in 2013 dollars) per year. By quantifying the possible monetary benefits of the ecosystem services, we can quantify the economic feasibility of conservation and determine the hot spot for achieving the conservation goal.

2. METHODS

2.1. Overall Methodology

Our overarching approach was to identify priority lands for conservation based on their provision of selected criteria and to demonstrate the benefits of potential conservation with quantitative facts, figures, and economic valuation. These criteria included flood mitigation, nutrient retention, habitat and biodiversity, human access to open spaces, benefits to underserved communities, and development vulnerability. In addition to individual criteria, our analysis assessed potential co-benefits by identifying regions where individual conservation actions can simultaneously prioritize multiple criteria.

A key challenge we faced in assessing tradeoffs and co-benefits of criteria such as flood mitigation, open space access, and development risk was that these criteria are measured using different quantitative units. For instance, human access to open spaces is expressed as a measure of distance to protected areas, while flood mitigation potential was measured by percent of precipitation attenuated by land. In order to make individual criteria comparable, we transformed the raw values to a linear, 0-1 utility or value scale scale (Clemen, 2013).

Once criteria were on a comparable scale, we were able to run several weighted conservation prioritization scenarios which considered all six criteria (Figure 2.1). In each scenario, we weighted one criteria more heavily than the others, applying a weighted sum to produce a new 0-1 score. The results of this scenario generation process were six new 0-1 scores. These reflected where conservation priorities could be located if all six criteria were considered but one criteria was of greatest importance to the conservation planner. (Table 2.3). This scaling and weighting approach is widely applied in multi-criteria decision analysis literature and research (Davis, 2006; Geneletti, 2003).

Parcels with potential to provide co-benefits were those that scored in the top 25% across many or all scenarios (methodology adapted from Geneletti, 2003). These are parcels that would be conservation priorities regardless of which criteria was of greatest importance. From a conservation standpoint, these parcels with overlapping criteria have the potential to provide multiple ecosystem services and values important to the Chesapeake Conservancy.

.

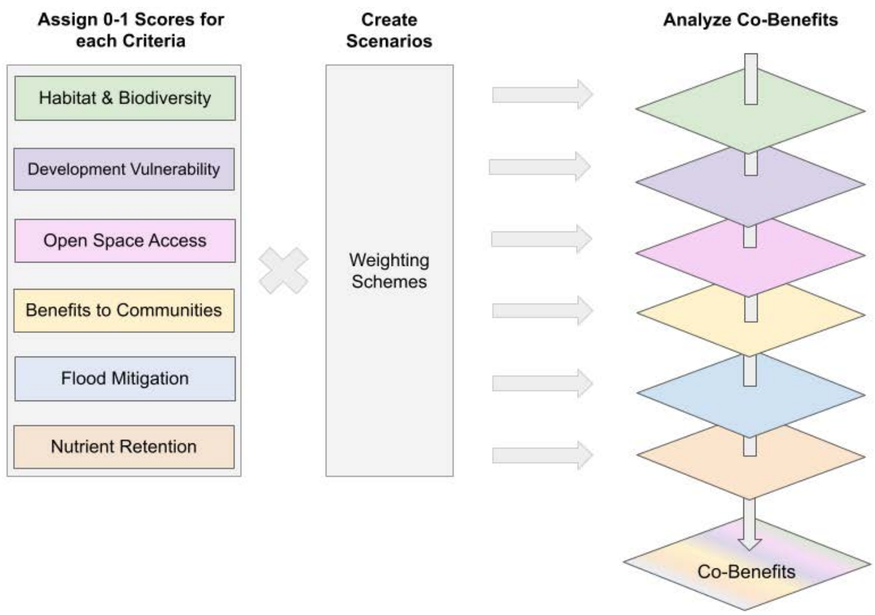


Figure 2.1. Conceptual Model of Criteria Scoring and Co-benefit Analysis.

We also conducted a financial valuation of multiple ecosystem services based on projected land use change from 2016 to 2025, which was summarized using HUC 12 watershed boundaries. Specifically, we assessed the spatial variance in the ecosystem service value by subtracting the 2016 values from 2025 values, and considered how this difference is driven by land use change. We also calculated the net present value of ecosystem services in perpetuity; this is based on land use in 2016 and 2025. These dollars are expressed in 2021 dollars without considering future inflation. Our results highlighted the cost-efficient regions for future conservation planning. The general approach for assessing the distribution of each criteria is detailed below.

2.2. Study Area Selection

For our analysis, we zoomed-in on a smaller study area within the greater Chesapeake Bay Watershed. Specifically, the intention was to analyze an area with an equal representation of land covers: farmland, forest, urban, wetlands, rural, exurban, and coastal. After consulting with specialists from the Chesapeake Conservancy, we adjusted the study area to include regions without extensive current analyses, lands needing urgent protection due to development pressure, and areas with a lower percentage of existing protected lands. HUC 8 watershed boundaries were used to delineate the study area. These are a standard watershed boundary delineated by the United States Geological Survey and used widely in U.S. hydrologic and ecological studies and planning. The final selection included five HUC 8 watersheds: the Lower Susquehanna, Paxtuent, Chester-Sassafras, Gunpowder-Patapsco, and Severn (Figure 2.2). These watersheds encompass the eastern and western shores of the Chesapeake Bay as well as critical lands directly upstream.

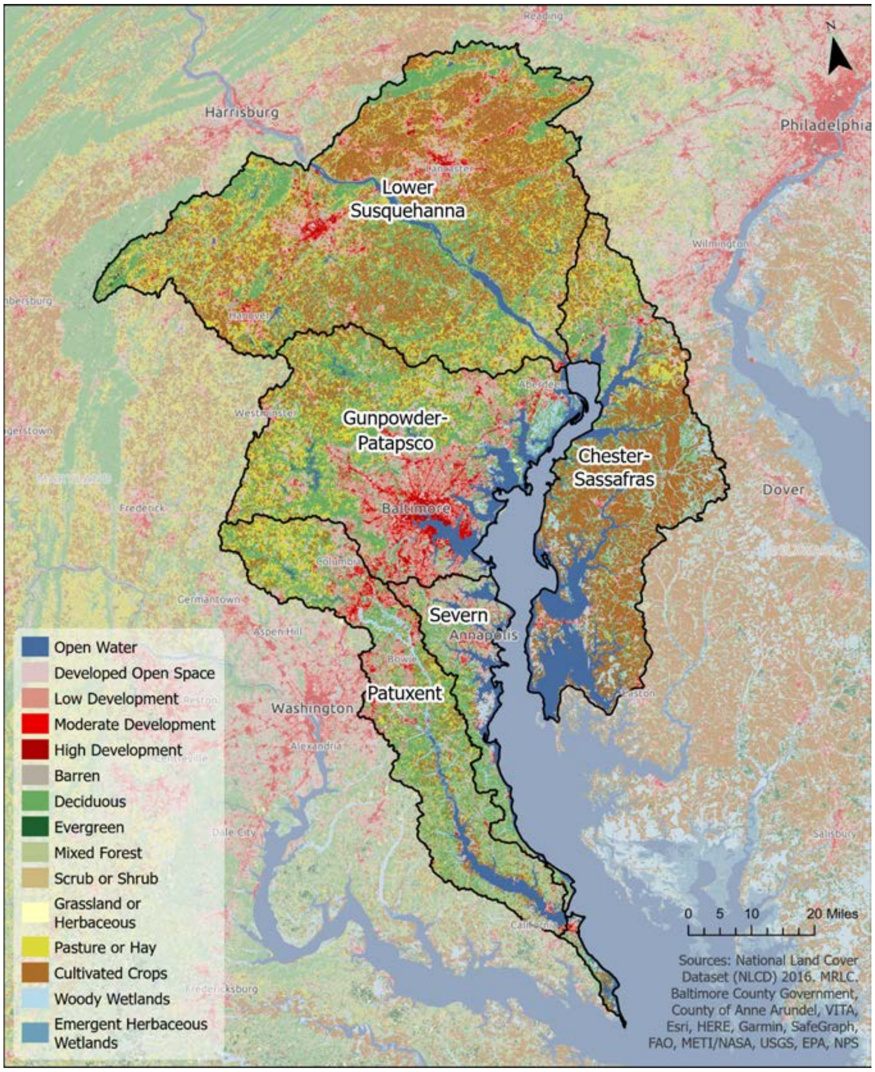


Figure 2.2. Study area with HUC 8 watershed boundaries and land cover.

2.3. Projection and Geographic Coordinate System

All analyses and data used herein are based on the USA Contiguous Albers Equal Area Conic USGS projected coordinate system (WKID = 102039) which uses the 1983 North American Datum (NAD 1983) geographic coordinate system (Snyder, 1982). This projection was selected for its ubiquity as it is the default coordinate system used by the United States Geological Survey. This projected coordinate system also preserves feature area, and area calculations are a key component of several analyses in this project.

2.4. Parcel Data Processing

The study area includes 25 counties across three states, and we collected parcel data layers from every county, accordingly (Table 2.1). These data layers were adjusted to remove parcels outside the study area, those smaller than 10 acres, and those already protected. We identified protected parcels using the 2018 Protected Lands database, which includes private conservation easements, state and federally-owned lands, fee-simple properties (e.g. parcels owned by a land trust), and locally owned parks (Chesapeake Bay Program). The counties' data were consolidated into a single data layer containing each parcel's unique ID, calculated acreage, county name, and state name (Appendix A, Figure A3).

Table 2.1. States and counties with parcels in our watershed study area.

Delaware	Kent, New Castle
Maryland	Anne Arundel, Baltimore, Baltimore City, Calvert, Carroll, Cecil, Charles, Frederick, Harford, Howard, Kent, Montgomery, Prince George's, Queen Anne's, St. Mary's, Talbot
Pennsylvania	Adams, Berks, Chester, Cumberland, Lancaster, Lebanon, York

2.5. Multicriteria Analysis

2.5.1. Biodiversity and Habitat Connectivity

Environmental organizations have used a range of methods to quantify biodiversity and habitat land assets (Genellitti, 2004; Bagstad, 2013; Warnell, 2019). Categorizing land as potential habitat areas is an option that does not require extensive field observations, yet can provide helpful recommendations. Habitat analysis can incorporate land cover, species' environmental needs, and connectivity pathways. The Chesapeake Conservation Partnership had previously created a habitat data layer with three tiers representing an area's habitat, land, and/or water value for biodiversity. They scored highly important habitat areas as Tier 1, important habitat areas as Tier 2, and land connectors as Tier 3. These data represent core habitat for imperiled species, terrestrial cores, aquatic cores, and terrestrial cores connectors. The Chesapeake Conservation Partnership created this habitat layer to better inform Chesapeake Bay Watershed conservation efforts. While several data layers demonstrating ecological assets are in circulation, this particular habitat layer was selected due to scientific consultation and client recommendations.

We overlaid the parcels with the habitat data layer, and assigned each parcel a biodiversity and habitat score representing the highest tier within the parcel's area. If a portion of a parcel has a high habitat worth, that means that the parcel includes that high worth and should be protected accordingly. These values were converted to a 0-1 scale using a linear transformation: zero for parcels with no scores, 0.333 for parcels with Tier 3 areas, 0.667 for parcels with Tier 2 pixels, and one for parcels including Tier 1 habitat areas (Appendix B).

2.5.2. Development Vulnerability

In seeking to highlight regions for conservation, development vulnerability scores show areas particularly susceptible to future land use changes. This categorizes an area's urgency for active protection from likely imminent development if left un-conserved. The Conservation Innovation Center calculated development vulnerabilities ranked 0-6 across the watershed using the Chesapeake Bay Land Change Model (CBLCM). They provided predictions for 2025, 2035, 2045, and 2055 with a 0-6 value for every pixel in the Chesapeake Bay Watershed. Areas ranked 6 indicated high development vulnerability and areas ranked 0 indicated localities that cannot be developed.

Using the 2025, 2035, 2045, and 2055 current zoning projections, we calculated 2030 and 2050 development vulnerability values by parcel. We calculated likely 2030 vulnerability scores by averaging the 2025 and 2035 values by pixel, and then assigned the parcel score depending on the maximum pixel value within its area. If any part of a parcel has high vulnerability to development, then the parcel as a whole has heightened protection urgency. The 0-6 scores were converted to a scale from zero to one (Appendix C). Parcels ranked 0 cannot be developed, and those ranked 1 have very high development vulnerability, corresponding with the 0-6 scale.

These provide helpful data to address the time-specific big-picture goals to conserve 30% of the Chesapeake Bay Watershed by 2030. These projected development layers were also integrated into nutrient retention analysis as described below (section 2.5.6.). While not incorporated into our overall 2030 recommendations, we also calculated the 2050 development vulnerability by averaging 2045 and 2055 projection pixel values and assigned parcel scores accordingly. Therefore, each parcel received two scores regarding development vulnerabilities: one for 2030 predictions and one for 2050 predictions. This aligns with the central goals of conserving 30% of the watershed by 2030 and 50% by 2050.

2.5.3. Human Access to Open Spaces

Open spaces, also called greenspaces, have been defined by accessible spaces for sports and recreation provision (Mears et al., 2019). Literature shows a variety of geospatial methods that can map the distribution of open space access with varying detail (Mears et al., 2019; Warnell, 2019). These published methods have included quantifying distance to green spaces or calculating the population proportion within a given distance of green spaces. Likewise, distance measurements have been measured as-the-crow-flies or by incorporating transportation networks (Mears et al., 2019). Since travel time to an open space can vary widely depending on mode of transportation (walking, biking, driving, or public transportation), distance measured as a straight line between two points (as-the-crow-flies, euclidean distance) provided a smoother method for quantifying human access for our team's analysis within the Chesapeake Bay Watershed.

We defined open space by those lands with federal or state protection that were neither privately owned conservation easements nor Federal proclamations such as military bases. Therefore, we determined these areas likely to be protected lands open for public access (2018 data layer provided by client). We created a new layer representing distances as-the-crow-flies from these protected lands, and assigned these distances to parcels accordingly (Appendix D). We used the minimum value per parcel, since that represents the distance from a parcel's edge to a park's edge.

To convert distances to scores on a 0-1 scale, literature shows a variety of processes and recommendations (Mears et al., 2019). Some publications define accessibility as 0.25 miles (400 m), while others use 2 miles. The UK recommends that everyone should live within a 5 minute walk, 300 meters, of green space. Meanwhile, studying the link between open space access and physical health have shown effects up to 2 kilometers away (Mears et al., 2019). Therefore, in order to incorporate inconsistent transportation access and to enable a better score distribution, parcels farther than 2 kilometers from green spaces were scored 1 for human access to open spaces. Parcels with the highest scores are farthest away from publicly available green spaces, and therefore have the highest urgency for land protection or restoration. Conversely, parcels adjacent to open spaces were given a value score of 0. The remaining parcels were given value scores between 0 and 1 with a linear transformation (Appendix D).

2.5.4. Benefits to Underserved Communities

Census data has been frequently used to assess regions' demographic characteristics as they relate with environmental justice analysis (Villa et al., 2020). The EPA's publicly available EJSCREEN web map offers downloadable data with demographic indicators (EJSCREEN, 2020). The EJSCREEN web map displays six demographic factors as they relate to toxic exposures: percent low income, percent minority, percent aged 25 or older whose education is short of a high school diploma, percent with linguistic isolation, percent under the age of 5, and percent over the age of 64 (EJSCREEN, 2021). The Center for Disease Control (CDC) has also released a Social Vulnerability Index that quantifies social factors by the census block and state level (CDC, 2020). These data focus on hazardous event vulnerabilities, highlighting areas likely to need support before, during, and after an event (CDC, 2020). Since the CDC layer focuses on hazardous events and is at a larger scale (census block), we decided to instead follow the US EPA's EJSCREEN approach using demographic indicators at the census block group scale to quantify how land conservation can benefit traditionally underserved communities.

Table 2.2. EJSCREEN demographic index components assigned by census block group.

Low-Income	Percent in households where the household income less than or equal to twice the federal "poverty level"
People of Color	Percent who list their racial status as a race other than white alone and/or list their ethnicity as Hispanic or Latino

The demographic index shown on the EJSCREEN is the average of two factors: percent low-income and percent minority (Table 2.2). Since the EJSCREEN demographic indicator measures the percent of households for a census block group that meet certain criteria, it already ranged between 0-1. Therefore, no data transformation was necessary for its application to parcels in our study area. We assigned scores representing benefits to underserved communities, where census block groups with low percentages of low income and people of color received lower parcel scores closer to 0. Likewise, census block groups with higher percentages of these two factors resulted in parcel scores closer to 1, representing heightened urgency to improve the environmental conditions for traditionally underserved communities (Appendix E).

2.5.5. Flood Risk Mitigation

The analysis of conservation opportunities for flood risk mitigation took place in two major steps. First, we mapped the distribution of flood risk mitigating lands in the focal area using an InVEST Ecosystem Service Model for Urban Flood Risk Mitigation (Sharp et al., 2020; Figure 2.2). The output of this first step was multiple spatial datasets of flood mitigation services in the focal area (refer to Appendix F for full list of outputs). In the second step of analysis, we combined a selection of outputs from the InVEST model, 100-year floodplains, and parcel data to generate a flood mitigation score ranging from 0-1 for unprotected parcels. Parcels with high scores contain lands that are more effective at attenuating runoff, are within 100-year floodplains, and are within watersheds likely to sustain costly damages to buildings in the event of a 100-year flood.

Modeling Runoff Attenuation with the InVEST Urban Flood Risk Mitigation Model

There is a wide variety of ecosystems and land cover types that can provide variable degrees of flood mitigation services including wetlands, forested riparian buffers, and many others. Adding to the complexity of any flood mitigation analysis are the dynamics of flood *risk*. As used in this paper, flood risk is defined by the potential of flood waters to damage or destroy property, infrastructure, or community assets. Flood risk, and associated demand for flood-reduction services, is strongly dependent on the location and size of at-risk communities, as well as the value of infrastructure in potential flood paths (Bousquin et al., 2019). As complex as flood-related ecosystem services can be, there is an equally complex variety of spatial and quantitative approaches for mapping these services.

To tackle this complexity and create a reliable spatial distribution of flood mitigation services within the timeline for this project, we selected an Urban Flood Risk Mitigation model from the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) suite of models. InvEST models are developed by the Natural Capital Project; a joint effort by Stanford University, the University of Minnesota, the Chinese Academy of Sciences, and the Stockholm Resilience Centre, The Nature Conservancy and World Wildlife Fund (Sharp et al., 2020). The GIS-based InVEST models combine ecological and economic data to generate spatial distributions of ecosystem services as well as spatial metrics of monetary service value. Outputs are particularly well-suited for *relative* comparison of service provision across an area of interest (Bagstad, 2013), an application which matches the scope of this project. The underlying deterministic models and equations of InVEST have been well-documented and applied in peer-reviewed literature (Bagstad, 2013; Kadaverugu et al., 2020; Redhead et al., 2016).

The model used in this analysis is outlined below in Figure 2.2, and detailed documentation of the model is publically available from the Natural Capital Project (Natural Capital Project, 2021).

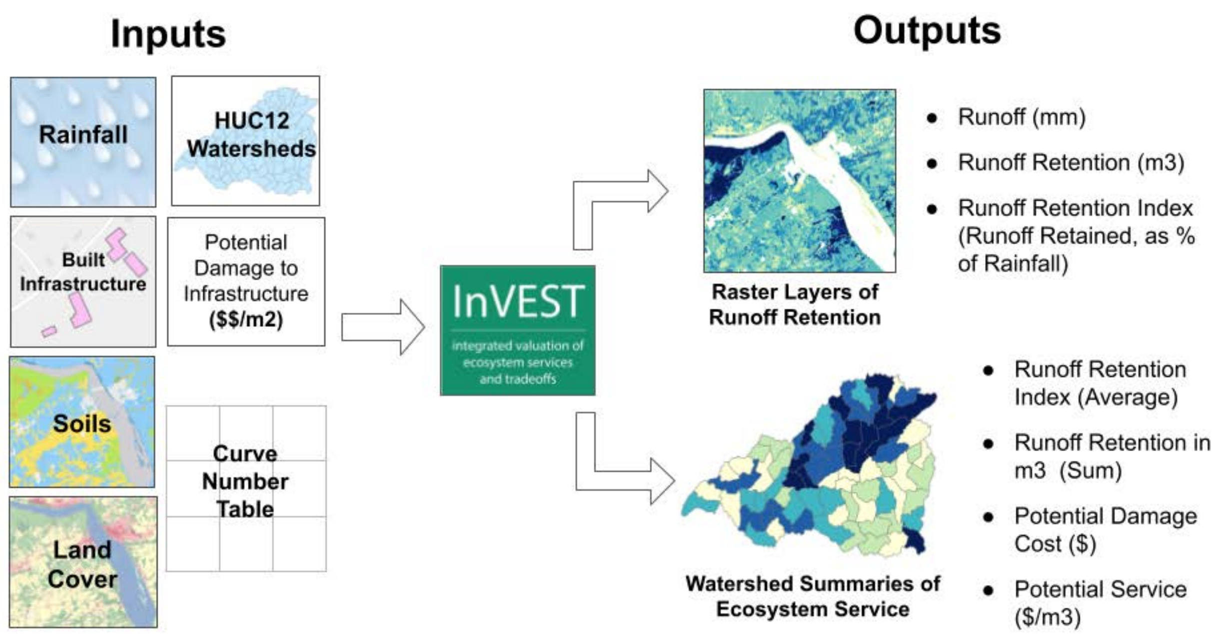


Figure 2.2. Overview of InVEST Urban Flood Risk Mitigation Model. Refer to Appendix C for full documentation on input datasets and sources.

The InVEST model requires the user to select a storm design by specifying a precipitation amount reflective of a chosen storm intensity in the region of focus. We selected a 100-year, 24-hour storm for all InVEST model runs. The 100-year storm is of particular relevance for conservation for several reasons. Firstly, FEMA and other federal and state agencies often use the 100-year floodplain as a key metric in delineating flood risk zones. For instance, benefits of the National Flood Insurance Program (NFIP) and associated Community Rating System (CRS) are typically limited to properties within the 100-yr floodplain, although this can vary between local jurisdictions and counties (Elliot, 2016). Secondly, 100 year flood events have historically been defined by a 1% chance of occurrence in a given year, but are becoming more commonplace as the climate changes (Wright et al., 2019). To generate this precipitation value for the study area, the team used the NOAA Atlas 14 Point Precipitation Frequency Data Server and interactive map to identify typical precipitation ranges for 100-year storms in the focal area. Based on these ranges, we selected two precipitation amounts: 7.5” for the Lower Susquehanna Watershed and 8.5” for all other portions of the Study Area (Appendix F, Table F3).

The InVEST model uses the curve number method to estimate runoff generation and attenuation for the set storm design. Curve numbers are a numeric value between 0 and 100 that represent expected runoff behavior for a given combination of land cover and soil hydrological group (USDA, 1986). The curve number method was originally developed through studies of runoff behavior in small watersheds by the United States Department of Agriculture (USDA) and associated National Soil Conservation Service (NRCS) (USDA Module 104). Land Cover-Soil combinations with very low curve numbers will, generally, attenuate a large proportion of rainfall and generate a small volume of runoff. Conversely, rainfall landing on areas with very high curve numbers will be almost entirely and immediately converted to runoff. The InVEST Urban Flood Risk Mitigation model requires the user to set custom curve numbers for combinations of land cover and soil hydrologic group. We assigned curve numbers based on USDA recommended curve numbers (Appendix F, Table F2).

Once the storm design and curve numbers were set, the team acquired and cleaned a variety of datasets for input to the InVEST model. These include land cover, HUC 12 watershed boundaries (the smallest watershed unit available for the study area), soil hydrologic group, and building footprints. The team accessed the 2016 National Land Cover Dataset (NLCD) at 30 by 30 meter resolution from the Multi-Resolution Land Characteristic Consortium (MRLC). A geodatabase of watershed boundaries was sourced from the National Watershed Boundary Dataset, published by the United States Geological Survey (USGS). The team acquired data on built infrastructure and monetary flood damages from two different sources: FEMA’s Hazus Program and OpenStreetMap. FEMA’s Hazus Program is an ArcGIS-based set of standardized tools, data and models used for estimating risk from natural hazards. OpenStreetMap is a widely used, open source dataset of built infrastructure features and objects, including building footprints. Refer to Figure 2.2 and Appendix F Table F2 for a full description of input datasets, sources, and pre-InVEST processing steps.

Creation of Final Parcel Score for Urban Flood Mitigation Services

Two of the output layers from the InVEST model run in Step #1 and a third layer of 100-year floodplains were used to create new parcel attributes (Refer to Figure 2.2 for Summary of InVEST outputs). The InVEST raster layer of “Runoff Retention Index”, already on a 0-1 scale, was averaged by parcel. The resulting new attribute quantified the average percent of precipitation retained by each parcel. The HUC 12 watershed sum of potential damages was assigned as an attribute to each parcel. Finally, the layer of 100-year floodplains was used to calculate the area of the 100-year floodplain within each parcel. The three new attributes were transformed to a 0-1 scale, assigned weights, and combined into a final parcel "score" for flood mitigation services, also on a 0-1 scale (Figure 2.3) .

The final score prioritizes parcels that contain a portion of the floodplain, have high capacities to attenuate runoff, and are within watersheds likely to experience substantial damages during a 100-year storm. A score of 1 indicates the highest provision of flood risk mitigation possible, while a value of 0 indicates a parcel does not provide any flood risk mitigation service. Note that the final score generated with this methodology may not have any parcels with an absolute score of 0 or 1.

Figure 2.3. Outline of process for creating final parcel score for flood mitigation service.

2.5.6. Nutrient Retention

Nitrogen and phosphorus occur naturally in the Chesapeake Bay Watershed from atmospheric deposition, geology, biota, and other factors. However, in recent decades, excessive surface runoff of nitrogen, groundwater transport of nitrate, and transport of phosphorus via eroded sediment have created a significant pollution issue in the Chesapeake Bay Watershed (Ator and Denver, 2015). This has resulted from an increasing variety of anthropogenic point and nonpoint sources, including septic systems, sewage treatment facilities, industry, lawns, and agriculture (US EPA, 2013). Excessive loading contributes to eutrophication, which has resulted in toxic algal blooms as well as a hypoxic environment capable of fostering harmful bacteria and negatively impacting humans, aquatic, and terrestrial biota (MDE, 2021).

Within the case study area, the Lower Susquehanna and eastern shore of the Chesapeake Bay, in particular, are known nutrient pollution producing hot spots due to intensive farming practices and land use change. Much of this pollution is unregulated, nonpoint source pollution, which has left the Chesapeake Bay "dangerously out of balance" (Chesapeake Bay Foundation, 2021). This makes land-based solutions (e.g., conservation, restoration, implementation of best management practices) attractive nutrient controls. Soil type, topography, moisture regime, and land use are some of the major factors driving the ability of landscapes to retrain these nutrients.

Analyses of conservation opportunities related to nutrient retention were based upon a number of geospatial datasets, tabulated data, InVEST-based models, with other processing done in ArcGIS Pro. The first step involved the creation of a quick-flow surface using the Seasonal Water Yield model (Sharp et al., 2020). Quick-flow indicates the potential for surface transport of nitrogen and phosphorus across the landscape and is used as a runoff proxy in the second step, the Nutrient Delivery Ratio model (Sharp et al., 2020), which estimated nitrogen and phosphorus export and retention at a 10m-pixel scale. The third step entailed creation of multiple land use change scenarios, which were used to measure the relative change in total nutrient export.

The raw, effective retention values from each scenario were transformed linearly on a 0-1 scale and then summarized according to the parcel layer boundaries. These final values were run in an optimized hot spot analysis; this indicates where high- and low-scoring parcels tend to aggregate throughout the study area based on their retention capability. Details and background on these analysis are provided herein with other relevant data sources, tables, and figures located in *Appendix G*.

Seasonal Water Yield Model

The desired product of the Seasonal Water Yield model is an annualized quick-flow raster (runoff in mm/yr) summed from a monthly timestep. Quick-flow is defined as the combination of surface runoff and interflow (lateral flow in the unsaturated vadose zone) that contributes to streamflow, usually over a residence time of hours to days (Sharp et al., 2020). The monthly timestep approach has proven usefulness for water budget modeling (Reitz and Sanford, 2019). Thus, quick-flow values are especially pertinent to modeling nutrient delivery across a landscape (especially in wetter climes like the CBW) where they serve as a proxy for nutrient runoff potential.

The quick-flow raster itself is based on the common curve number (CN) approach. A CN is a unitless value ranging from 30-100 that represents hydrologic connectivity from low to high according to land use land cover (LULC) class and soil type. The 2016 National Land Cover Dataset (NLCD) was used to delineate LULC, and a soils database was obtained from the gSSURGO platform. CN components and related pre-processing are described in *Section 2.v.e*. Calculation of the quick-flow raster also requires spatially explicit data of monthly precipitation and monthly number of rain events (a.k.a. wet days); these values were summarized and averaged by month for the years 2000-2019 from the Climatic Research Unit (CRU) TS4.04 database (Jones and Harris, 2020). Additional parameters and the complete biophysical table are provided in Appendix G, Table G1.

Since quick-flow is highly conditional upon land use change (Fohrer et al., 2005), independent model runs were conducted for the land use change scenarios described herein with unique quick-flow rasters used as a runoff proxy in each run of the Nutrient Delivery Model. As a standalone output, differences in quick-flow values would indicate the effect of land use in attenuating runoff. As an input to the NDR model, the datasets help to better account for local hydrologic conditions and soil heterogeneity.

Nutrient Delivery Ratio Model

Nutrient retention can be viewed as both an intermediate and final ecosystem service in that it supports (a) indirect processes such as plant growth upon which humans ultimately depend and (b) outputs such as clean drinking water upon which humans directly depend. The desired outputs of the Nutrient Delivery Ratio model include: (1) the nutrient delivery ratio itself, which is the percent of nutrient in a given cell that actually reaches a stream or waterbody relative to other downstream pixels; (2) the effective retention ratio, which is the maximum retention efficiency of a cell provided by the downslope flow path of each pixel; (3) the total nutrient export in the study area in kg/yr, which can be summarized at various scales.

Large nutrient delivery ratio values specify the ability of cells to export nutrients and indicate pollution producing hotspots. These areas represent locations where nutrient retention services are most needed and, thus, could be effective targets for restoration-minded conservation given the additional benefits that could be provided. Large effective retention values indicate cells that mitigate the downstream flow of nutrients; these areas already have high ecosystem service value and could be effective targets for outright conservation, thus protecting nutrient retention services from development or other land clearing. The nutrient delivery and effective retention ratios were summarized by parcels. Since the magnitude and delivery mechanisms for nitrogen and phosphorus differ considerably, it was important to transform these outputs to a linear 0-1 scale. In the last step, effective retention of nitrogen and phosphorus were given equal weight to produce a composite nutrient retention score.

Total nutrient export is an important factor for consideration given that the 30 by 30 and 50 by 50 land protection goals can most likely be realized through coordination with regulatory groups already tasked with meeting TMDL requirements. Nutrient export of nitrogen and phosphorus were summarized at the scale of the study area and by HUC 12 watershed boundaries in kg/yr. At the study area scale, land use scenarios provided the relative percent change in nutrient export, with negative values indicating additional retention and positive values indicating additional export. Total export was also compared to adjusted values (*Appendix G, Figure TK*) from the Chesapeake Bay Program Phase 6 Watershed Model using the CAST (Chesapeake Assessment Scenario Tool) 2019 Progress Report.

Land Use Change Scenarios

Modeled land use change is an effective tool for assessing where ecosystem services are most needed or most beneficial (Han et al., 2021). For example, projected future development may alter where ecosystem services tend to aggregate and can aid strategies for land protection. Nutrient flux is also highly impacted by land use change (Sharp et al., 2020) and simulating change presents an effective means for quantifying the benefit of various land

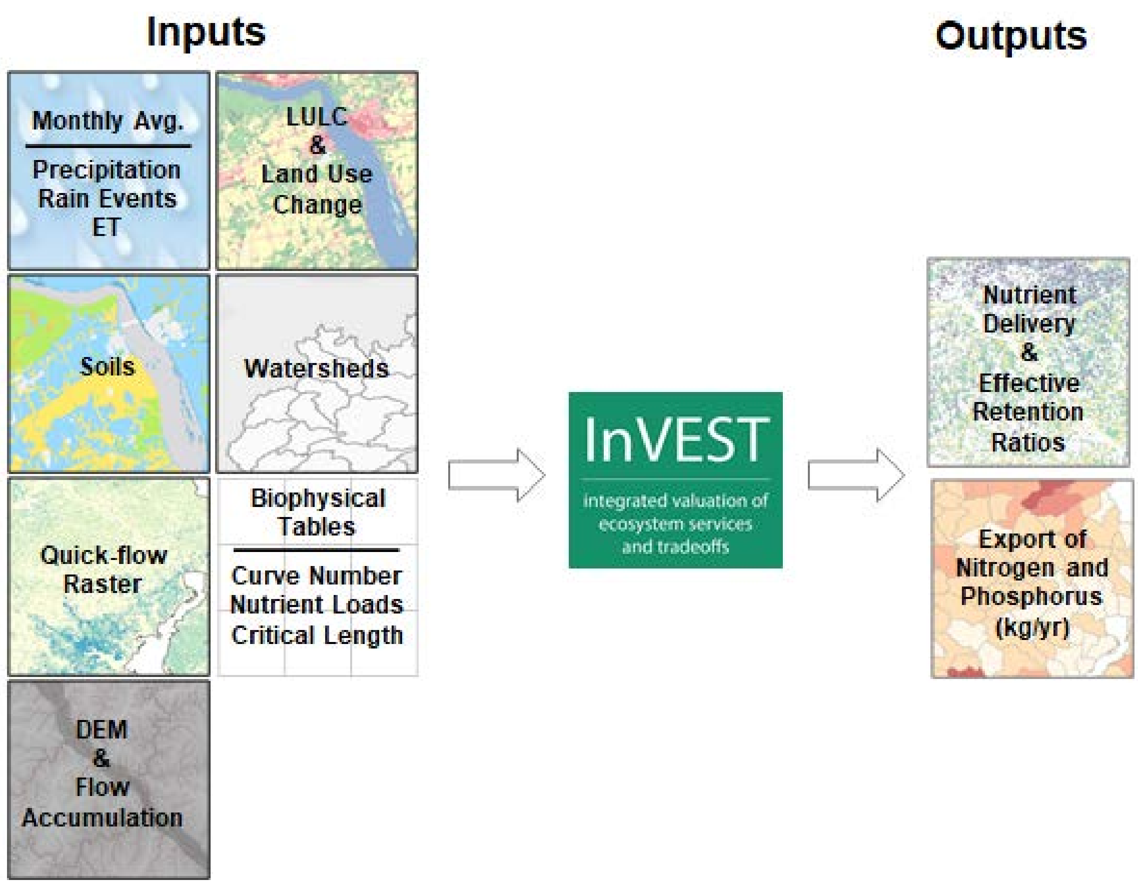


Figure 2.4. Overview of InVEST Nutrient Delivery Ratio model. Refer to Appendix G for full documentation on input datasets and sources.

protection strategies. Scenario generation was focused on agriculture, forest, and urban land uses and with each scenario run independently in the SWY and NDR models.

Future projected development was considered for both 2030 and 2050, since these dates coincide with planning for the 30 by 30 and 50 by 50 timelines. These two scenarios were informed by the Chesapeake Bay Land Change Model (CBLCM) Current Zoning Vulnerabilities, where vulnerability to development represents the cumulative frequency that a cell was developed in the model (based on 101 iterations); this is represented on a scale from 0 (area cannot be developed) to 6 (very high probability of development). We averaged existing CBLCM layers from 2025, 2035, 2045, and 2055 to create projected development scenarios for 2030 and 2050. This assumes a linear relationship between 2025 and 2035, for example, to create the 2030 layer. We calculated constant value rasters for values 4–6 (moderate to very high probability of development); these rasters were used to update the baseline NLCD 2016, where constant values were set equal to the Developed, High Intensity class.

The InVEST Proximity-Based Scenario Generator (Sharp et al., 2020) was used to create additional land use change scenarios for agriculture and forest lands. This is a stochastic model that relies upon the user to define the maximum area (in hectares) of a convertible land use class(es). A singular, replacement land use code specifies the new land use, and the focal land use code specifies the distance to/from a chosen land use. For purposes of this study, the model was run in a single step simulation.

Three scenarios were developed with two levels each: (1) Forest to agriculture simulates a 5% and 10% change in total area of forested lands to cultivated crops. This scenario simulates the effect of devoting increased acreage to food crop production at the expense of forest lands. (2) Agriculture to forest simulates a 5% and 10% change in total area of agricultural lands. This scenario simulates edge-of-field forest buffers, which may be more practical than in-field buffers in flat landscapes such as the southeast piedmont and coastal plain (Dabney et al., 2006). Forested field borders, like other vegetative and riparian buffers, can be a productive means for eliminating excess nutrients by attenuating runoff to streams, increasing infiltration, and facilitating positive biogeochemical processes before nutrients can leach into groundwater (USDA NRCS, 2011). (3) Likewise, stream buffers were considered for agricultural lands. For this simulation, 5% and 10% of the total agricultural land area directly abutting riparian zones was converted to forest.

The final products of scenario generation are new LULC rasters of each simulation. Through integration into the SWY and NDR models, we are able to show relative percent change in total nutrient export between the baseline and each projected scenario.

Optimized Hot Spot Analysis

The hot spot analysis is intended to inform approaches to conservation and restoration such as (a) prioritizing connected ecosystems for provision of nutrient retention services, (b) conserving or restoring lands that are needed most for their retention value, or (c) maximizing efficiency of existing monitoring and administrative resources (i.e., protecting parcels near each other). In brief, the hot spot analysis generates the Getis-Ord Gi* statistic, which is a measure of the relationship between a parcel’s final nutrient retention score and the amount of spatial clustering. The z-scores and p-values used to calculate a confidence level are relative to what would be expected in a random distribution. Larger, positive z-scores and small p-values indicate “hot spots” of high-scoring parcels, while “cold spots” are based upon small, negative z-scores and small p-values. The hot and cold spots indicate parcels which are significantly different from average occurrences and can be useful for identifying tradeoffs in land protection relative to other criteria in this study.

2.6. Multicriteria Analysis

The above steps created six scores valued 0-1 for every parcel to capture its characteristics for the six measured criteria. The scores represent a parcel's ability to provide ecosystem services and conservation assets. Specifically, the six scores capture a parcel's contributions for biodiversity and habitat connectivity, protection from land change due to development, human access to open spaces, benefits to underserved communities, flood risk mitigation, and nutrient retention. We combined these scores to yield a final score for each parcel using seven weighting strategies (Table 2.3). Each strategy resulted in a final parcel score output for its specific conservation prioritization scenario. These seven possible prioritization maps showed seven possible conservation recommendations.

Rather than providing our client with seven possibilities, we analyzed the areas of overlap across scenarios, highlighting regions with high conservation urgency regardless of the scenario chosen. Such multicriteria analysis techniques have been helpful in aiding decision-making throughout other studies, by showing conclusive outcomes regardless of the ranking choices made (Geneletti, 2003).

To consolidate highlighted parcels across different criteria, we clipped the outputs from six scenarios to their top 25% ranked parcels. The six selected scenarios were from when one criteria was weighted at 50% and the remaining each weighted at 10% (Table 2.3). We overlaid these six clipped layers, calculating new parcel scores that reflected the number of scenarios in which they fell in the top 25% of total parcels in our study area. The result was a final data layer of unprotected parcels most likely to provide co-benefits (multiple ecosystem services), and thus are the highest priority lands for 30 by 30 and 50 by 50 conservation planning. These parcels are referred to as "co-benefit priority parcels" in the following methods, results and conclusion.

To summarize the regional distribution of co-benefit priority parcels across the study area, we identified statistically significant clusters of these parcels. We also calculated the total number and acreage of co-benefit priority parcels for each HUC 12 watershed within the overall study area. These more localized watersheds can serve as a guide for targeting conservation towards regions where tradeoffs between conservation benefits are minimized and conservation co-benefits are maximized.

Table 2.3. Weighting strategies for incorporating six factors into a final score representing each parcel's conservation urgency and ecosystem services. The factors were weighted differently in seven scenarios, creating seven different final parcel ranking systems.

	Biodiversity and Habitat Connectivity	Development Vulnerability (2030)	Human Access to Open Space	Benefits to Underserved Communities	Flood Risk Mitigation	Nutrient Retention
Equal Weighting	16.67%	16.67%	16.67%	16.67%	16.67%	16.67%
Habitat	50%	10%	10%	10%	10%	10%
Development	10%	50%	10%	10%	10%	10%
Open Space	10%	10%	50%	10%	10%	10%
Demographic	10%	10%	10%	50%	10%	10%
Flood	10%	10%	10%	10%	50%	10%
Nutrients	10%	10%	10%	10%	10%	50%

2.7. Value Estimation of Ecosystem Services

By quantifying the possible monetary benefits of the ecosystem services, we were able to gain an impression about the change in ecosystem service value caused by the change in land-use that is projected according to the current conservation planning. This would show spatially and statistically the foundation of the conservation plan. Based on this estimation, we identified the areas where limited improvement to the conservation strategies are required and areas where other conservation planning should be considered for avoiding ecosystem service value loss. In this part of the study, we employed three steps to estimate the ecosystem service value of the Chesapeake Bay Watershed:

1. Reclassify land cover data in the Chesapeake Bay Watershed to one of six land uses (water, urban, forest, farm, barren, wetland). The current acres of different land use in each parcel were generated through tabulating the 2016 National Land Cover Dataset. The future acres in each parcel were generated through tabulating the Phase 6 Historical Trends scenario land use raster dataset created by USGS. Zoning, land suitability, pre-development land cover conditions, proximity to recent growth hot spots, urban areas, amenities, and sewer infrastructure dictate these future patterns of growth.
2. Calculate the value of ecosystem services in each scenario, by multiplying land area (acres) times dollars-per-acre-per-year for those services. Calculate the sum of ecosystem service value in given areas, and generate the corresponding future value.
3. Analyze the geospatial trends and change in land-use drives the changes in the ecosystem service value.

Landcover Reclassification and Land Use Change

As mentioned above, the first step in the process was to determine the area in different land use groups in Chesapeake Bay. For the acreage estimation, we categorized the land use into six main land uses: Open water, Urban, Forest, Farmland, Wetland and Barren Land. These six main land uses were chosen due to the categorization in previous ecosystem service value studies (Kauffman, 2011). We obtained the current land use data set from the 2016 National Land Cover Dataset with 15 land use categories. To align with the Chesapeake Bay Program's classification of the habitats, we incorporated the shrub/scrub and grassland in the forest habitat category (Table H.1).

Chesapeake Bay land use change was based on the projection to 2025 produced by the Chesapeake Bay Program. We chose the historical trends scenario, which represents a continuation of recent development patterns and trends over the period 2000–2010. We chose this scenario because this could demonstrate the greatest value of land use planning and land conservation Best Management Practices (BMPs). Similar to the categorization we made for the current land uses, we included the scrub in the forest habitat category (Table H.2).

We used the Classification tool to assign the revised land use to the current raster and future projection. Estimates of the number of pixels in six land uses in each parcel are obtained by tabulating tool. The total area was calculated through multiplying the number of cells by 900 square meters (the original raster data has a 30 x 30m resolution), and converting these units to acres.

Estimating the Ecosystem Service Value

Data for these calculations come from a case study estimating the economics value of the Delaware Estuary Watershed (Kauffman, 2011). The reason we are choosing these values is that the Delaware Estuary Watershed has similar landscape characteristics as our study area, including developed, agricultural, and coastal regions. Delaware Estuary Watershed study also values the services provided by the local ecosystems, in line with our project focus. According to their comprehensive report, the ecosystem service value they calculated includes the value of carbon sequestration, air filtration, nutrients recycling, soil conservation, flood control, hydrologic-cycle regulation, erosion/sediment control, water temperature regulation, pest control, and pollination. They generated a dollar value per acre per year for each land use type by combining the estimation from previous studies (List H.1), and calculated the net present value by 2010 (Kauffman, 2011).

Table 2.4. Ecosystem Service Value for different Land Use. (The data for the $/acres/year in 2011 dollars comes from the comprehensive report, Economic Value of the Delaware Estuary Watershed, Kauffman, 2011.)

Revised Land Use Used in Present Study	$/acre/year 2010	$/acre/year 2021
Open Water	1946	2694
Urban	342	473
Barren land	0	0
Forest	1978	2738
Farmland	3215	4450
Wetland	13621	18855

The Delaware case study calculates the ecosystem service value for Delaware estuary Watershed and Delaware separately, with the main difference as the estimation of the farmland services. Because our study area is focused on the area near the sea, we used the estuary watershed value instead of the value including their entire study area.The wetlands Chesapeake Bay Watershed contains more than 80 percent area including non-tidal wetlands that contain fresh water, so we used the ecosystem service value of freshwater wetland to estimate the wetland service value (Chesapeake Bay Program, 2021). To align with the date of our land use data set, values were adjusted to 2021 dollars based on 3% annual growth.

We obtained the total ecosystem service value through multiplying the total area by the overall value per acre per year. By comparing the net present value of the current land use and the future projection, we estimated the change of net present value of ecosystem service when applying land conservation BMPs. Net present values were calculated based on an annual discount rate of 3% in perpetuity (over 100 years in the future).

3. RESULTS

Our analysis quantified four ecosystem services and two additional conservation criteria in our study area within the Chesapeake Bay Watershed. Biodiversity and habitat connectivity, development vulnerability, human access to open spaces, benefits to underserved communities, flood mitigation, and nutrient retention each yielded a conservation prioritization score for every unprotected parcel over 10 acres in our study area. These analyses highlight regions throughout the study area with particular importance for each factor. We then combined all six criteria into final scores, and filtered parcels to include only those ranking in the top 25% for each of the six categorizations. This highlights areas with particular conservation or restoration importance, regardless of the prioritization methods used.

We then compared these conservation prioritizations with ecosystem valuation, quantifying the financial importance of ecosystem services. The results from each factor considered as well as the consolidated outputs highlighting parcels with co-benefits are demonstrated below.

3.1. Biodiversity and Habitat Connectivity

Within our study area, parcels with high importance for biodiversity and habitat connectivity were largely concentrated in the southern part of the Patuxent Watershed and in the northern part of the Chester-Sassafras Watershed. This can be seen in the dark green imagery at the bottom left and middle right of the map display (Figure 3.1). These both overlap with major waterways. Highly important habitat areas in the northern part of the Chester-Sassafras Watershed are in close proximity to the mouth of the Susquehanna River.

Likewise, highly important areas in the southern part of the Patuxent Watershed are concentrated around the Pawtuxet River. Following the dark green patterns for each aligns with the rivers' upstream paths. Other areas with highly important habitat areas correspond with forested areas on the north-western and north-central areas of our study area (Figures 3.1, 2.2). See Appendix B for the ArcGIS Pro models used for these classifications.

3.2. Development Vulnerability

More concentrated areas of predicted development by 2030 are in the south central part of the study area, specifically in the Severn and Patuxent Watersheds. These highly vulnerable areas tend to be surrounded by parcels removed from our analysis, either due to current land protection status or parcels smaller than 10 acres in size. The central region of the Lower Susquehanna HUC 8 Watershed, on the northern edge of our study area, was especially highlighted for development vulnerability (Figure 3.2). See Appendix C for the ArcGIS Pro processes as well as visualization of 2050 development vulnerability distribution.

3.3. Human Access to Open Spaces

Parcels' distances from protected lands with likely public accessibility ranged greatly across the study area. Assigned scores represented a parcel's opportunity for conservation or restoration, and thus the opportunity to expand publicly accessible green spaces. Parcels adjacent to protected public lands received a score of zero, since residents of that parcel already have excellent opportunities for open space access. Meanwhile, parcels 2 kilometers or farther from protected public lands received a score of one, since residents of that parcel have less accessibility to public green spaces (Appendix D). Some parcels in our study area were calculated to be over 9 kilometers from open spaces with public access. As the distances increased, the number of parcels appeared to decrease exponentially. High scores represent the desire to increase public open space in the region, and therefore that parcel's heightened need for environmental protection and/or restoration.

This analysis highlighted areas in the northwest, southwest, and central-eastern regions of our study area as regions needing greater public access to open spaces (Figure 3.3). These fall into the western side of the Lower Susquehanna HUC 8 Watershed, central areas of the Chester-Sassafras Watershed, and southern areas of the Patuxet Watershed. This scoring system shows varying levels of need for restoration opportunities and park development to improve residents’ access to public open space.

3.4. Benefits to Underserved Communities

Regarding community characteristics, the EJSCREEN demographic index measured percent people of color and percent low income by census block group. Therefore, areas scoring highly on this index represent regions with higher percentages of both characteristics. This visualization showed clusters ranked highly surrounding cities, particularly Lancaster, PA; Baltimore, MD; Bowie, MD; and Columbia, MD (Figure 3.4). The eastern edge of our study area, in the Chester-Sassafras HUC 8 Watershed, also shows a cluster of residents ranked high on the EJSCREEN demographic index. These areas highlight census block groups with high percent minority residents and high percent low income residents, showing areas that have been traditionally underserved. Therefore, focusing conservation and restoration efforts in these areas provides an opportunity to incorporate environmental justice into land conservation work.

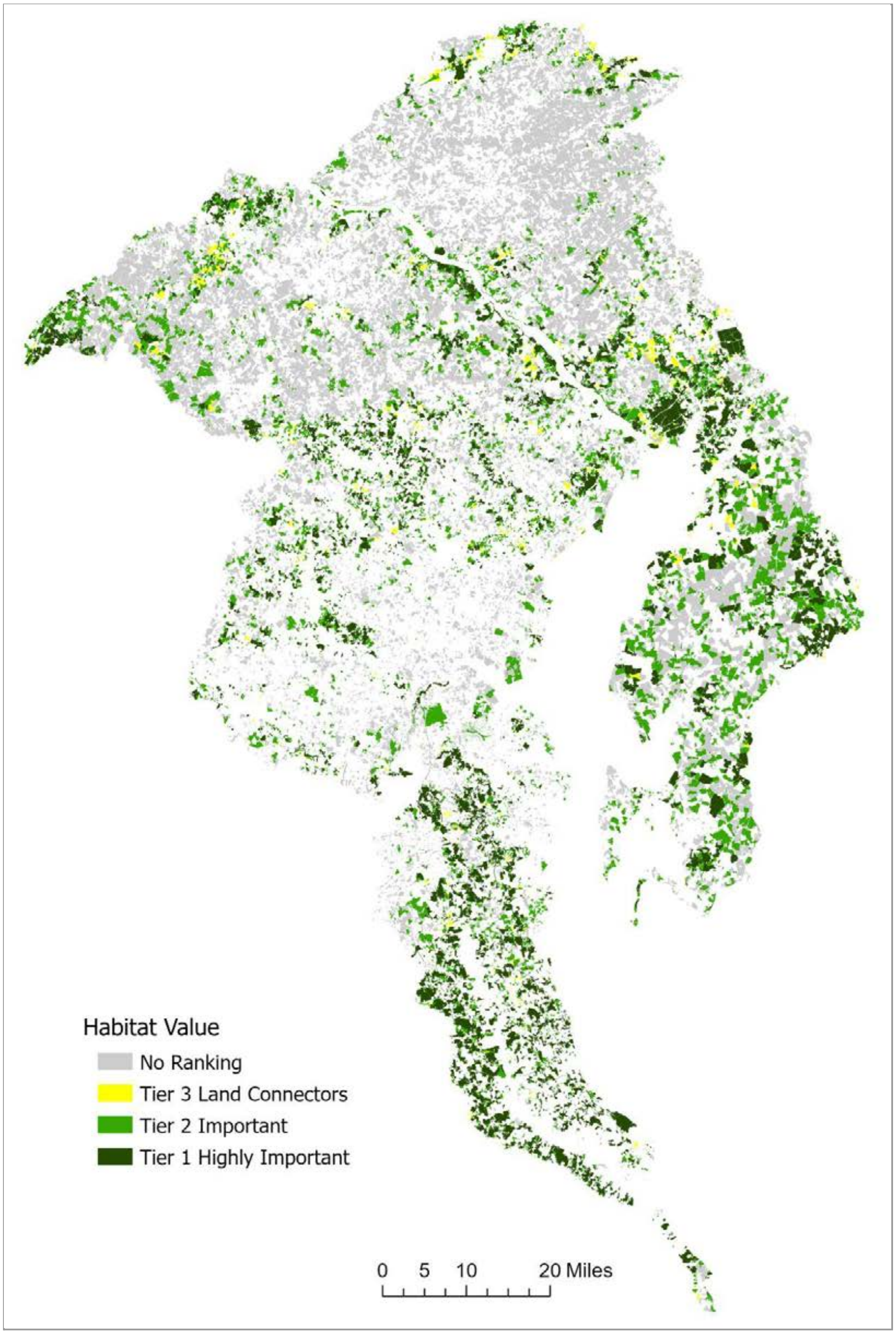


Figure 3.1. Scored parcels in the watershed study area for biodiversity and habitat values.

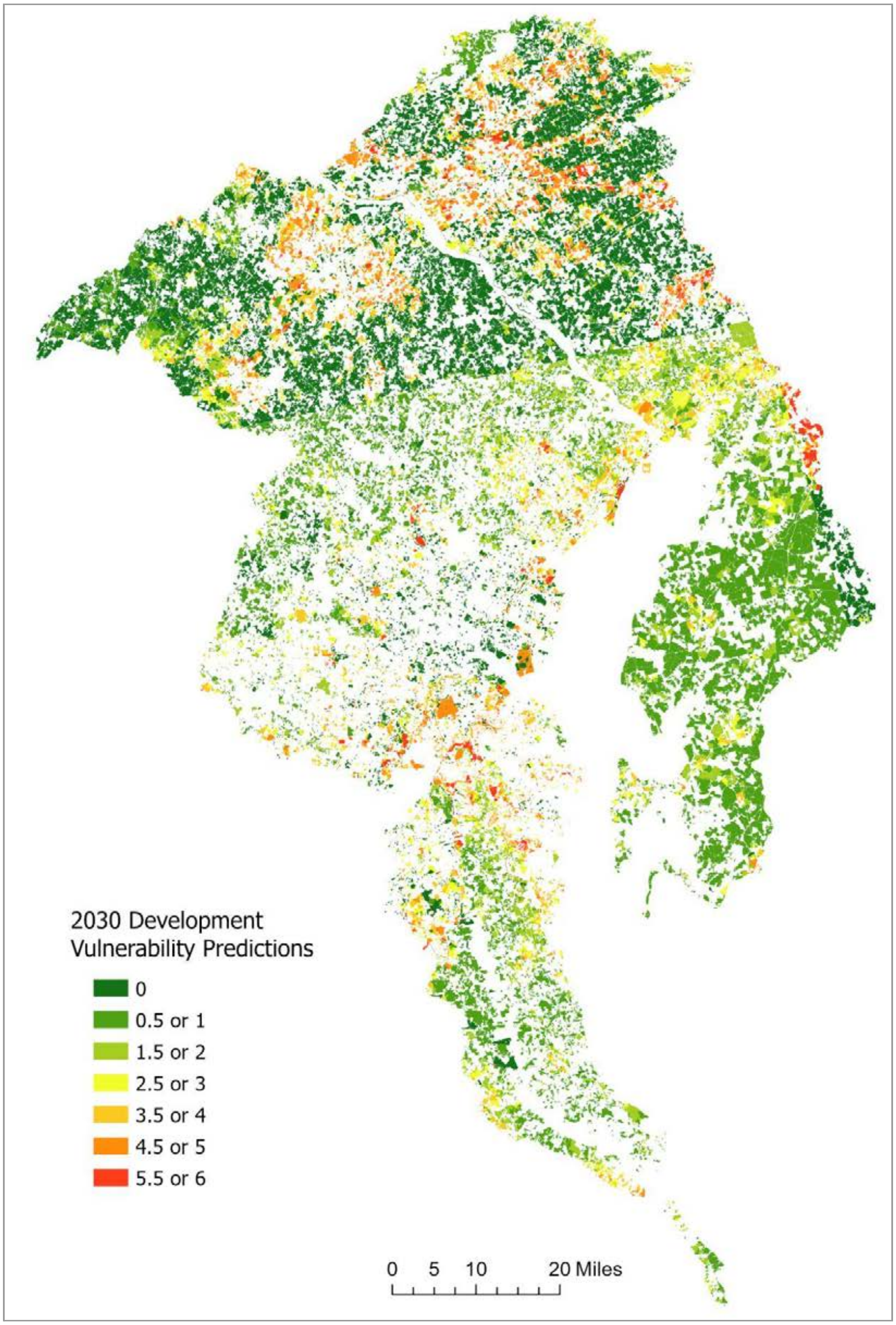


Figure 3.2. Development vulnerability for 2030 predictions across our study area, assigned at the parcel level.

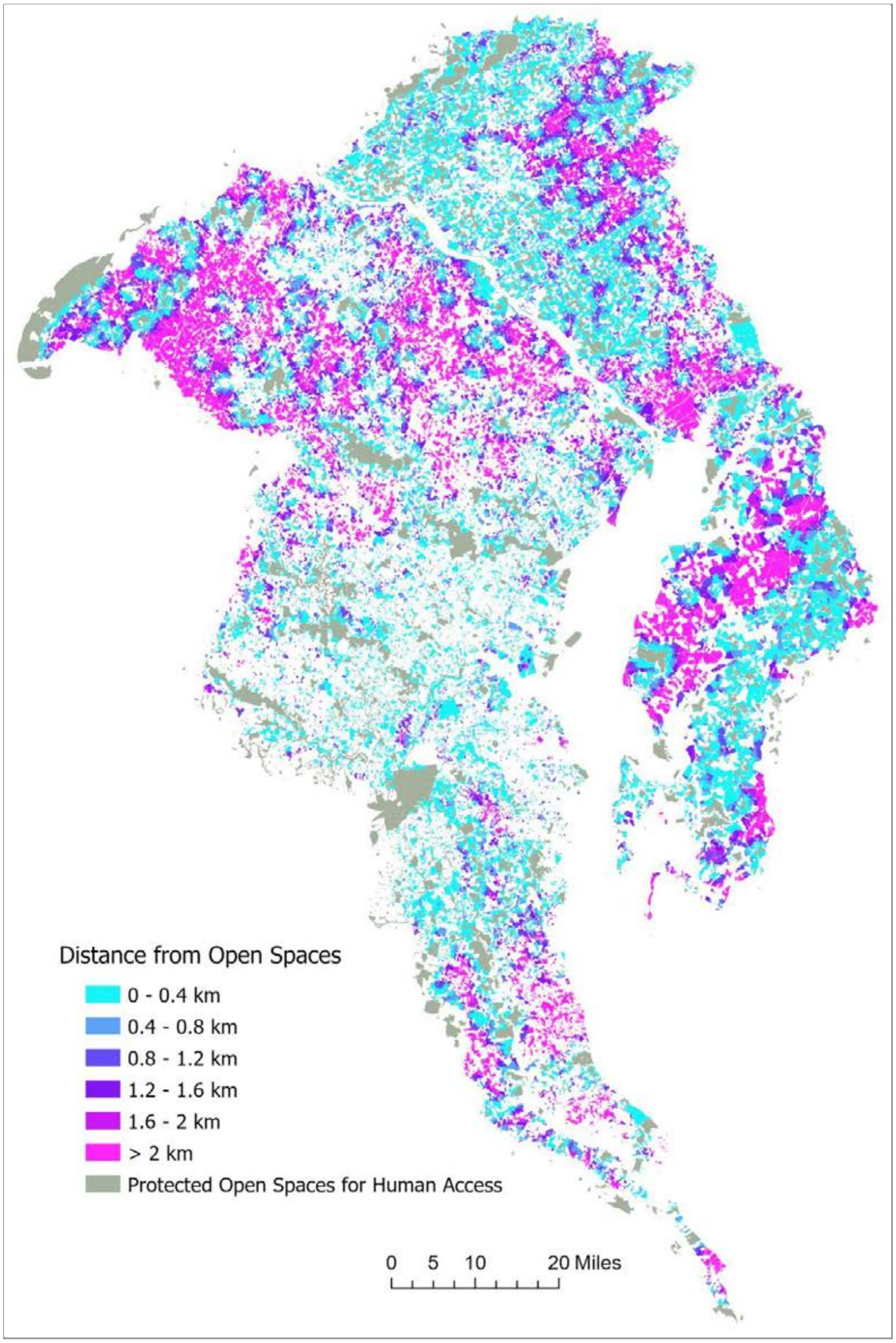


Figure 3.3. Scored parcels in the watershed study area representing human access to open spaces. Higher scores were given to parcels farther from accessible open spaces, and lower scores were given to parcels adjacent to existing green spaces.

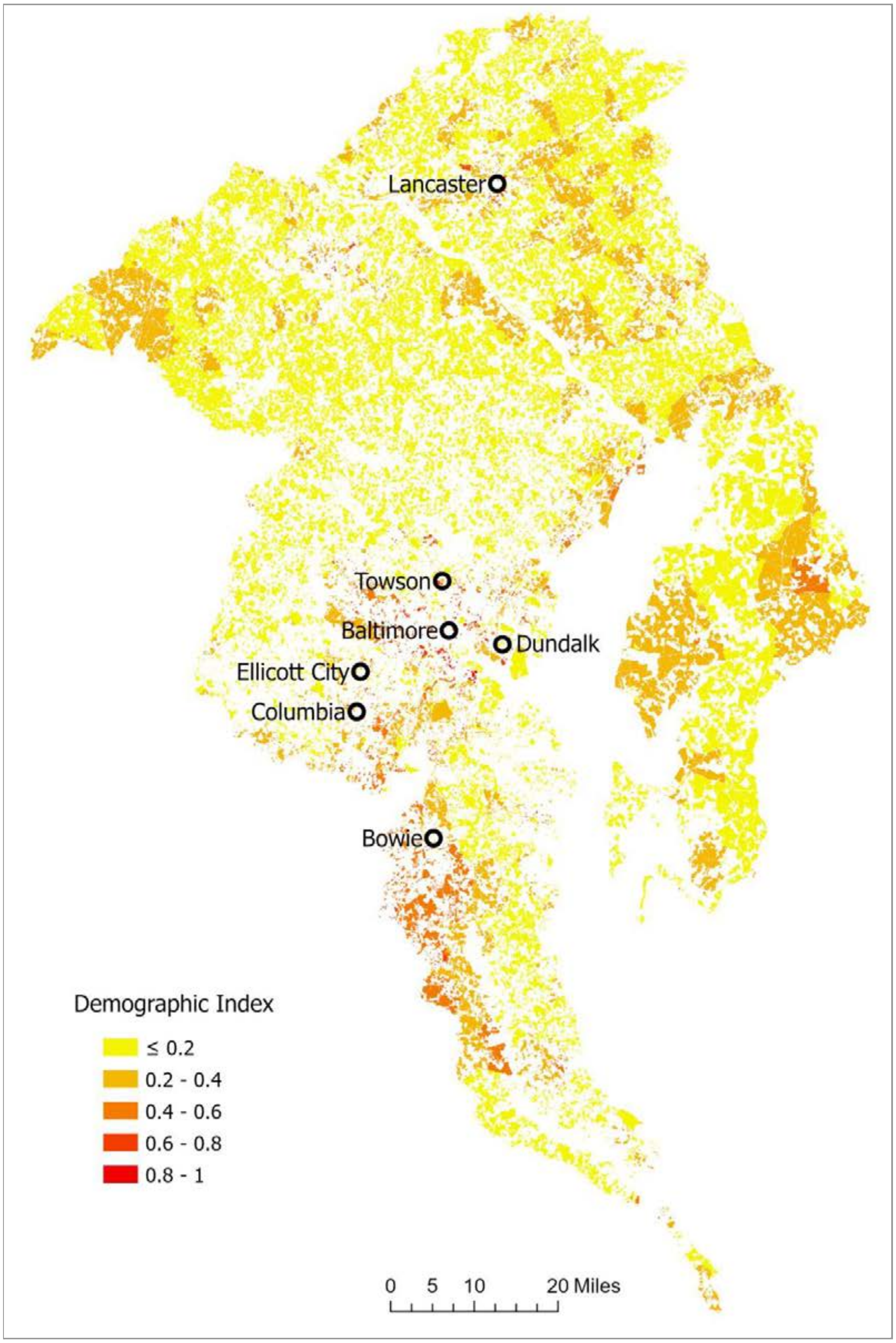


Figure 3.4. Demographics Index showing percent low income and percent people of color by census block group from the EJSCREEN data, as assigned to parcels. Cities shown here have populations over 50,000 residents.

3.5. Flood Analysis

Given the increasing frequency of floods and the dangers they pose to communities and infrastructure, it is crucial that conservation strategies consider the flood mitigation potential of unprotected lands. The InVEST model produced multiple data layers of flood mitigation services in the study area. Two of these datasets, runoff attenuation as a percent of precipitation and potential damage to building infrastructure, contributed to a final flood mitigation score (Figure 3.6). For maps of all InVEST outputs, refer to Appendix F.

Unprotected parcels which, on average, attenuate greater than 80% of rainfall during a 100-year storm are concentrated in the northwest and southern extents of the study area (Figure 3.5, “Average Runoff Attenuation”). Just south of Baltimore is another patch of parcels which may attenuate 80% or more of precipitation. A broad band of parcels which may attenuate between 40 and 60% of precipitation spans the northern section of the study area, and are particularly concentrated in regions adjacent to the Susquehanna River. Watersheds with large potential flood damages to buildings are concentrated around urban centers such as Baltimore, York, and Lancaster (Figure 3.5, “Potential Damage to Building Infrastructure). Potential damages are also high in watersheds where a large number of buildings are located in the 100-year floodplain, such as the several watersheds just south of Baltimore in the coastal extents of the Western Shore. Notably, potential damages are low along the Eastern Shore and Delmarva Peninsula, likely due to an underrepresentation of rural and agricultural buildings in the dataset used in this analysis (See Discussion for more details).

A third dataset of the total acres of 100-year floodplain within a parcel contributed to the final Flood Mitigation parcel score (Figure 3.5, “Total Acres of Floodplain). Parcels with large acreages of 100-year floodplain tended to have larger total acreages and are distributed throughout the study area. Clusters of these parcels occur in the northwest and southern portion of the study area, as well as along coastal areas of the Delmarva Peninsula.

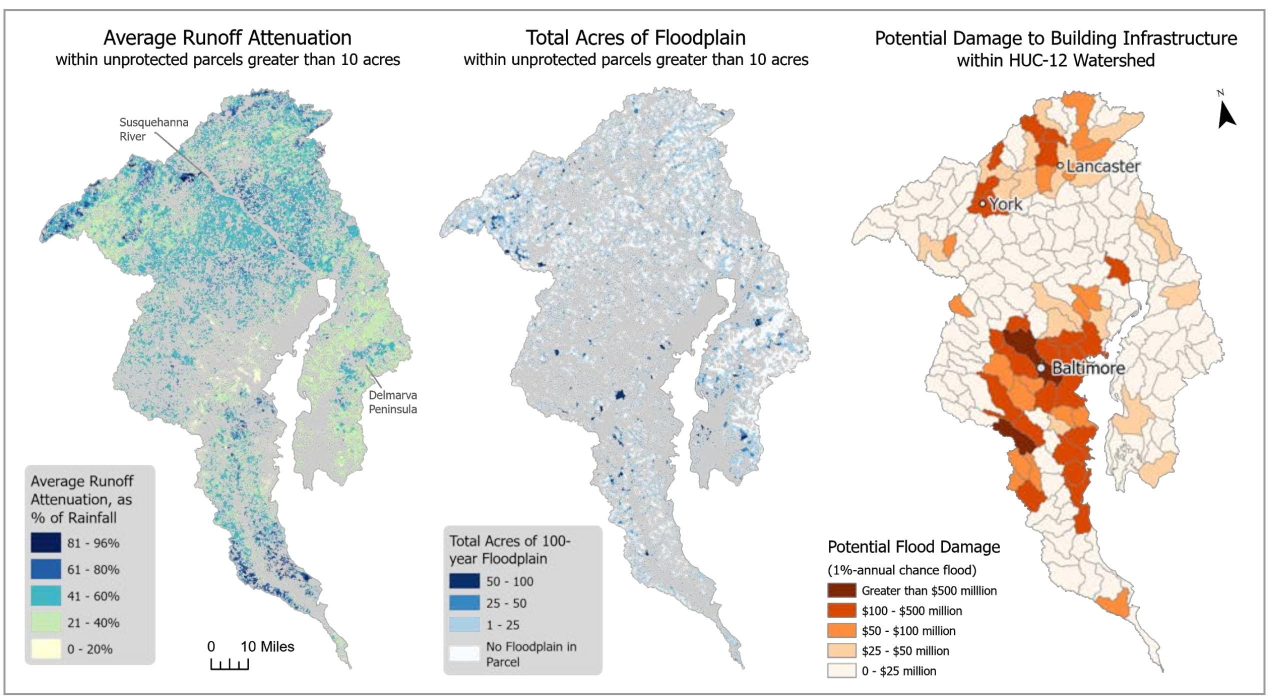


Figure 3.5. The three datasets used to generate a final 0-1 Flood Mitigation Score. Final score shown in Figure 3.6.

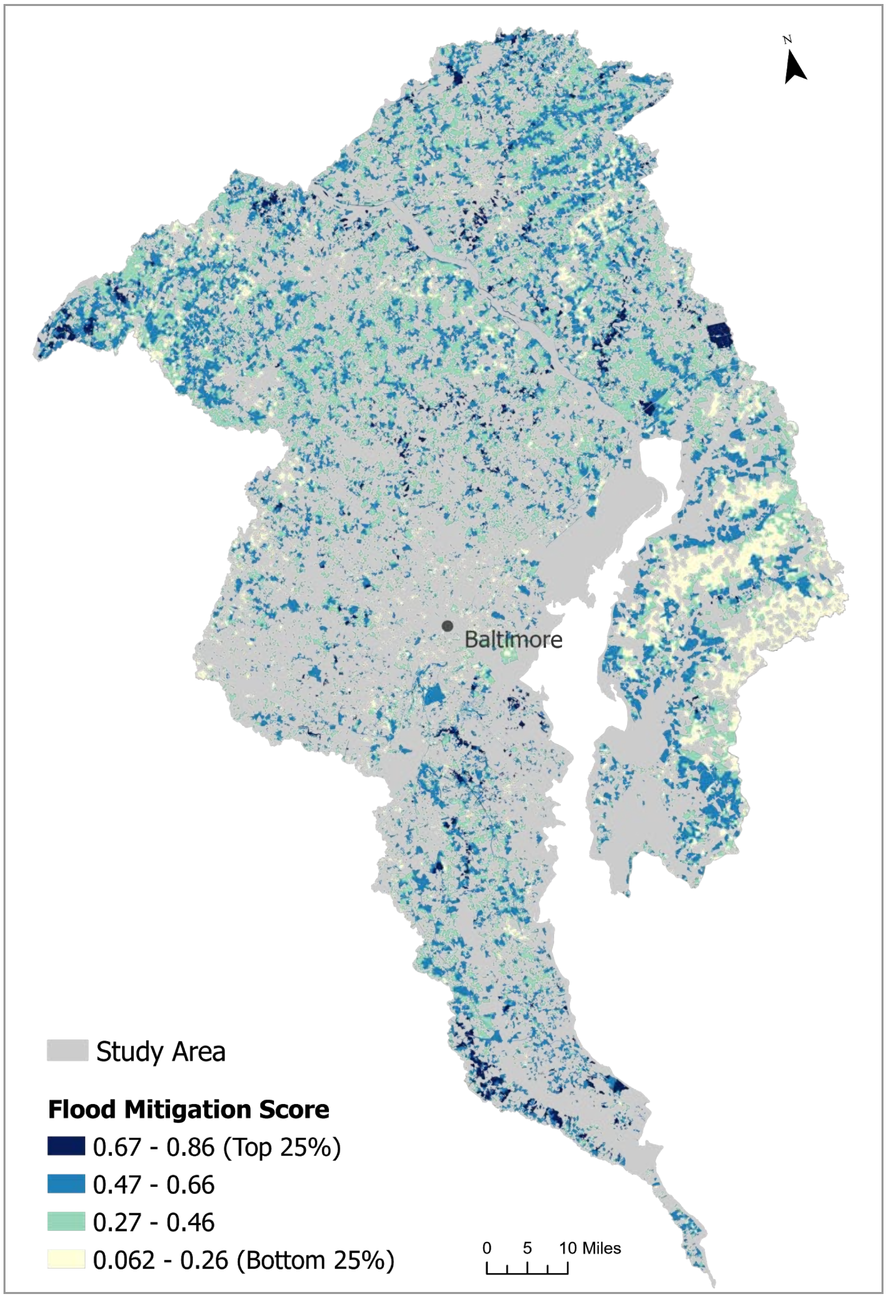


Figure 3.6. Final parcel score for flood mitigation.

The final flood mitigation parcel scores varied substantially across the study area. The parcel scores range from 0 to 1, with a score of 0 indicating no provision of 100-year flood mitigation service and a value or 1 indicating the maximum possible provision of 100-year flood mitigation services. Notably, no single parcel received the best score of 1 nor the worst score of 0, as the final score was created using a weighted sum of three 0-1 scores. The top 25% of scored parcels ranged from .062 to .86 on a 0-1 scale, and this should be noted for future applications of this final score. This estimation of service provision is based on 2016 land cover, and reflects the "current" ability of the land to mitigate runoff. The highest scoring parcels are clustered in the southern tip and northwestern corner of the study area, in patches south of Baltimore, and in patches adjacent to the Susquehanna River (Figure 3.6).

3.6. Nutrient Retention

Given the significant effects of nutrient pollution from both nitrogen and phosphorus in the Chesapeake Bay Watershed, it is crucial that conservation organizations consider nutrient retention services when deciding where to protect land or focus restoration efforts. The results of the nutrient retention analysis are geared toward providing Chesapeake Conservancy with parcel-scale information on this vital ecosystem service to (1) enhance collaboration on the existing TMDL mandate and (2) aid communication with decision makers on the 30 by 30 framework.

The InVEST Seasonal Water Yield model was used to generate an estimate of annual quick-flow runoff for multiple land use scenarios. These raster surfaces indicate the combined surface and interflow runoff in mm/yr across a 10m grid and were used as a runoff proxy to predict nutrient flux (Appendix G, Figure G1). For the baseline scenario, mean quick-flow for a 10m cell was calculated at 66.10 mm/yr with a high value of 1,276.10 mm/yr. Comparatively, average annual precipitation for the study area over the years 2000-2019 was 1177.72 mm/yr based on aggregation of the CRU dataset.

The InVEST Nutrient Delivery Ratio model generated two outputs: the nutrient delivery ratio and effective retention ratio. The nutrient delivery ratio for the baseline scenario shows the proportion of nitrogen and phosphorus delivered to streams and waterbodies across a 10m grid (Appendix G, Figure G3).

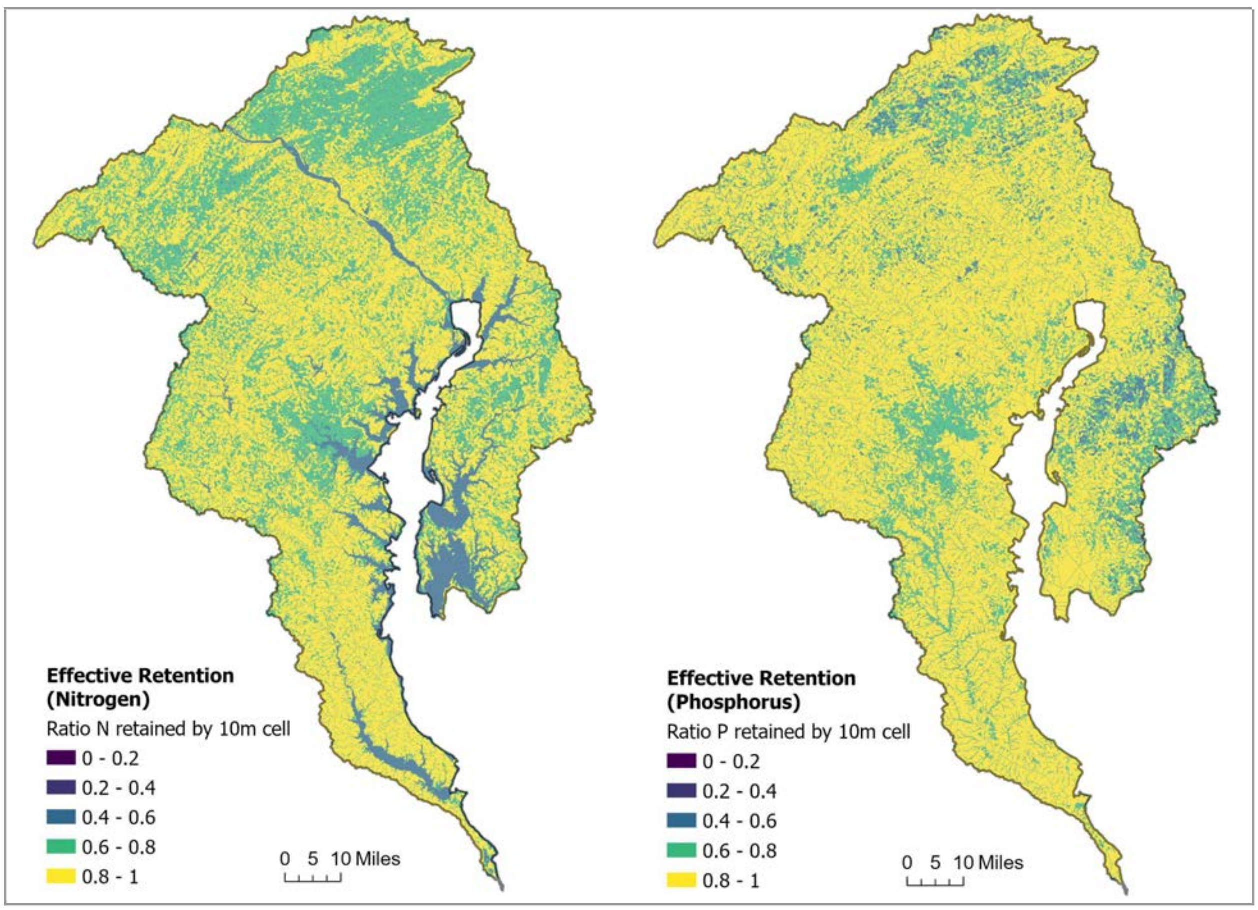


Figure 3.7. Effective retention ratio for nitrogen and phosphorus, which reflect the proportion of nutrients retained by a 10m cell. Yellow shaded areas indicate relatively high effective retention. The 10x10m grids were summarized for unprotected parcels over 10 acres and given equal weight to create the final 0–1 Nutrient Retention Score.

The effective retention ratio for the baseline scenario reflects the proportion of nitrogen and phosphorus retained by downslope cells across a 10m grid (Figure 3.7). Areas with the greatest nitrogen and phosphorus retention tend to exist in the central and southern portions of the study area while low retention areas tend to exist in the northern portion of the study area, pockets of the eastern shore, and in the greater Baltimore area.

Effective retention of nitrogen and phosphorus for the baseline scenario were summarized for all unprotected parcels over 10 acres in area and then given equal weight to produce the final, nutrient retention score. Optimized hot spot analysis based on parcels' final nutrient retention scores indicated clusters of high-scoring parcels in numerous zones, particularly along the northern boundary of the study study area, the outlet of the Susquehanna River, and the western shore (south of Baltimore). Cold spots with low-scoring parcels are located primarily in the northeast corner of the study area and the eastern shore (Figure 3.8).

The InVEST Nutrient Delivery Ratio model also provided estimates of total nutrient export within the study area (Table 3.1). These estimates were found to be lower than those calculated with the Chesapeake Bay Program Phase 6 Watershed Model using nonpoint-source adjusted loads from CAST (Chesapeake Assessment Scenario Tool). The InVEST model estimations represent 28.49% (N) and 17.39% (P) of the adjusted CAST loads. A summary of total nutrient export by HUC 12 watersheds shows individual HUC 12s with relatively high amounts of nutrient export in terms of standard deviation from the mean (Appendix Figure G.4).

Table 3.1. Total Nutrient Export Estimations (kg/yr) for the study area and baseline scenario using InVEST Nutrient Delivery Model and Phase 6 model using CAST (2019 adjusted loads). The InVEST loads represent 28.49% (N) and 17.39% (P) of the adjusted CAST loads.

Total Nutrient Export (Study Area)

(kg/yr)	Nitrogen	Phosphorus
InVEST	7,325,417.34	216,798.26
CAST	25,711,769.53	1,246,902.76

Table 3.2. Relative change in nutrient export among land use scenarios compared to baseline (NLCD 2016), with positive values indicating additional nutrient export to water bodies and negative values indicating reduction in nutrient export. Note: the slight increase in P under Ag to Forest 10% is not significantly different from zero.

Relative Change in Nutrient Export by Land Use Change Scenario

	Nitrogen	Phosphorus
Scenario	(% change from baseline)	
Development 2030	7.06%	8.96%
Development 2050	13.02%	15.99%
Forest to Ag 5%	6.19%	9.08%
Forest to Ag 10%	11.38%	16.32%
Ag to Forest 5%	-1.11%	0.03%
Ag to Forest 10%	-4.22%	-3.81%
Stream Buffer 5%	-4.54%	-7.90%
Stream Buffer 10%	-7.99%	-12.11%

Simulated land use change had a measurable impact upon total nutrient export (Table 3.2). Within the study area, total export of nitrogen and phosphorus increased under four of the eight land use change scenarios, including: projected development in 2030 and 2050 and conversion of existing forest to agriculture. Nutrient export decreased in the remaining scenarios, including: conversion of agriculture to forest and conversion of agricultural land to stream/riparian buffers.

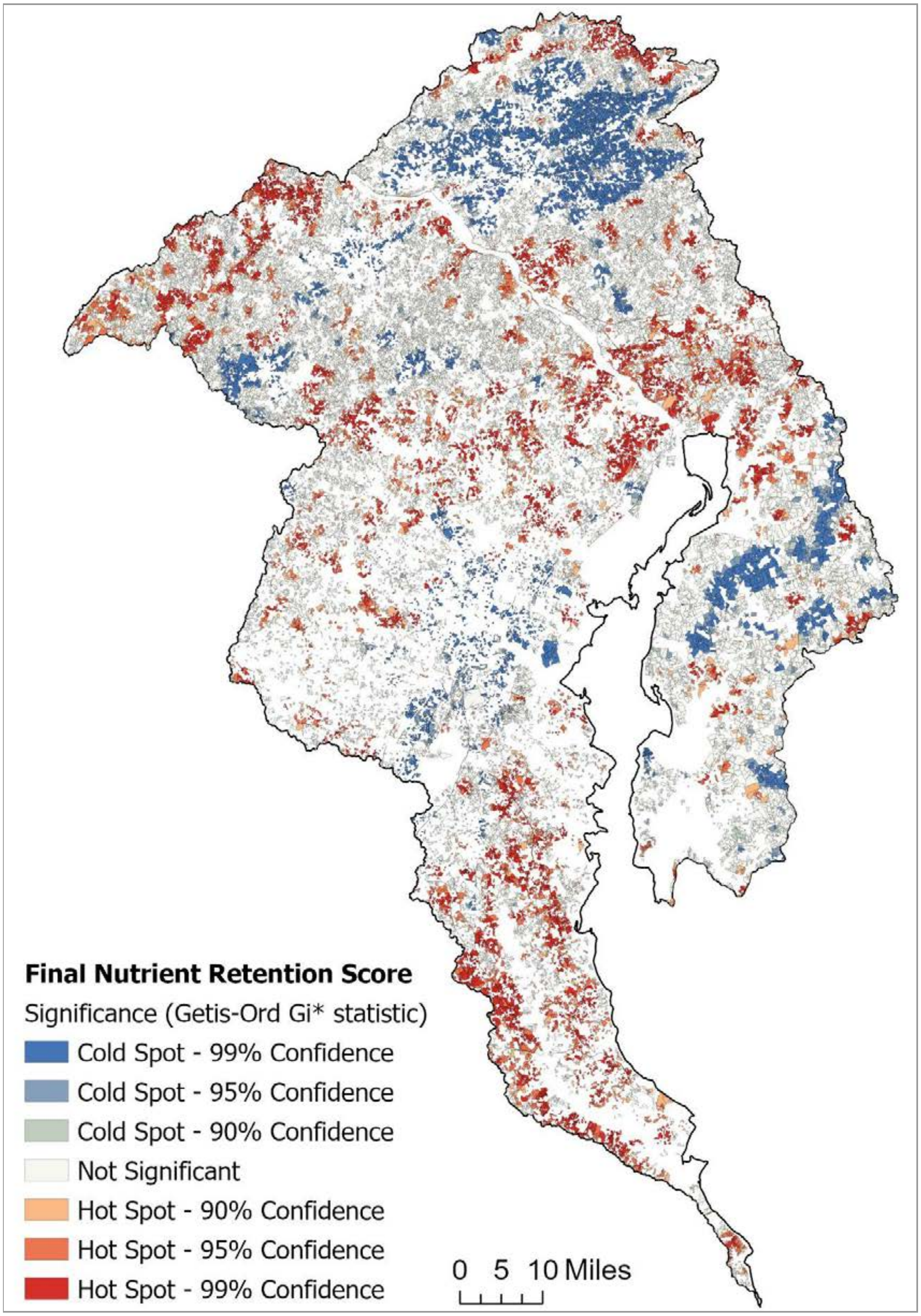


Figure 3.8. Results of optimized hot spot analysis based upon the final nutrient retention score for unprotected parcels greater than 10 acres. Parcels shaded orange to red (hot spots) reflect high-scoring nutrient retention values with parcel clustering greater than what would be expected in a random distribution. Parcels shaded grey to blue (cold spots) indicate significant clusters of low-scoring values.

3.7. Economic Valuation

Based on the 2016 land use observation (the baseline in our study), the estimated value of the ecosystem services in our study area is 12.4 million dollars with a net present value of 413 billion (in 2021 dollars). The farmland and forest have similar areas in total. The farmland has the highest ecosystem value about $6,616 million and the forest has $3,887 million dollars ecosystem service value. The land use with the highest per acre value is the wetlands. However, wetlands only cover less than one percent of the total area. So, the total estimated ecosystem service value of wetlands in our study area is only 553 million dollars, about 60% if the ecosystem value of open water and slightly higher than the urban area. (Appendix H, Table H4).

According to the historical trends' scenario 2025 land use projection, the estimated value of the ecosystem services in our study area is decreasing to 12.2 million with a net present value of 406 billion (in 2021 dollars). The farmland and forests still provide the highest total ecosystem services value about $6,303 million dollars and $3,596 million dollars respectively (Appendix H, Table H3).

With implementation of the land conservation Best Management Practices (BMPs) combined with most possible development patterns, the total value of the ecosystem service provided by our study area will experience a $202 million decrease per year, or 1.63%, over the 2016 baseline. This decrease is largely due to the decrease in area and corresponding ecosystem service value of forest and farmland. The forest decreased about 106,396 acres, about 7.39%, based on the historical trends from 2016 to 2025, and the farmland decreased about 70,438 acres, about 4.74%. These two main decreases lead to 604 million in ecosystem service value. This huge decrease is offset by the 10,969 acres, about 37.34% increase in wetland area, which leads to 206.82 million dollars gain in ecosystem service value.

Table 3.3. Summary of change in ecosystem service value, by land use.

	Projected 2025 ESV (millions of 2021 $)	Baseline ESV (millions of 2021$)	Change from Baseline (millions of 2021$)	Change from Baseline (%)
Open Water	1,070.49	928.09	142.40	15.34%
Urban	463.88	410.75	53.13	12.93%
Barren land	0	0	0.00	0.00%
Forest	3596.35	3887.66	-291.31	-7.49%
Farmland	6303.23	6616.68	-313.45	-4.74%
Wetland	760.78	553.96	206.82	37.33%
Total	12,194.73	12,397.14	-202.41	-1.63%

We also explored the ecosystem service value for HUC12 geographic units. This map shows the change in ecosystem service value (in 2021 dollars) from 2016 to 2025 under the historical trends' scenario projection. The red shades show a potential gain in ecosystem service value, and the blue shades show a potential loss in future projection. The results measure the monetary ecosystem service value of the land-use changed by the implementation of BMPs. Geographically, the total ecosystem service value tends to increase near the tidal Bay, and the inland area will have a higher possibility to experience a potential loss in ecosystem service loss. These results imply that the correlation between the geospatial characteristic and the change in monetary value that the natural systems of the study area could contribute to the economy on annual bases. The BMPs could result in an increase in value due to the conversion from less ecosystem-service-productive habitats to more productive habitats, or slower conversion to the less-productive land use at the tidal bay area, but the same conservation planning will not lead to higher monetary ecosystem service value at the inland area.

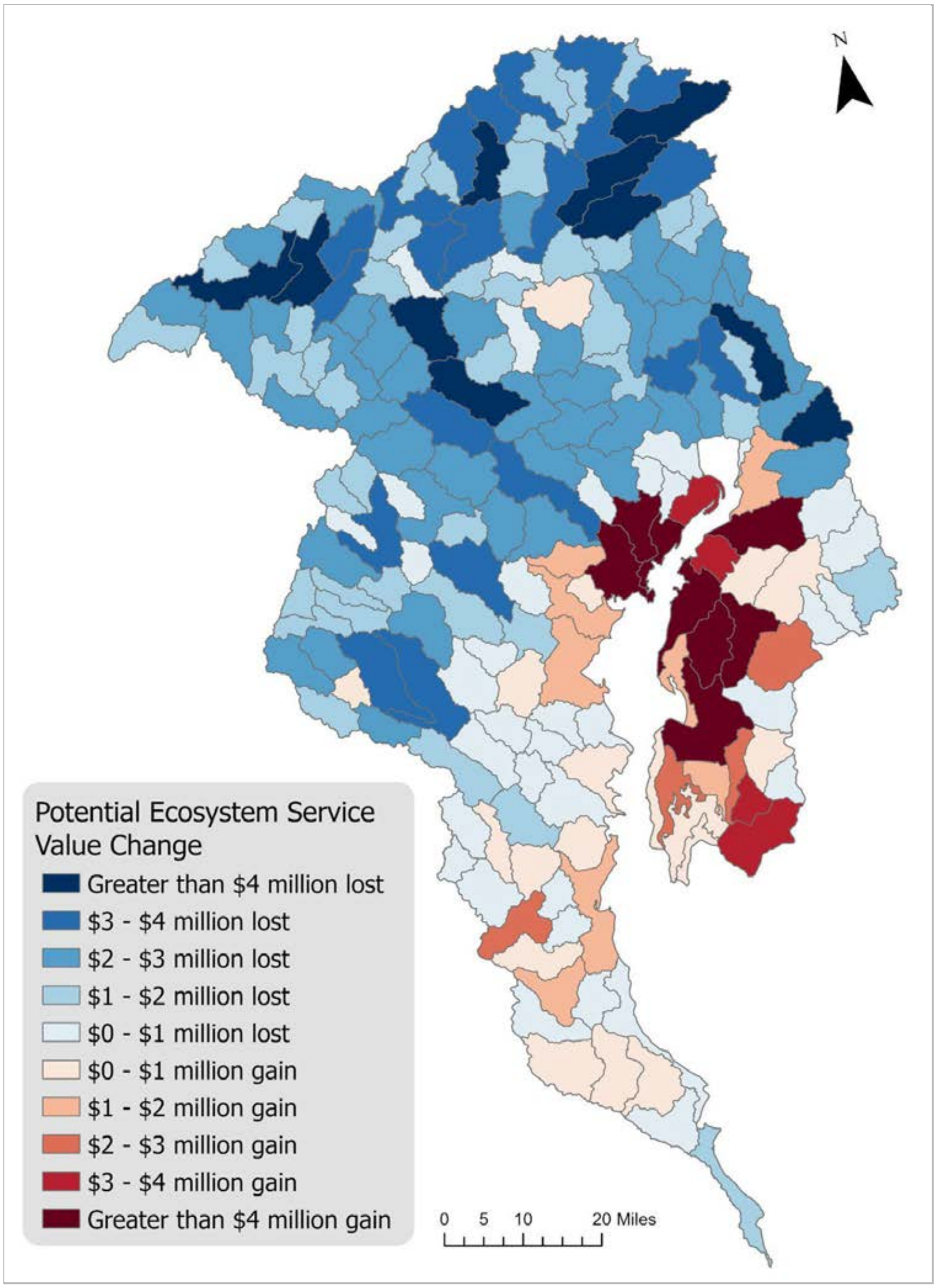


Figure 3.9. Potential Ecosystem Service Value Change arranged by HUC 12 watershed across the study area from 2016 to projected land use in 2025 under Historical Trends Scenario. The blue shades indicate a potential loss in ecosystem service value and the red shades show the regions with increasing ecosystem service value.

3.8. Multicriteria Analysis

We performed a multicriteria analysis of the criteria described above to identify parcels with co-benefits. This multicriteria analysis employed six conservation criteria—biodiversity and habitat connectivity, development vulnerability (2030), human access to open spaces, benefits to underserved communities, flood risk mitigation, and nutrient retention—to yield unique outputs for the various weighting schemes. The top 25% of high-scoring parcels for each prioritization show significantly different spatial distributions and some areas of consistent overlap. The table on the next page shows how differently the top 25% of parcels were distributed across the study area for each scenario (Table 3.4).

The results from overlapping these unique outputs highlight three regions as hotspots for co-benefit provision: the lower Patuxent Watershed (south-western section of study area), the northern Chester-Sassafras Watershed (central-eastern section of study area), and the western edge of the Lower Susquehanna Watershed (north-western side of study area) (Figure 3.11). These areas ranked consistently high for all six factors: biodiversity and habitat connectivity, development vulnerability, human access to open spaces, benefits to underserved communities, flood mitigation, and nutrient retention. Analyzing these overlapping co-benefits revealed several regional concentrations of unprotected parcels that provide multiple co-benefits.

In our analysis, several HUC 12 watersheds contained notably large numbers of parcels that scored highly for all ecosystem services (Figure 3.12). These included parcels that scored well, no matter which ecosystem service was prioritized. If a parcel scored in the top 25% for four or more of the six scenarios, it was labelled a "co-benefit priority parcel". These consistently high-scoring parcels are likely to provide multiple co-benefits, and thus represent high priorities for conservation in the central Chesapeake Bay Watershed (Table 3.4). In total, there are 364,688 acres of co-benefit priority parcels in the study area. If all of these co-benefit priority acres were conserved by 2030, 30 by 30 goals would be met within the study area (Table 3.5).

We conducted an optimized hot spot analysis that revealed statistically significant clusters of parcels scoring in the top 25% of four or more ecosystem service scenarios. Hot spots show clusters of unprotected parcels that provide multiple benefits and services, while cold spots show regions where unprotected parcels are unlikely to provide co-benefits (Figure 3.13). Hot spots of parcels are divided into two main regions, the southern portion of the study area and mouth of the Susquehanna River in the north-central section, with additional pockets throughout the study area. Cold spots contained parcels that scored lower than what would be expected in a random distribution. Cold spots of parcels are divided into three clusters, located at the northern part of our study area, inland area next to Baltimore, and the regions at the eastern shore of the bay (Figure 3.12).

We performed a second hot spot analysis at the HUC 12 watershed scale based on the count of co-benefit priority parcels within each watershed. The HUC 12 regions at the northern part of our study area includes less than 2,000 acres of co-benefit priority parcels, and this matches the cold spots representing lower priorities for conservation planning. The hot spot cluster appears at the western shore of the bay and below Baltimore. This result is consistent with the clusters of co-benefit parcels, and highlights similar areas representing high priorities for conservation. Specifically, watersheds where over 100 parcels had 4 or more benefits may be good targets for conservation activities that aim to conserve lands with multiple co-benefits (Figure 3.12). Half of the HUC 12s that contain the largest unprotected co-benefit priority lands are located at the western shore of the bay, and the rest of the regions located at that hot spot contains more than 2,000 acres per HUC 12. The total unprotected co-benefit priority lands contained in the hot spot reach 90,500 acres.

Table 3.4. The seven weighting scenarios and the five HUC 8 watersheds included in the study area. This shows: (1) The total acres of parcels scoring in the top 25% for each weighting scenario; the largest area in each column is shown in green. (2) This acreage is expressed as a percent of the total unprotected acres in each watershed; the largest percentage in each column is shown in purple.

	Equal Weighting		**Habitat**		**Flood Mitigation**		**Development**		**Open Space Access**		**Benefits to Underserved Communities**		**Nutrient Retention**	
Watershed Name	*Top 25% Acreage*	*As % of Total Unprotected Acres*	*Top 25% Acreage*	*As % of Total Unprotected Acres*	*Top 25% Acreage*	*As % of Total Unprotected Acres*	*Top 25% Acreage*	*As % of Total Unprotected Acres*	*Top 25% Acreage*	*As % of Total Unprotected Acres*	*Top 25% Acreage*	*As % of Total Unprotected Acres*	*Top 25% Acreage*	*As % of Total Unprotected Acres*
Patuxent	112,317	28.4	119,991	30.3	106,678	26.9	92,368	23.3	36,687	9.3	130,973	33.1	110,621	27.9
Lower Susquehanna	170,167	13.3	157,588	12.3	220,264	17.2	187,916	14.7	236,727	18.5	101,942	8	149,448	11.7
Chester-Sassafras	151,539	29.5	175,912	34.2	126,387	24.6	93,557	18.2	131,850	25.7	130,802	25.5	131,629	25.6
Gunpowder-Patapsco	75,406	12.7	89,183	15	81,040	13.7	74,051	12.5	39,868	6.7	115,157	19.4	73,061	12.3
Severn	39,811	26.4	42,044	27.9	37,090	24.6	42,091	28	15,984	10.6	27,220	18.1	39,757	26.4

Table 3.5. Summary of 30 by 30 status and land protection targets for each watershed in the study area.

Watershed Name	Total Watershed Acres	Percent Currently Protected	Acreage to Reach 30 by 30 in Watershed	Total Co-Benefit Priority Parcel Acreage
Patuxent	593,229	28.9	65,256	87,045
Lower Susquehanna	1,591,180	19.4	168,665	99,984
Chester-Sassafras	833,477	22.3	64,178	95,866
Gunpowder-Patapsco	907,202	29.6	3,629	49,605
Severn	235,968	16.5	31,856	32,188
Total Study Area	**4,161,056**	**23.4**	**333,584**	**364,688**

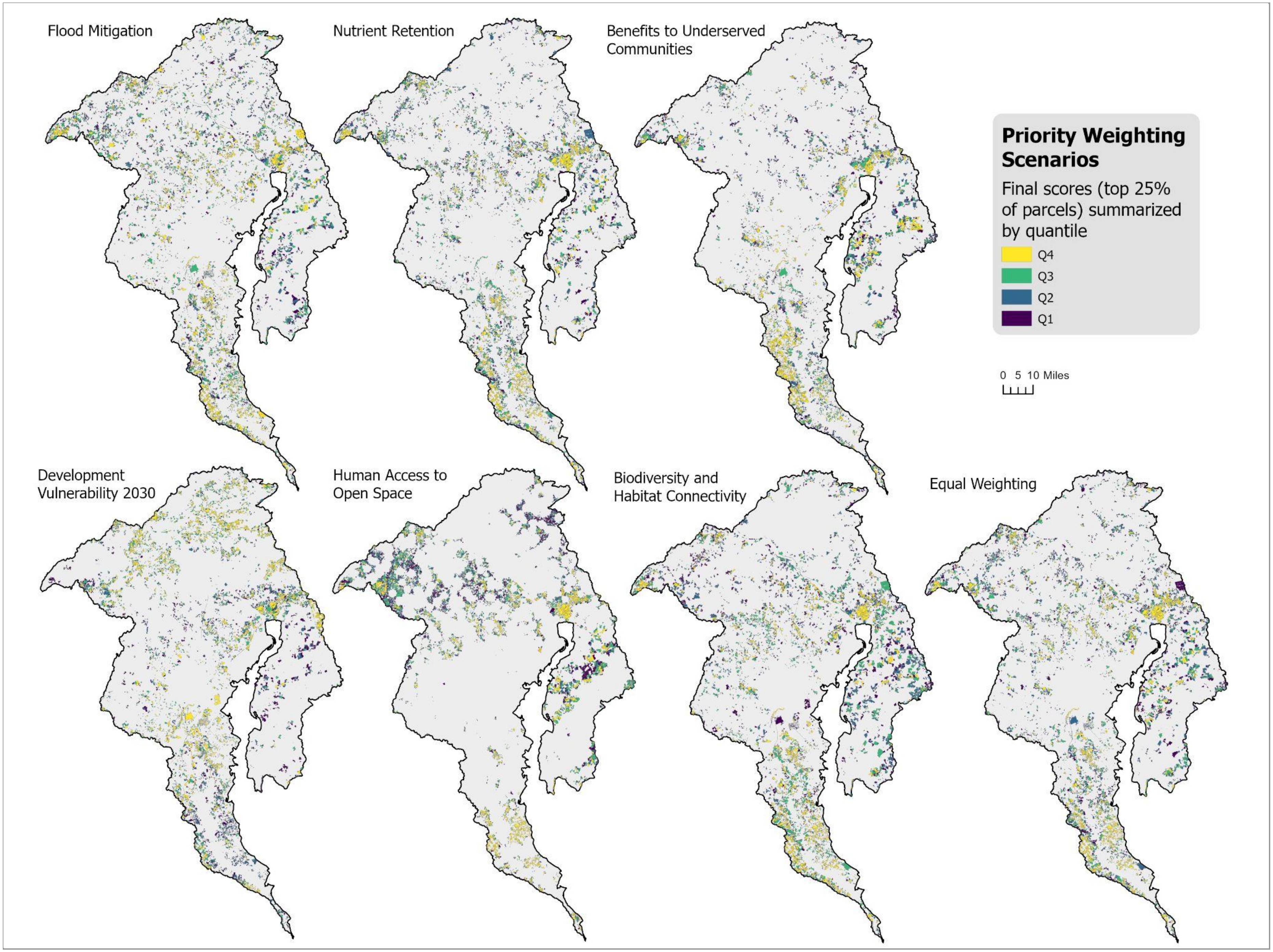


Figure 3.10. Priority weighting scenarios for each of the six criteria and equal weighting (bottom right map). The top 25% of high-scoring parcels are shown by equally distributed quantiles, with Q4 reflecting parcels with more co-benefits.

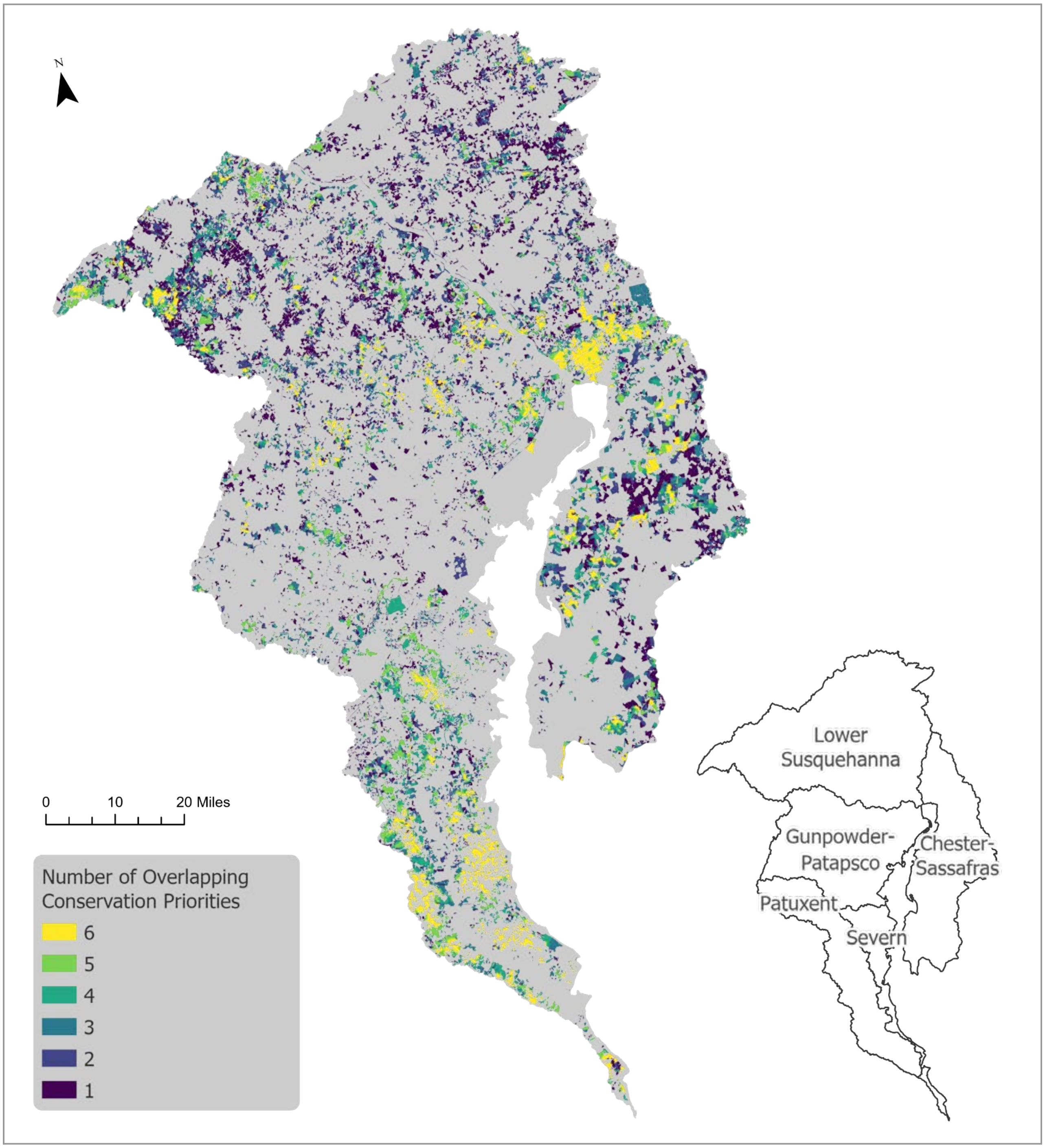


Figure 3.11. The distribution of unprotected parcels which scored in the top 25% of one or more criteria prioritization scenarios. Parcels where priority parcels from six scenarios overlap have the highest potential to provide co-benefits, and are likely high priorities for conservation activities. Parcels with four to six overlapping benefits were named co-benefit priority parcels.

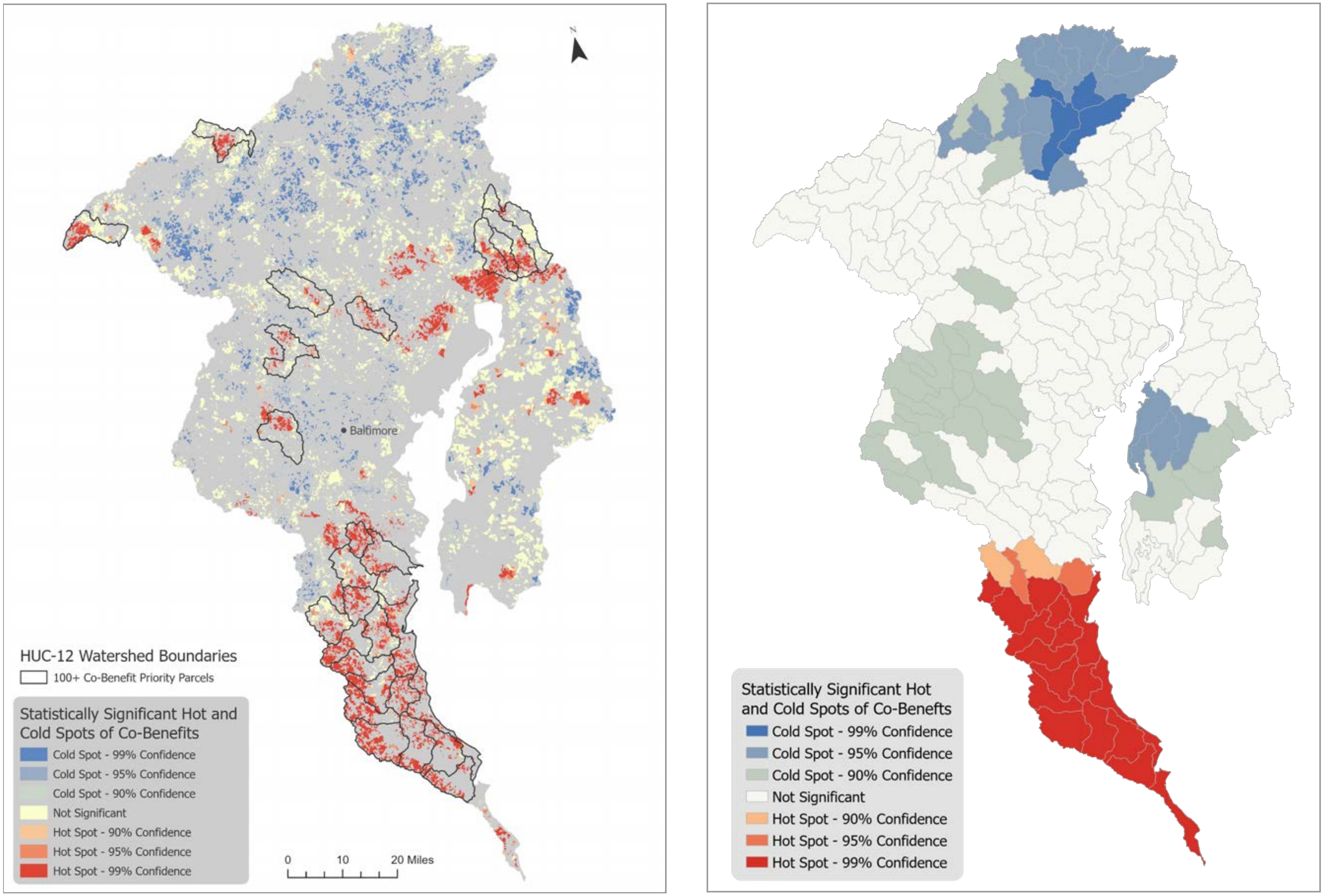


FIgure 3.12. Hot spot analysis by parcels (left figure) and by HUC 12 watershed boundaries (right figure). The parcel figure shows HUC 12 watershed boundaries containing over 100 parcels having four or more co-benefits.The watershed figure is based upon the total count of “co-benefit priority parcels” within each HUC 12.

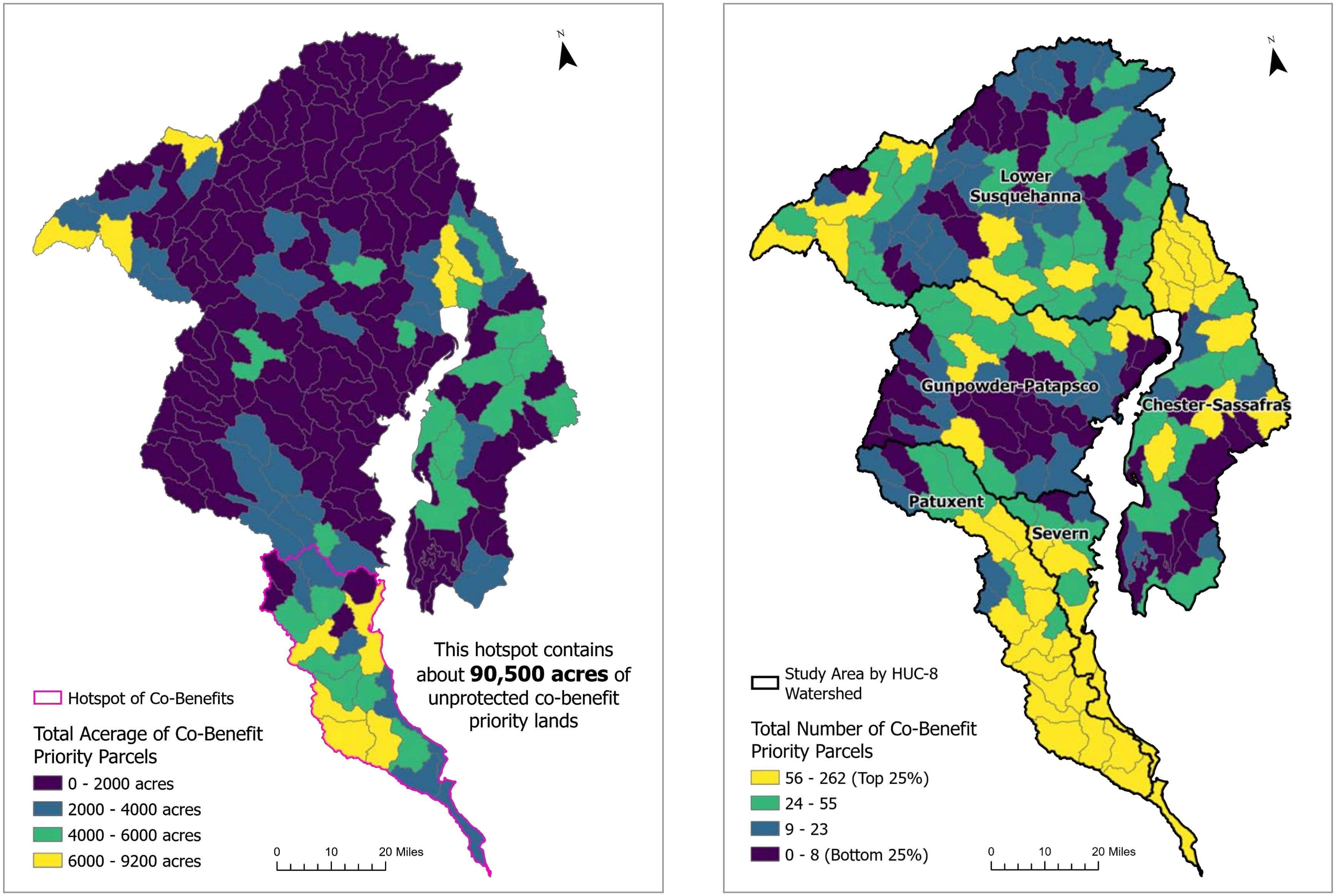


Figure 3.13. The map on the left shows the total acreage of co-benefit priority parcels for each HUC 12 watershed in the study area. Co-benefit priority parcels scored in the top 25% for 4 or more scenarios. The left map highlights the hotspot identified in Figure 3.12. The map on the right shows the total number of co-benefit parcels within each HUC 12 watershed, overlaid with the larger HUC 8 watershed boundaries and names.

4. DISCUSSION

A central goal of this project was to identify, quantify, and map the key ecological and economic benefits of conserving additional lands. We aimed to provide a case study on how a 30 by 30 conservation strategy could look in the Chesapeake Bay Watershed when targeted for specific ecosystem services, co-benefits, and criteria valued by the Chesapeake Conservancy and regional stakeholders. The results of individual criteria are discussed below, followed by our recommendations, limitations of this analysis, and suggested extensions of this work.

Biodiversity and Habitat Connectivity

Areas with high biodiversity and habitat importance are concentrated around water and in areas with dense forest cover (Figures 2.2, 3.1). Regions with high development do not have high habitat value scores, likely due to the lack of established forests, wetlands, and grasslands to provide habitat resources. While every HUC 8 watershed included areas with highly important habitats, the Chester-Sassafras and Patuxent Watersheds showed particularly high densities of valuable lands for biodiversity. These are likely due to the central rivers and corresponding riparian corridors. Riparian corridors can offer opportunities to integrate a variety of ecosystem services in addition to habitat locations, since rivers often provide the opportunity for public spaces with meandering trails, and they play an integral role in both flood mitigation and nutrient retention.

Development Vulnerability

Areas with development vulnerability are focused more in the central region of the Upper Susquehanna Watershed, and also include the western coastline of the Chesapeake Bay (Figure 3.2). Highlighted areas with particular vulnerability tend to be surrounded by unclassified parcels. This means that the neighboring parcels are either protected from development or under 10 acres in size, both of which could increase the likelihood for development. Small parcels tend to link with higher population densities, and therefore population growth could be more notable in those areas. Additionally, if in close proximity to protected areas, future development would necessarily concentrate in the unprotected areas as the only possible option for regional growth.

Human Access to Open Spaces

While many open spaces are listed as publicly accessible throughout our entire study area, several regions have no public spaces within 2 kilometers of a parcel's edge. Our analysis highlighted areas in the western half of the Lower Susquehanna HUC 8 Watershed, as well as the central Chester-Sassafras Watershed and the southern Patuxent Watershed. If the land cover offers forest, wetlands, or other areas without development, our categorization highlights areas to potentially convert to publicly accessible trails. If the land cover does include developments, the highlighted areas offer restoration opportunities. Providing greater public access to open spaces can improve human health by increasing opportunities for physical activity and stress reduction (Mears et al., 2019). Converting highly developed areas to green space can directly improve the urban heat-island effects, and address the regional inequities regarding communities' access to open space (Jennings, 2015; Lee, 2021; Plummer, 2020).

Benefits to Underserved Communities

Our study area demonstrated high scores regarding traditionally underserved communities surrounding cities, particularly Baltimore, Maryland; Bowie, Maryland, and

Lancaster, Pennsylvania. An additional region with high scores is located in the western edge of our study area, in Kent County, Delaware. For the Chesapeake Bay Watershed, assigning demographic scores for each parcel highlights the tools to incorporate environmental justice through this analysis.

Since this research centers on recommendations for future land conservation, incorporating social characteristics is an essential piece. The environmental movement in the United States was founded on a clear distinction of ‘civilized’ areas and ‘natural’ areas. Whether John Muir’s emphasis on preserving sacred areas or Gifford Pinchot’s emphasis on utilizing available resources, both sides meant vast displacement of Indigenous communities from these ‘natural’ areas (Van Houtan et al., 2010). Additionally, racial and economic demographics are frequently intertwined with heightened levels of toxic exposure, reduced access to publicly available green spaces, and community voices being ignored by decision makers (Villa et al., 2020). The events of 2020 have been bringing racial inequalities to the forefront of American dialogue (Lee, 2021). Sierra Club verbalized their historic ties to leaders who also promoted conserving the white race, in addition to recognizing their organization’s foundation from the white, privileged demographic (Brune, 2020). Therefore, incorporating demographic data representing traditionally underserved communities into land conservation efforts provides the opportunity to recognize environmental justice as a topic worthy of inspiring action.

Flood Risk Mitigation

There are many types of flooding that impact the Chesapeake Bay Watershed including storm surge, flash flooding, and stormwater-driven floods (Hogan, 2008; Krikstan, 2014). This analysis generated parcel scores for flood mitigation that are specific to stormwater driven floods. Strongly influenced by data on soil type and land cover, the flood mitigation score highlights unprotected lands that are likely good at capturing stormwater runoff, are likely within a 100-year floodplain, and may be within a watershed which experiences high flood damages. In including data on potential damages, this score prioritizes clusters of parcels for conservation both by the supply of runoff retention, but also by the local need (demand) for those flood-mitigating services. The inclusion of demand into ecosystem service mapping, and into flood risk mapping in particular, is a critical step in ensuring conservation directly benefits and is relevant to communities. Without considering where flood mitigation is needed and where flood damages are mostly likely to occur, conservation- and restoration-based approaches to flood resilience may be ineffective or inequitable in application. This type of supply and demand scoring could potentially be paired with local resilience plans and existing community planning efforts to inform conservation targets. These data could support planning for several existing flood mitigation programs such FEMA’s buyout program or identification of conservation opportunities for FEMA’s National Flood Insurance Program (Elliot, 2016).

There were several areas and watersheds that stood out as opportunities for further assessment. Under the conservation planning scenario that prioritized flood mitigation services, the Lower Susquehanna watershed - encompassing the Pennsylvania towns of Lancaster and York - had the greatest acreage of high-scoring conservation opportunities at 220,264 acres (Table 3.4). Over a quarter (26%) of the unprotected lands in the Patuxent watershed scored highly in this same scenario (Table 3.4). The high acreage in the Lower Susquehanna is partially attributable to the high overall acreage of this watershed. The sizable percentage of high-scoring unprotected lands in the Patuxent watershed may be driven by the large patches of soils with high infiltration capacities (Appendix F, Figure 2), and an abundance of forested land covers in this region (Figure 2.2).

Nutrient Retention

The central benefit of the nutrient retention analysis was identifying areas of individual parcels based on their capacity to retain both nitrogen and phosphorus. This is important because nutrient concerns in the Chesapeake Bay Watershed have typically been quantified at a larger spatial scale using other modeling approaches. However, most conservation today happens at the parcel scale, and organizations like Chesapeake Conservancy need more spatially-relevant data on nutrient retention to help direct those conservation efforts.

The 30 by 30 and 50 by 50 land protection goals can most likely be realized through the Conservancy's coordination with partner organizations tasked with meeting TMDL requirements and who are looking for least-cost solutions to make incremental improvements. The results can also help Chesapeake Conservancy' communication with landowners, local governments, and other service contractors by providing evidence to encourage adoption of specific management practices or communicate why a new conservation easement or restoration project may or may not meet the organization's nutrient management goals.

Parcels with a high value of effective retention are likely to be good candidates for outright conservation through easements or fee-simple purchases since they already provide nutrient retention services. Parcels with a high proportion of nutrient delivery are likely to be good candidates for restoration or conservation coupled with restoration. This might include water protection activities such as revegetation with field or riparian buffers around agricultural lands, actions that were shown in the NDR model to be effective at reducing the total export of N and P to water resources. A recent, unsuccessful attempt to pass the Comprehensive Conservation Finance Act (SB0737) in March 2021 would have made it easier to establish pay-for-success contracts to enable this work. Though the bill encompassed Maryland, an allowance was provided for cross-state loans within the Susquehanna River watershed for organizations tied to the Chesapeake Bay Program.

Although the distribution of N and P in the study area varied spatially, assigning equal weight to each helped minimize potential tradeoffs in the final nutrient retention score. The results of the hot spot analysis based on this final nutrient retention score indicates a number of parcels with a high degree of effectiveness for retaining both N and P (hot spots). These tend to be located near the Lower Susquehanna River and along the lower western shore of the bay itself. Dense areas of parcels with poor nutrient retention scores (cold spots) are located primarily in the northeast corner of the study area and along the eastern shore of the bay.

Total nutrient export varied substantially between the current baseline and potential land use changes. Notably, nutrient export increased under scenarios of future projected development (urban/exurban) and the conversion of forestlands to agriculture. Nutrient export decreased substantially by increasing the area of agricultural field and riparian buffers. These land use change scenarios and the distribution of priority parcels in the priority weighting scheme highlight the importance of taking action to prevent land conversion and improving vegetation management for agricultural lands, urban, and exurban areas for their nutrient retention services.

In terms of conservation planning, the relative change in nutrient export between land use change scenarios can also be thought of in economic terms when weighing the costs of pollution reduction technology, BMP implementation, or restoration to meet TMDL goals. For example, at a given percent reduction in N or P, paying farmers to implement additional field or stream buffers—or the outright purchase of farm and forest lands that are vulnerable to development—may be achievable at a lower cost than removal of an equivalent volume of N or P through on-farm technologies, improvements to infrastructure, or wastewater treatment (Hopkins et al., 2018).

This general theory has been long utilized in Water Quality Trading markets, where point source reduction efforts typically feature diminishing marginal returns and increasing marginal abatement costs compared to non-point source controls (BenDor et al., 2021). At scale, broad, land-based strategies that target nutrient retention can serve the dual function of restoring or conserving enough expanse of natural ecosystems to meet 30 by 30 and 50 by 50 conservation goals. The avoided cost of losing this ecosystem service offers a common pathway for regulatory groups and conservation organizations to achieve their requisite goals by least-cost means (Beecher, 1996).

Ecosystem Service Valuation

We assessed the spatial variance in the ecosystem service value by subtracting the 2016 values from 2025 values for better understanding of its correlation to the geographic characteristics of the area. The total ecosystem service value tends to increase near the tidal Bay, and the inland areas will have a higher possibility to experience a potential loss. Thus, different conservation strategies could increase the potential ecosystem service value or avoid potential loss.

The HUC 12 watersheds that have the highest potential increase in ecosystem service value share similar changes in land uses. The conservation planning and development trends in those places result in a high increase in the area of wetland. Although they have considerable urban development and forest and farmland lost, the increase in ecosystem service value from conserved wetland will cover the cost and increase the potential ecosystem service value. They also show a trend to have decreasing barren land area (Appendix H, Table H7). These HUC 12s are concentrated in the bay area, where the conservation of wetlands is easier to implement. For future conservation, these areas could be planned to maintain the current conservation plan and follow the recent development trends without any other extra implementation of conservation plan.

The HUC 12s that might suffer from the huge decrease in ecosystem value have larger increases in urban and open water area, and correspondingly experiencing considerable loss in forest land and farmland. There is insignificant change in barren and wetland, however, the gain from the wetland does not cover the monetary loss from the forest and farmland (Appendix H, Table H6). These HUC 12s are concentrated in the inland areas, which also connects to higher development. The water resources are conserved in a proper way, but the conservation and restoration of forest and farmland are neglected in future projection. However, for the future conservation, the successful conservation of the open water could raise the potential in restoration in farmland, and even wetland, which could efficiently increase the ecosystem service value (Appendix H, Table H5).

Multicriteria Analysis for Co-Benefits

Our analysis of co-benefits identified parcels likely to provide multiple services or meet multiple conservation criteria. The final distribution of co-benefit priority parcels reveals several regions with notable clusters of unprotected lands likely to provide co-benefits (Figure 3.11), most notably hotspots in the southern study area within the Patuxent Watershed (Figure 3.12). The concentration of co-benefits in this coastal area is likely driven by several factors. First, this region contains large swaths of ecosystems that support several services. For example, the high amount of forest lands, soils with high infiltration capacity, and proximity to coastal marshes and wetlands means this landscape is likely good at both attenuating runoff and filtration of nutrients like nitrogen and phosphorus. In addition to these water-based services, this southern region encompasses the suburbs of Washington D.C., Annapolis, and is just to the south of populus Baltimore. This proximity to communities likely drives the high scores seen in the

Human Access to Open Spaces and Benefits to Underserved Communities scenarios. These clusters of co-benefit priorities highlight areas which would be strong candidates for further investigation of conservation opportunities with site-specific data, such as the 1 by 1 meter land cover and land use datasets produced by Chesapeake Conservancy.

While there are many hotspots of overlapping ecosystem services throughout the landscape, the final distribution of scores for each weighting scenario have notable differences (Table 3.4). The Lower Susquehanna and Chester-Sassafras Watersheds have the largest acreage of unprotected lands in the study area. Accordingly, these watersheds also have the greatest acreage of high-scoring parcels across most weighting scenarios (Table 3.4). The magnitude and distribution of each criteria varies across the landscape. Therefore, the results of our conservation prioritization scenarios have different distributions across watersheds. For instance, a large proportion of unprotected lands in the Chester-Sassafras Watershed score very well in the Biodiversity and Habitat Connectivity and Human Access to Open Spaces scenarios. The coincidence between these two scenarios may be based on the dual role that conserved open space fills, serving both as a recreational area and biodiversity-supporting habitat. The Patuxent Watershed has the greatest proportion of high-scoring unprotected lands in the Flood Mitigation, Benefits to Underserved Communities, and Nutrient Retention scenarios. The Severn Watershed has the highest percent of unprotected lands scored highly in the Development Vulnerability scenario (Table 3.4).

Results of these scenarios can inform conservation strategies and provide insight on how conservation priorities may change when based on different ecosystem services. If conservation strategies wish to target lands most likely to be developed, the Severn Watershed, which contains Annapolis and is sandwiched between Baltimore and Washington D.C., would be a good candidate for further investigation. Based on the distributions described above and in Table 3.4, the Patuxent Watershed might be a good candidate for further investigation if conservation aims to provide co-benefits for water-based ecosystem services such as flood mitigation and nutrient retention.

4.1 Recommendations

Described herein are key results from this research and recommendations. The coastal reaches of the Chesapeake Bay’s western shore, which includes portions of the Paxtuent and Severn Watersheds, are a hotspot for co-benefits relative to the study area used in this case study. Conservation targeted in this area is more likely to protect lands that could provide critical co-benefits such as flood mitigation, nutrient retention, human access to open space, and habitat connectivity.

Ecosystem services provided by lands on the Delmarva Peninsula (Chester-Sassafras Watershed) and western shore are projected to increase in monetary value over time. For some HUC 12 watershed boundaries, this increase in value exceeds $4 million dollars. This increase is principally driven by the expected increase in wetland area and the limited decrease in forest and farmland area. Conservation in these locations may be cost-effective in that such action preserves lands which, without additional restoration or management, will provide ecosystem services that increase in value over time.

Significantly, watersheds in the southernmost regions of the study area currently provide a high density of co-benefits with some projected to increase in their ecosystem service value. Collectively there are 90,500 acres of unprotected co-benefit priority parcels in this region. These are the highest priority conservation areas for protection in terms of the current provision of ecosystem services and benefits. Conservation actions in these areas would likely minimize potential tradeoffs between ecosystem services.

It should be noted that while the cumulative acreage of co-benefit priority parcels is generally higher in the southern region of the focal area and along the Delmarva Peninsula, there are still a high number of co-benefit priority parcels in the central areas of the Lower Susquehanna Watershed (Figure 3.13). While priority parcels in these central areas may tend smaller in size, they represent numerous opportunities for conservation activities.

Watersheds in the northern part of the study area (the Lower Susquehanna Watershed) have some localized hotspots of co-benefits. However, based on projected land use change, the economic value of those services is projected to decrease over time without conservation action. As discussed above, this decrease in value is likely driven by a projected loss of forest and farmland to open water (sea level rise) and urbanization. Conservation in these regions would be most effective in providing ecosystem services and benefits when paired with restoration activities targeted towards working forests, farms, and riparian corridors as the Chesapeake Conservancy and its regional partners have been implementing and facilitating.

Spatial scale is important to consider in assessing ecosystem services for conservation. For example, comparisons of hotspot analyses at the parcel scale and the larger HUC 12 watershed scale (Figure 3.12) indicate different areas to focus conservation and/or restoration efforts. While results at the HUC 12 scale can help guide regional planning efforts, this may miss viable opportunities for land protection at smaller scales. For instance, parcel-scale hotspots near the mouth of the Susquehanna River are not visible at the HUC 12 scale. In a densely-populated watershed with limited remaining opportunities to reach the 30 by 30 goal, every parcel counts.

A final takeaway from this research is that the quantification of co-benefits, as shown in this analysis, is likely to play an increasingly important role in future conservation efforts. For example, in March 2021, Chesapeake Conservancy and other regional partners advocated for the passage of the Comprehensive Conservation Finance Act (SB0737) in Maryland. The bill would have prioritized funding for conservation and restoration projects with already quantified co-benefits. Although the bill unanimously passed the house, it was ultimately delayed from a senate vote. Despite this, the CCFA highlights what is almost sure to be a future trend in conservation funding and the need for the conservation community to begin critically examining co-benefits at a fine, spatial scale.

4.2 Limitations

It is important to highlight some of the overarching limitations to this analysis. The data produced here are principally for landscape-scale assessment of ecosystem services, not a localized site-specific evaluation or application. The data layers and ecosystem service scores generated here are excellent tools to evaluate the relative services provided by watersheds or sub-watersheds within the central Chesapeake Bay Watershed, and can be used to identify specific subregions for further investigation of conservation opportunities and benefits. However, these data should not be used for individual parcel selection or as a proxy for on-the-ground conditions in a specific location.

Limitations of Parcels Analysis

The assembled parcel data layer may not accurately reflect the parcel boundaries. The majority of counties released their data with such a disclaimer. Additionally, parcels protected after 2018 were not included in the data layer used in our analysis. Likewise, parcels were excluded if the parcel shape was incongruent with the protected lands layer and its centerpoint fell outside the layer. Therefore, the unprotected parcels data layer created could have included a minimal number of parcels that are protected or have recently been protected. Local research and interviews could clarify this for specific areas.

Another limitation of the parcel data is that many counties in Maryland included roads and electric lines as polygons in their parcel data. This resulted in the likely inclusion of long, large polygons representative of paved roads, highways, and electrical lines in the unprotected parcels layer. We removed most road and highway parcels in cleaning the parcel data (see methods), however some may have remained in the dataset used in our classification analysis.

Assumptions of Mathematical Transformations

The habitat connectivity, human access to open spaces, development vulnerability, flood mitigation, and nutrient retention parcel values were converted to a 0-1 scale using a linear transformation. While this provides the smoothest mathematical processing, such a transformation assumes that every score is equidistant away from other values as to their levels of importance. For example, it assumes that the difference between 0 and 0.2 kilometers distance from public green space is equal to the difference between parcels with distances 1.8 and 2 kilometers away. Likewise, it assumes that a Tier 1 habitat area is more valuable than Tier 2 to the same extent as Tier 2 is from Tier 3, and as Tier 3 is to areas without scores. Consultation with scientific experts could be beneficial, especially for the categorical values such as habitat (0-3) and development vulnerability (0-6). Specialists could provide a more detailed mathematical transformation capturing the relationship between values for a certain criterion. This could enable a more ecologically accurate calculation of scores, and improve the parcel rankings accordingly.

Limitations of Biodiversity and Habitat Connectivity Analysis

The biodiversity and habitat connectivity values were transferred directly from the Chesapeake Conservation Partnership's compiled data layer. Meanwhile, biodiversity value can be quantified using a variety of metrics such as imperiled species' habitats, quantity of total animals present, or solely land cover. Future classifications could continually refine the habitat layer, incorporating updated land covers due to climate change and development. Additionally, scientific consultation could provide more precision to this scoring conversion scale as described above.

Limitations of Development Vulnerability Analysis

The development vulnerability scores were assigned from the estimates for development along the current zoning trajectory, not including other possible adjustments. The Conservation Innovation Center created four different future trajectories to categorize development vulnerabilities using the Chesapeake Bay Land Change Model (CBLCM, 2020). The current zoning trajectory did not incorporate forest conservation, agricultural conservation, or growth management into its predictions. Therefore, in choosing the current zoning trajectory, some parcels may have a lower true vulnerability if local efforts for guided development do take place in the future. Meanwhile, the current zoning trajectory highlights areas in need of intentional conservation. Other projections would be more likely to miss parcels for conservation urgency by assuming they would be protected by directed growth patterns, when this intentionality is not necessarily guaranteed. The hope is that taking such consideration into account will align the reality of land change more closely to one of the other predictions that did visualize intentional growth patterns.

Limitations of Human Access to Open Space Analysis

Published literature uses a variety of methods to quantify levels of human access to open spaces (Mears et al., 2019). Our process of creating parcel scores for accessibility to open spaces entailed several assumptions. Distance from open space was measured as the crow flies, without integrating road distances or transportation types to estimate travel time. Straight-line distances may overestimate accessibility, since transportation and entry points can increase travel time over a short distance (Mears et al., 2019). Rather than straight distance, network distance offers an alternative by incorporating transportation networks such as roads and bus lines into analysis (Mears et al., 2019). Meanwhile, network distances are less straight-forward to quantify across a large study area, since they often require manual corrections from local knowledge.

Another assumption of open space analysis was that protected lands have greater tree cover than unprotected lands. This assumption led to the conclusion linking open space access and urban heat island effects. This could be adjusted in future analysis by incorporating land use land cover data. Additionally, interviews with community members could provide more information on specific park components and plans for establishing a shaded tree canopy.

The access to open space scores also generalized that all access must be tied to publicly accessible land. Certain private properties could have open space available to its residents and potentially its neighbors, providing health benefits of time spent outdoors without an official public open space. If a property itself contained acres of undeveloped land and maturing ecosystems, its residents would have high access to open space despite the parcel's official lack of public greenspace access. Such land areas were not integrated into this analysis. Therefore, these scores are most relevant when applied to regions with residents on small parcels and highly developed land, assessing the status of publicly accessible land proximity. Similar to the tree cover assumption discussed above, incorporating private lands with open space could be fine-tuned for future analysis using land cover data across private parcels, as well as with local interviews to assess the levels of open space accessibility.

Limitations of Benefits to Underserved Communities Analysis

Using the EJSCREEN scores to quantify how land conservation can benefit underserved communities includes several assumptions. While the census block group is the smallest available unit with census data, assigning it to the parcel level assumes that every household has the same demographic representation as the census block group overall. The values provide percentages for the block group, therefore interpretation should include this context when interpreting a particular parcel's score. Census data also marks a point in time, not necessarily reflecting the demographic composition at the present. Future analysis could replace this layer with 2020 census data when it becomes publicly available. Also, the demographic index used for the EPA's EJSCREEN and for our analysis measures demographic indicators with solely two factors: percent low-income and percent minority. The Social Vulnerability Index uses 15 indicators including housing type and number of individuals with a disability over 5 years old, yet this index is quantified at the census tract or state level. EJSCREEN aligns with EPA's current categorization system. Meanwhile, these demographic indicators could be adjusted with census data to provide more detail and incorporate other social factors. More detailed research, such as a literature review and personal communications with residents, could clarify ways to improve quantifying potential benefits for underserved communities for future analyses.

Limitations of Flood Risk Analysis

As constructed, the Flood Mitigation Score is likely to prioritize large parcels within the 100-year floodplain and within an urbanized watershed. Because the data source for building footprints, OpenStreetMap, is open source, some regions may have better data coverage than others. Specifically, urbanized areas with higher populations are more likely to be thoroughly mapped, while buildings in rural areas and buildings pertaining to agricultural use are likely underrepresented (OpenStreetMap Wiki & Documentation). This pattern is clearest in Figure 3.5, and may explain why some of the highest scoring parcels are concentrated in relatively more urbanized watersheds.

The Urban Flood Risk Mitigation model used in this analysis strictly considers flood hazards and damages posed by stormwater runoff during high precipitation events. Notably, this analysis does not consider damages or services relevant to coastal storm surge or riverine flash floods (Sharp et al. 2020), which may occur independently of, or simultaneously with, stormwater-driven flooding. The InVEST model also involves several other assumptions. The curve number method, while commonly applied in runoff modeling at scales ranging from 1 acre sites to entire HUC 12 watersheds, was developed at small watershed scales almost 40 years ago (USDA/NRCS, 1986). We used the best available literature when applying the curve number method to estimate runoff, but results generated using this method should be viewed as approximations, not site specific estimates of runoff attenuation and production. Further, our methodology does not account for tree canopy interception, which can either increase or decrease runoff generation depending on the underlying land cover and soil characteristics (Green Infrastructure Center & USFS, 2019).

The flood service parcel score highly ranks unprotected parcels which are effective at attenuating runoff in their current state. Restoration of riparian buffers and forested lands has the potential to improve the current capacity of land to attenuate runoff. Thus, conservation can also be targeted at lands which are poor at attenuating runoff but may be good candidates for restoration because of specific land cover or soil characteristics. However, this analysis does not consider the restoration potential of lands which are currently poor at attenuating runoff. For instance, a parcel which is currently covered by some impervious surface but has restoration potential would still have a low Flood Mitigation Score.

The estimates of potential damages to buildings in a given HUC12 are likely over estimates. The potential damage values provided by Hazus are a *replacement* cost per square meter, and represent the expected cost to replace a square meter of building footprint if it were entirely destroyed in a flood (Hazus 4.2 User Guide). Often flood damages do not completely destroy buildings but may require less costly renovation and repair. Buildings type data are generalized to five broad classes and not for estimation of damages at local scales. In fact, Hazus user guidance explicitly recommends that damage functions be applied at large spatial scales (Hazus 4.2 User Guide).

The use of building infrastructure to estimate potential damages excludes consideration of other common flood damages such as erosion on agricultural lands, loss of crop yield, and road or highway washouts. Also notable is the underrepresentation of agricultural buildings in both OpenStreetMap footprints and Hazus aggregated building type data. While the damages to buildings are likely overestimates, the total flood damages expected in a given watershed or subwatershed could be underestimated due to the underrepresentation of agricultural infrastructure in the data. Finally, population and vulnerability are not considered in the final flood service score. Other ecosystem service scores developed for this project do consider community vulnerability to hazards, but the flood service score alone does not. Caution should be employed if applying this score to areas with environmental justice concerns and inequitable resource distribution. That is, the areas with the highest potential flood damage to buildings may not be the most vulnerable to a flood event, as hazard vulnerability is informed by a wide variety of social and economic factors beyond infrastructure damage.

Limitations of Nutrient Retention Analysis

Some notable limitations arise from modeling nutrient flux with the InVEST software package and particular datasets. The quick-flow index (runoff proxy) derived from the Seasonal Water Yield model adopted curve numbers (CN) based on broad hydrologic soil groups. These CN may not reflect the high variability of soil condition and ground cover found in the study area. This, in part, is amplified by use of the National Land Cover Dataset for a precision hydrologic application. Beyond limitations of its 30m spatial resolution, the NLCD has been shown to exert varying bias in the classification of impervious and vegetated surfaces in the Baltimore area (Smith et al., 2010); this may have additional implications for the estimation of nutrient flux.

The Nutrient Delivery Ratio model is not calibrated to instream measurements. It also does not consider more complex biogeochemical processes. The application of other advanced models to the Chesapeake Bay Watershed, such as SPARROW (Ator et al., 2011), are calibrated to gauge data and utilize an intricate mass balance approach to interpolate nutrient flux at the scale of stream reaches (ranging in scale from 300 to 1,000-plus ha). Similarly, the Chesapeake Bay Program Phase 6 Watershed Model interpolates nutrient flux at the scale of land-river segments (small catchments approximately 4,856 ha in area).

Since the NDR model utilizes an average nutrient loading rate parameter in kg/ha/yr (also referred to as an export coefficient or EC), it is difficult to account for concentrated point source pollution from agriculture, urban areas, wastewater, or septic. These sources are known to have a major effect on water integrity in the Chesapeake Bay Watershed; however, they are better regulated through existing TMDLs than typically diffuse non-point sources (Han et al., 2021). The average loading rates for nitrogen and phosphorus used in the NDR model were adopted from values used in the CBP Phase 6 Watershed Model. These average rates (over years 1990-2014) are based on a swath of modeling approaches and are “land-based loads,” meaning that effects from livestock feeding areas, septic, wastewater, and specific BMPs have been removed (Chesapeake Bay Program, 2020). For example, the reference load for cropland in the CBW is approximately 40 kg/ha/yr; the load from a feedlot may be up to 3,000 kg/ha/yr, two orders of magnitude greater.

Although average loading rates of nitrogen and phosphorus fit the scope of needs for this project, one issue is translating these land use-based rates to the land use categories in the 2016 NLCD. A one-to-one translation of these loads is also not possible for the 2013 Phase 6 Mapped Land Uses dataset that is specific to the Chesapeake Bay Watershed. The NLCD was chosen simply for congruence with other non-nutrient based analyses in this study. Total export of nitrogen and phosphorus estimated via the NDR model are substantially lower than edge of stream (EOS) estimations in the Phase 6 model for the HUC 8 watersheds. This is likely due to removed effects, upstream effects not considered in the study area, and sensitivity of the InVEST parameters.

Limitations inherent to the modeled land use change scenarios include the threshold used to classify additional development in the NLCD, which was based on averaging multiple iterations of the Chesapeake Bay Land Change Model’ Current Zoning Vulnerability (“4: Moderate - High Vulnerability to Development” to “6: Very High Vulnerability to Development”). The forest and agricultural change scenarios may not reflect realistically convertible land cover at a fine spatial scale and should be viewed as a general strategy for conservation and/or restoration rather than a precision planning tool. Overall change in nutrient export and retention for various scenarios should be interpreted relative to the baseline scenario created with

InVEST. Further monetary valuation from these scenarios should exercise caution given model sensitivities and limited calibration to monitoring data.

Limitations of Ecosystem Service Valuation

The central limitation inherent to the estimation of change in ecosystem service value is the suitability of the land use value. The dollar value per acre per year is adjusted based on the number generated by calculations from a study in Delaware in 2010, which used an earlier dataset from 2004. In our case study, we used the same consumption as the Delaware study assuming the annual 3% discount rate, which does not consist of the actual change in value, but better for analysis on a common decision. The region difference and the actual change in ecosystem service value causes the imprecise estimation of the ecosystem service value, but the estimation made in our case study is enough for providing a general impression of geospatial trends in ecosystem service value based on historical trends.

4.3 Suggested Extensions and Applications

Over 40 million acres of land remain unprotected in the Chesapeake Bay Watershed. With the emerging regional and national objectives of conserving an additional 3.1 million acres by 2030 and another 8.2 million by 2050, determining where conservation should occur within this 40 million acres is an increasingly relevant and pressing planning challenge. In quantifying the many specific services and benefits conserved lands provide, this case study presents a methodology for planning and enacting the 30% by 2030 conservation vision in the larger Chesapeake Bay Watershed.

Our analysis has highlighted the importance of conserving unprotected coastal lands on both the eastern and western shores of the Bay, as these regions provide a diverse set of co-benefits and will only become more important to local communities and ecosystem function as the climate changes.

Future Directions

Future analyses could incorporate the restoration potential of lands when assigning scores for conservation criteria and co-benefits. Likewise, future study could combine the data layers generated in this project with layers of restoration potential or higher precision land cover data to prioritize conservation based on restoration potential. These layers of restoration potential already exist from several sources including a “Conservation and Restoration Composite" published by the Chesapeake Bay Program, and Wetland and Stormwater Restoration scores published by the Watershed Resource Registry for Pennsylvania and Maryland (Thompson, 2017; Water Resource Registry, 2021).

This analysis could include the analysis of the cost in conservation planning and BMP implementation and maintenance in future conservation. For further understanding of the economics suitability of different regions to achieve the conservation goal, future analyses should combine the cost of different conservation plans with the estimation of change in ecosystem service value to generate the rate of returns of different conservation strategies. The cost and benefits also vary between states and regions due to geographic characteristics and development patterns, local case study will better present the detailed economic benefits and the cost-efficiency of the conservation plans in that region.

4.4 Conclusion

Land conservation efforts have the opportunity to yield vast environmental, social, and economic benefits. Despite the limitations described above, we recommend further investigation of conservation opportunities in the regions highlighted by our analysis. These areas show co-benefits across four, five, or six of the criteria considered: biodiversity and habitat connectivity, development vulnerability, human access to open space, benefits to underserved communities, flood mitigation, and nutrient retention. Our geospatial analyses demonstrate opportunities for key ecological and economic benefits with conservation and restoration efforts. Specifically, the Chester-Sassafras and Patuxent Watersheds have notable co-benefits projected to increase in economic value from 2016 to 2025. The Lower Susquehanna watershed contains multiple, smaller co-benefit hotspots projected to decrease in economic value, making restoration a critical component of conservation strategies in this area.

Protecting the approximately 365,000 acres of co-benefit priority lands highlighted in our study area can contribute to the conservation of the 3.1 million acres needed to meet the 30 by 30 goal throughout the Chesapeake Bay Watershed. Further, focusing land protection on parcels that provide co-benefits is an opportunity to maximize and communicate the long-term benefits and monetary value from conservation actions. At a smaller scope, in four of the five HUC 8 watersheds we analyzed, protecting some or all of the co-benefit priority parcels would achieve 30 by 30 in these individual watersheds. In the Gunpowder-Patapsco Watershed, only 3,629 acres are needed to reach 30 by 30; we identified almost 50,000 acres of unprotected land as co-benefit priorities in this watershed alone. This analysis could be expanded to highlight similar areas across the entire Chesapeake Bay Watershed, beyond our study area.

The Chesapeake Conservancy and its regional partners are translating the global goals of 30 by 30 and 50 by 50 to the local scale. While our specific recommendations are for our study area, they provide a blueprint for how to implement these ambitious conservation goals in the larger Chesapeake Bay Watershed. The current political momentum behind 30 by 30 supports this mission. By considering and quantifying key ecosystem services, decision makers and community partners can provide defensible evidence for land protection goals. We hope that our analysis can contribute tools and resources toward reaching the goals for 30% land conserved by 2030 and 50% by 2050 across our study area, the Chesapeake Bay Watershed, and the planet as a whole.

REFERENCES

Ator, S.W., and Denver, J.M. (2015). Understanding nutrients in the Chesapeake Bay watershed and implications for management and restoration—The Eastern Shore (ver. 1.2, June 2015): U.S. Geological Survey Circular 1406, 72 p., https://dx.doi.org/10.3133/cir1406.

Bagstad, K. J., Semmens, D. J., Waage, S., Winthrop, R. (2013). A comparative assessment of decision-support tools for ecosystem services quantification and valuation. *Ecosystem Services*, *5*, 27–39. https://doi.org/10.1016/j.ecoser.2013.07.004

Beecher, J. A. (1996). Avoided Cost: An Essential Concept for Integrated Resource Planning. https://core.ac.uk/download/pdf/60536417.pdf

BenDor, T. K., Branham, J., Timmerman, D., & Madsen, B. (2021). Predicting the Existence and Prevalence of the US Water Quality Trading Markets. Water, 13(2), 185. MDPI AG. Retrieved from http://dx.doi.org/10.3390/w13020185

Boone, C.G., Buckley, G.L., Grove, J.M., Sister, C. (2009). Parks and People: An Environmental Justice Inquiry in Baltimore, Maryland. *Annals of the Association of American Geographers*, 99:4, 767-787.

Brune, Michael. 22 July 2020. "Pulling Down Our Monuments." Sierra Club, https://www.sierraclub.org/michael-brune/2020/07/john-muir-early-history-sierra-club, accessed April 7, 2021.

CBLCM. (2020). "Chesapeake Bay Land Change Model Current Zoning Vulnerability." https://data-chesbay.opendata.arcgis.com/datasets/chesapeake-bay-land-change-model-current-zoning-vulnerability, accessed December 3, 2020.

Center for Disease Control (CDC). 31 Jan. 2020. "CDC SVI 2018 Documentation - 1/31/2020." https://svi.cdc.gov/Documents/Data/2018_SVI_Data/SVI2018Documentation.pdf, accessed Feb 29, 2021.

Chesapeake Bay Foundation. (2021). "2020 State of The Bay Report." https://www.cbf.org/document-library/cbf-reports/2020-state-of-the-bay-report.pdf

Chesapeake Bay Program. (n.d.). Population Growth. https://www.chesapeakebay.net/issues/population_growth, accessed April 23, 2021.

Chesapeake Bay Program. (2021). Wetlands. https://www.chesapeakebay.net/issues/wetlands#:~:text=Tidal%20wetlands%20are%20found%20along,the%20wetlands%20in%20the%20watershed, accessed April 23, 2021..

Chesapeake Conservation Partnership (CCP). (2019) "Marking Milestones: Progress in Conserving Land in the Chesapeake Bay Watershed." https://www.chesapeakeconservation.org/wp-content/uploads/2019/08/CCP_publication_SD_FD-R-FINAL.pdf, accessed September 25, 2020.

Claggett, P.R., Jantz, C., Goetz, S.J., Bisland, C. (2004). Assessing Development Pressure in the Chesapeake Bay Watershed: An Evaluation of Two Land-Use Change Models. *PubMed: Environmental Monitoring and Assessment*, 94 (1-3), pp. 129-146.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387, pp. 253-260.

Davis, F., Costello, C., & Stoms, D. (2006). Efficient Conservation in a Utility-Maximization Framework. *Ecology and Society, 11*(1). Retrieved March 22, 2021, from http://www.jstor.org/stable/26267791

Dinerstein, E., Vynne, C., Sala, E., Joshi, A.R., Fernando, S., Lovejoy, T.E., Mayorga, J., Olson, D., Asner, G.P., Baillie, J.E.M., Burgess, N.D., Burkart, K., Noss, R.F., Zhang, Y.P., Baccini, A., Birch, T., Hahn, N., Joppa, L.N., Wikramanayake, E. (2019). A Global Deal For Nature: Guiding principles, milestones, and targets. *Science Advances*, 5 : eaaw2869.

Dirzo, R., Young, H.S., Galetti, M., Ceballos, G., Isaac, N.J.B., Collen, B. (2014). Defaunation in the Anthropocene. *Science*, 345 (6195), pp. 401-406.

Egoh, B., Reyers, B., Rouget, M., Richardson, D. M., Le Maitre, D. C., & van Jaarsveld, A. S. (2008). Mapping ecosystem services for planning and management. Agriculture, Ecosystems & Environment, 127(1), 135–140. https://doi.org/10.1016/j.agee.2008.03.013

Egoh, Benis, Belinda Reyers, Mathieu Rouget, David M. Richardson, David C. Le Maitre, and Albert S. van Jaarsveld. (2008). "Mapping Ecosystem Services for Planning and Management." *Agriculture, Ecosystems & Environment* 127, no. 1: 135–40. https://doi.org/10.1016/j.agee.2008.03.013.

EJSCREEN. (2016) "How was EJSCREEN Developed?" United States Environmental Protection Agency. https://www.epa.gov/ejscreen/how-was-ejscreen-developed, accessed April 14, 2021.

EJSCREEN. (2020) "EPA's Environmental Justice Screening and Mapping Tool (Version 2020)." United States Environmental Protection Agency. https://ejscreen.epa.gov/mapper/, accessed March 21, 2021.

EJSCREEN. (2021) "Overview of Demographic Indicators in EJSCREEN." United States Environmental Protection Agency. https://www.epa.gov/ejscreen/overview-demographic-indicators-ejscreen, accessed March 21, 2021.

Elliot, Jessica. (2020). "Land Conservation and the Community Rating System: Mapping Open Space Preservation Opportunities in Maryland Communities". *Chesapeake Conservation Partnership & the Chesapeake Conservancy.*

Fan, H., Zipf, A. Fu, Q., Neis, P. (2014). Quality assessment for building footprints data on OpenStreetMap. *International Journal of Geographical Information Science.* 28. 700-719. 10.1080/13658816.2013.867495.

Federal Emergency Management Agency (FEMA). "Hazus 4.2 Flood User Manual." Accessed Online January 5, 2021. https://www.fema.gov/sites/default/files/2020-09/fema_hazus_flood-model_user-manual_2.1.pdf

Felipe-Lucia, María, Francisco Comín, and Elena Bennett. (2014) "Interactions Among Ecosystem Services Across Land Uses in a Floodplain Agroecosystem." *Ecology and Society* 19, no. 1. https://doi.org/10.5751/ES-06249-190120.

Fohrer, N., Haverkamp, S., Frede, H.G. (2005). Assessment of the effects of land use patterns on hydrologic landscape functions: Development of sustainable land use concepts for low mountain range areas. Hydrological Processes, 19(3), 659–672. https://doi.org/10.1002/hyp.5623.

Geneletti, D. (2003). A GIS-based decision support system to identify nature conservation priorities in an alpine valley. *Elsevier*, https://doi.org/10.1016/j.landusepol.2003.09.005.

Greater Baltimore Resilience Coalition (GBRC). (2016)."Greater Baltimore Wilderness Coalition: Mapping Resiliency." *Resiliency Maps : GBWC Resiliency Groundtruthing Application*, http://resiliency.cicapps.org/coastal-resiliency/resiliency-maps/, accessed Sept 30, 2020.

Green Infrastructure Center Inc., United States Forest Service (USFS). (2019). "Trees to Offset Stormwater: A Study of 12 Communities". http://www.gicinc.org/PDFs/TreesStormwaterSummaryReportJune2019.pdf, accessed Jan 6, 2021

Han, B., Reidy, A., Li, A. (2021). Modeling nutrient release with compiled data in a typical Midwest watershed. Ecological Indicators, 121, 107213. https://doi.org/10.1016/j.ecolind.2020.107213.

Harris, I., Osborn, T. J., Jones, P., Lister, D. (2020). Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. Scientific Data, 7(1), 109. https://doi.org/10.1038/s41597-020-0453-3.

Hogan, D.M. (2008). Management of urban stormwater runoff in the Chesapeake Bay watershed: U.S. Geological Survey Fact Sheet 2008–3101, 3 p., available online at https://pubs.usgs.gov/fs/2008/3101.

Hopkins, K. G., Noe, G. B., Franco, F., Pindilli, E. J., Gordon, S., Metes, M. J., Claggett, P. R., Gellis, A. C., Hupp, C. R., Hogan, D. M. (2018). A method to quantify and value floodplain sediment and nutrient retention ecosystem services. Journal of Environmental Management, 220, 65–76. https://doi.org/10.1016/j.jenvman.2018.05.013.

Jennings, V. and Gaither, C. J. (2015). Approaching environmental health disparities and green spaces: an ecosystem services perspective. *International journal of environmental research and public health*, *12*(2), 1952-1968.

Kadaverugu, A., Nageshwar Rao, C. Viswanadh, G.K. (2021). Quantification of flood mitigation services by urban green spaces using InVEST model: a case study of Hyderabad city, India. Model. Earth Syst. Environ. 7, 589–602. https://doi.org/10.1007/s40808-020-00937-0.

Kauffman, G. J. (2011). Economic Value of the Delaware Estuary Watershed COMPREHENSIVE REPORT (pp. 1-78, Rep.). Delaware: University of Delaware.

Krikstan, Catherine. 4 Aug 2014. "East Coast to experience more 'nuisance floods' as sea levels rise." Chesapeake Bay Program https://www.chesapeakebay.net/news/blog/east_coast_to_experience_more_nuisance_floods_as_sea_levels_rise.

Layer: Historic Trends Scenario, 2025 (ID: 14). (n.d.). Retrieved February 21, 2021, from https://gis.chesapeakebay.net/ags/rest/services/LandUseDataViewer/Watershed/MapServer/14.

Lee, C. (2021). Confronting Disproportionate Impacts and Systemic Racism in Environmental Policy. *Environmental Law Reporter*, 51-ELR 10207.

Li, M., Zhang, F., Barnes, S., Wang, X. (2020). Assessing storm surge impacts on coastal inundation due to climate change: case studies of Baltimore and Dorchester County in Maryland. *Nat Hazards* 103, 2561–2588. https://doi.org/10.1007/s11069-020-04096-4.

Liu, Y., Bi., J., Lv, J., Ma, Z., Wang, C. (2017) "Spatial Multi-Scale Relationships of Ecosystem Services: A Case Study Using a Geostatistical Methodology." *Scientific Reports* 7, no. 1: 9486. https://doi.org/10.1038/s41598-017-09863-1.

Maryland Department of the Environment. (n.d.). Pollution in the Bay. Retrieved April 18, 2021, from https://mde.maryland.gov/programs/Water/TMDL/TMDLImplementation/Pages/pollution-in-the-chesapeake.aspx#excess_nutrients.

Mears, M. and Brindley, P. (2019). Measuring Urban Greenspace Distribution Equity: The Importance of Appropriate Methodological Approaches. *ISPRS Int. J. Geo-Inf. Vol. 8*, 286.

Najjar, R., C. Pyke, M.B. Adams, D. Breitburg, C. Hershner, M. Kemp, R. Howarth, M. Mulholland, M. Paolisso, D. Secor, K. Sellner, D.Wardrop, and R. Wood. (2010). Potential climate-change impacts on the Chesapeake Bay. Estuarine, Coastal, and Shelf Science, 86:1-20. https://doi.org/10.1016/j.ecss.2009.09.026.

Natural Capital Project (2021). Urban Flood Risk Mitigation Model User Guide. Accessed online November 2020. https://invest-userguide.readthedocs.io/en/latest/urban_flood_mitigation.html#equation-runoff

Paolisso, M., Trombley, J., Hood, R.R., Sellner, K.G. (2015). Environmental Models and Public Stakeholders in the Chesapeake Bay Watershed. *Estuaries and Coasts* 38, 97–113. https://doi.org/10.1007/s12237-013-9650-z

Phillips, S., McGee, B. (2014). The Economic Benefits of Cleaning Up the Chesapeake. A Valuation of the Natural Benefits Gained by Implementing the Chesapeake Clean Water Blueprint (pp. 1-44, Rep.). KEY-LOG Economics LLC, Chesapeake Bay Foundation.. https://conservationtools-production.s3.amazonaws.com/library_item_files/1328/1219/FINALBenefitsOfTheBlueprint_TechReport_and_Summary20141002.pdf

Pimm, S.L., Jenkins, C.N., Li, B.V. (2018). How to protect half of Earth to ensure it protects sufficient biodiversity. *Science Advances*, 4 : eeat2616.

Plumer, B. and Popovich, N. 24 Aug 2020. "How Decades of Racist Housing Policy Left Neighborhoods Sweltering." *The New York Times*, www.nytimes.com/interactive/2020/08/24/climate/racism-redlining-cities-global-warming.html.

Poon, Linda. 24 May 2019. “In a Town Shaped by Water, the River Is Winning”. Bloomberg CityLab. https://www.bloomberg.com/news/articles/2019-05-24/a-historic-river-town-confronts-a-flooded-future, accessed Feb 2021.

Qiu, J. and Turner, M.G. (2013) “Spatial Interactions among Ecosystem Services in an Urbanizing Agricultural Watershed.” *Proceedings of the National Academy of Sciences* 110, no. 29: 12149–54. https://doi.org/10.1073/pnas.1310539110.

Rae, D.W. (2003). *City: Urbanism and its End.* Yale University Press, New Haven, CT.

Redhead, J.W., Stratford, C., Sharps, K., Jones, L., Ziv, G., Clarke, D., Oliver, T.H., Bullock, J.M. (2016). Empirical validation of the InVEST water yield ecosystem service model at a national scale, *Science of The Total Environment*, Volumes 569–570, Pages 1418-1426, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2016.06.227.

Reitz, M. and Sanford, W. E. (2019). Estimating quick-flow runoff at the monthly timescale for the conterminous United States. Journal of Hydrology, 573, 841–854. https://doi.org/10.1016/j.jhydrol.2019.04.010

Schwartz, A. and Kocian, M. (2014). Beyond Food: The Environmental Benefits of Agriculture in Lancaster County, Pennsylvania. Earth Economics, Tacoma, WA.

Sharp, R., Douglass, J., Wolny, S., Arkema, K., Bernhardt, J., Bierbower, W., Chaumont, N., Denu, D., Fisher, D., Glowinski, K., Griffin, R., Guannel, G., Guerry, A., Johnson, J., Hamel, P., Kennedy, C., Kim, C.K., Lacayo, M., Lonsdorf, E., Mandle, L., Rogers, L., Silver, J., Toft, J., Verutes, G., Vogl, A. L., Wood, S, Wyatt, K. (2020). InVEST 3.8.9 User’s Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

Snyder, J. P. (1982). *Map projections used by the US Geological Survey* (No. 1532). US Government Printing Office. https://pubs.usgs.gov/bul/1532/report.pdf.

Sterner, G. E., Bryant, R., Kleinman, P. J., Watson, J., & Alter, T. R. (2015). Community implementation dynamics: Nutrient management in the New York City and Chesapeake Bay Watersheds. *International Journal of Rural Law and Policy*, (1), 1-15.

Teodoro, Jose D.; Nairn, Bruce. (2020). "Understanding the Knowledge and Data Landscape of Climate Change Impacts and Adaptation in the Chesapeake Bay Region: A Systematic Review." *Climate* 8, no. 4: 58.

The White House. 27 Jan 2021. Briefing Room Statements and Releases. “FACT SHEET: President Biden Takes Executive Actions to Tackle the Climate Crisis at Home and Abroad, Create Jobs, and Restore Scientific Integrity Across Federal Government.”

Thompson, Renee (2017). “Conservation and Restoration Wetlands Composite, Chesapeake Bay Watershed”. Chesapeake Bay Program, Habitat Goal Implementation Team. Data published on Data Basin, Conservation Biology Institute. https://databasin.org/datasets/dd1b2ed11c774d55b05b0324d31c066c/.

United States Department of Agriculture, Natural Resources Conservation Service (USDA, NRCS). (1986). “Urban Hydrology for Small Watersheds”. *Technical Release 55.* https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

United States Department of Agriculture. (2018). Natural Resources Conservation Service Chesapeake bay Watershed Action Plan. https://www.nrcs.usda.gov/Internet/FSE_MEDIA/nrcseprd1415210.pdf

USDA NRCS. (2011). Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Chesapeake Bay Region. Conservation Effects Assessment Project (CEAP). https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcsdev11_023934.pdf.

USDA NRCS. (2018). Chesapeake Bay Watershed Action Plan. National Resources Conservation Service. https://www.nrcs.usda.gov/Internet/FSE_MEDIA/nrcseprd1415210.pdf.

US Environmental Protection Agency (EPA). (2016). Chesapeake Bay TMDL Fact Sheet. https://www.epa.gov/sites/production/files/2015-07/documents/bay_tmdl_fact_sheet.pdf.

US EPA. (2013). Addressing Nutrient Pollution in the Chesapeake Bay [Overviews and Factsheets]. US EPA. https://www.epa.gov/nutrient-policy-data/addressing-nutrient-pollution-chesapeake-bay.

Van Houtan, K.S., Northcott, M.S. (2010). Nature and the Nation-state: Ambivalence, Evil, and American Environmentalism. – in Van Houtan, K.S. and Northcott M.S. (eds), *Diversity and Dominion: Dialogues in Ecology, Ethics, and Theology.* Cascade Books, pp. 138-156.

Villa, C., Ahmad, N., Bratspies, R., Lin, R., Rechtsaffen, C., Gauna, E., O'Neill, C. (2020). *Environmental Justice: Law, Policy & Regulation - Third Edition.* Carolina Academic Press, LLC., Durham, NC.

Warnell, Katie. (2019). "Mapping Ecosystem Services for the Southeast United States: Conservation Priorities for Open Space Recreation Access." NI MB 19-03. Nicholas Institute for Environmental Policy Solutions, Duke University.

Water Resources Registry. (2021). EPA Region 3 Water Protection Division. https://watershedresourcesregistry.org/

Watson, J.E.M., Dudley, N., Segan, D.B., Hockings, M. (2014). The performance and potential of protected areas. *Nature*, 515, pp. 67-72.

World Bank. (2017). "Implementing nature-based flood protection: Principles and implementation guidance." https://www.gfdrr.org/en/publication/implementing-nature-based-flood-protection

Wright, D. B., Bosma, C. D., Lopez-Cantu, T. (2019). U.S. hydrologic design standards insufficient due to large increases in frequency of rainfall extremes. *Geophysical Research Letters*, 46, 8144– 8153. https://doi.org/10.1029/2019GL083235

Yuan, Y., Liu, J., Liu, H., Tan, L. (2012). Spatial-temporal variation of ecosystem services in response to land use changes: Case study in the 38°N ecological transect of Northern China. Journal of Food, Agriculture and Environment. 10. 794-802.

APPENDIX

Appendix A: Study Area & Parcel Data

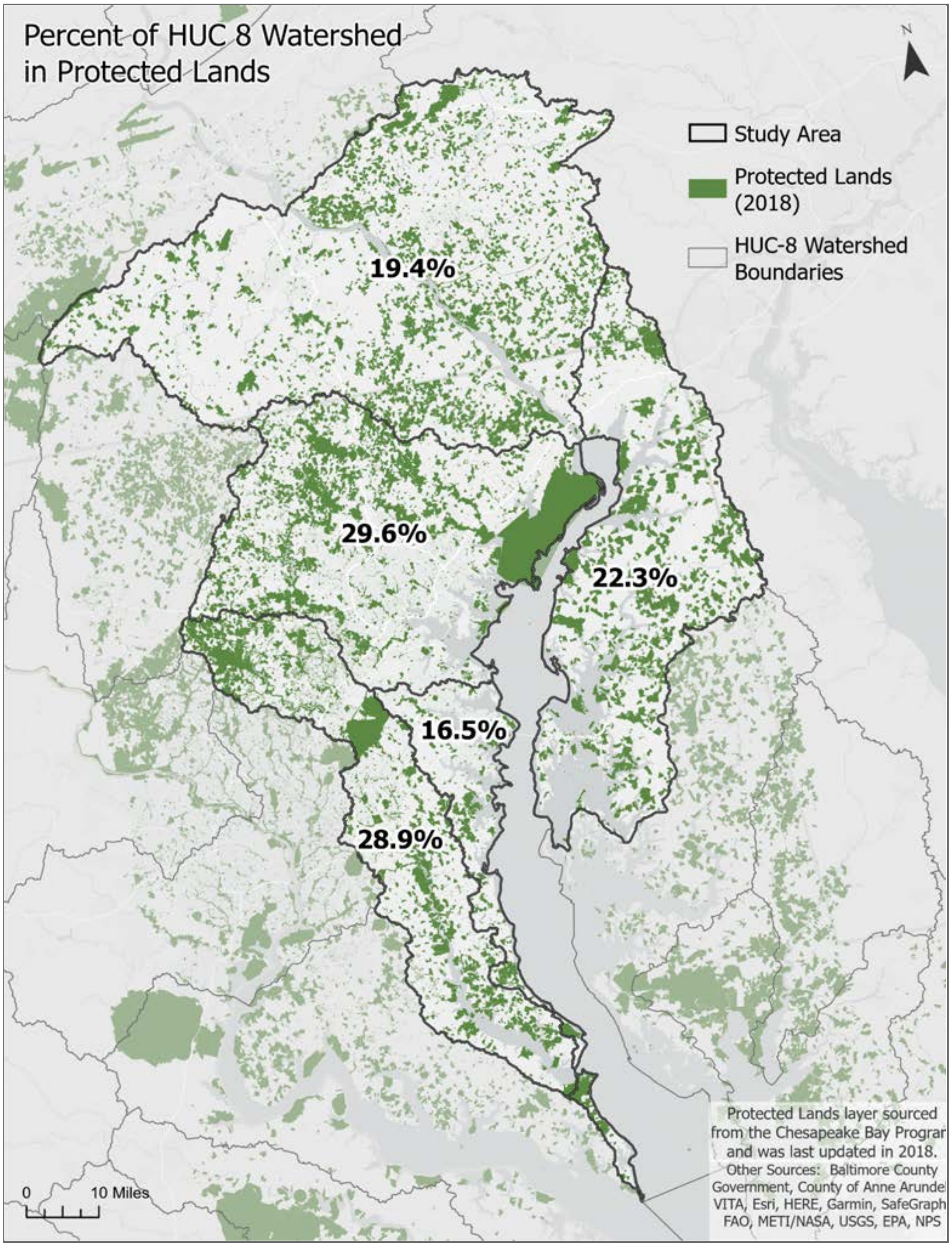


Figure A1. Summary protected lands in the focal area for analysis. Protected lands include state, federal, local protected lands, as well as private lands in farm and conservation easements, as of 2018.

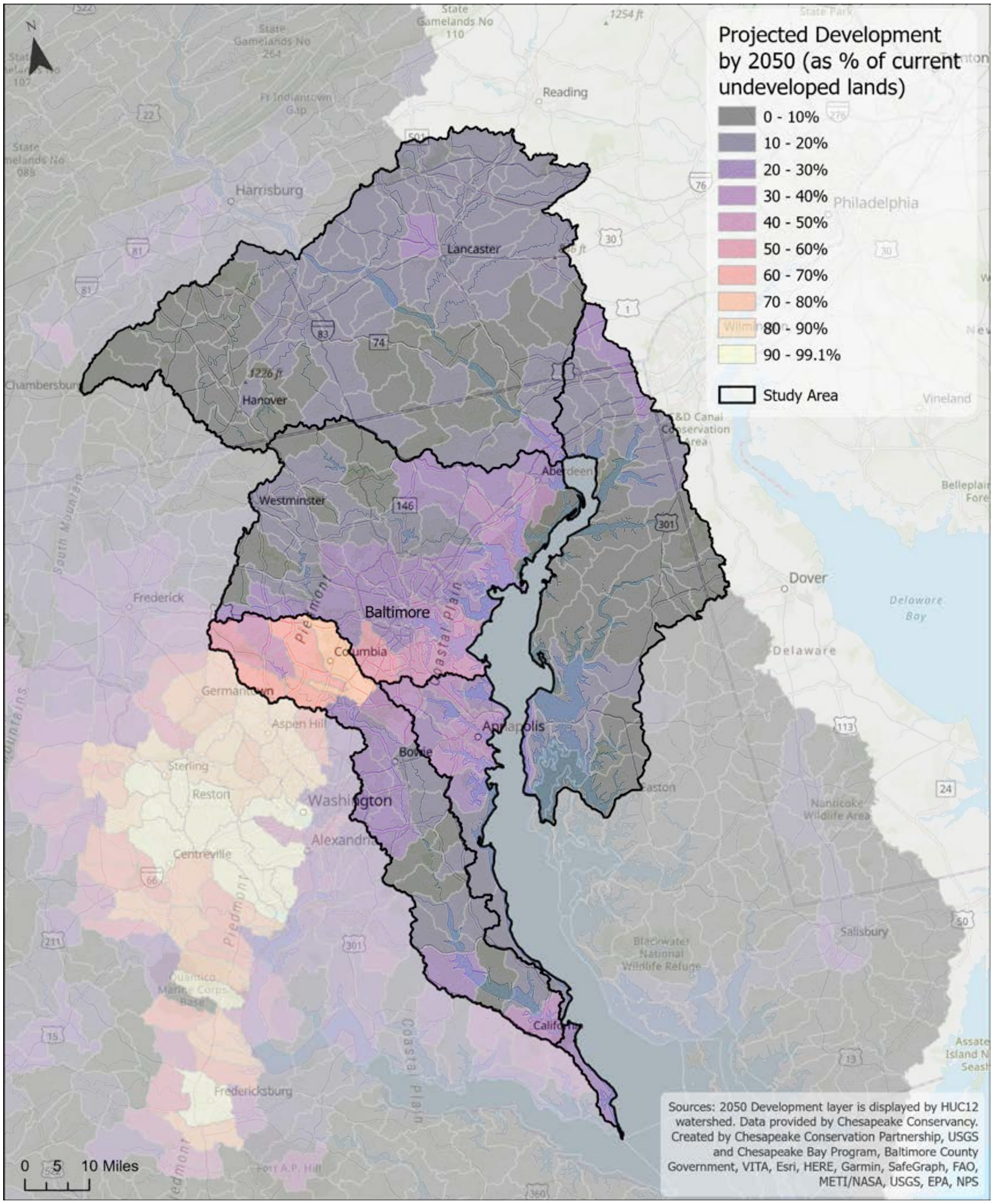


Figure A2. Summary of projected development trends in the study area. Development is projected as a percent of current undeveloped lands for 2050 at HUC-12 watershed scale. Data layer was created by the Chesapeake Conservation Partnership and provided by the Chesapeake Conservancy.

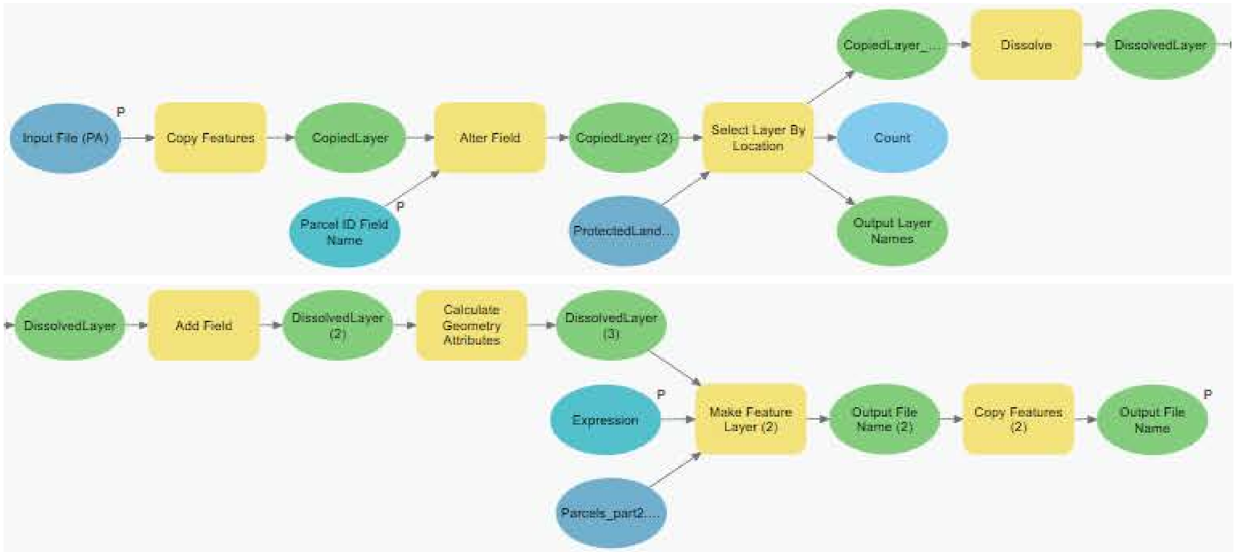


Figure A3. One of the ArcGIS Pro Models used to isolate parcels of interest and complete new fields for county data layers within our study area. These tools can be opened and adjusted as needed, to accommodate different counties' formats. Overall steps for all counties are described below.

Of the 25 counties in our study area, several parcel data layers were publicly accessible, and others required individual county requests. Once all counties within the study area were obtained, the data layers were each clipped to the study area and simplified to include solely four characteristics: parcel ID, acres, county, state. They were filtered to solely include parcels over 10 acres in size. These clipped layers were merged to create one shapefile with all parcels in the study area. This layer was then trimmed to remove parcels where the land is already under protection, such as conservation easements and established parks. This was defined by parcels having centerpoints in the 2018 protected lands data layer provided by the Chesapeake Bay Program (ProtectedLands_2018_All.shp).

In some counties, parcel ID was not a unique identifier due to subdivisions or bi-sections by another feature such as a road or highway. The result is that one parcel may be represented by two or more polygon features with the same parcel ID. In order to ensure parcel ID was a unique feature identifier in analyses, parcel polygons were dissolved by parcel ID, so that each parcel was represented by a single polygon feature. A new area field (in acres) was calculated in GIS for this dissolved parcel dataset. Thus, the parcel acreage used in the team's analysis was calculated within GIS, and is not the acreage reported by individual counties in their raw parcel data.

Appendix B: Biodiversity and Habitat Connectivity

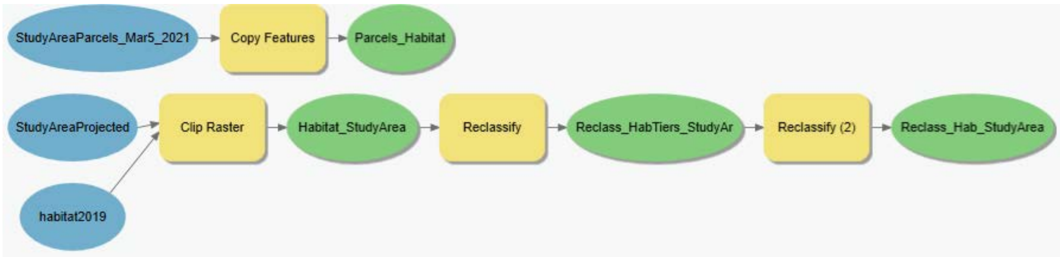


Figure B1. The ArcGIS Pro Model used for data preparation regarding biodiversity and habitat connectivity data.

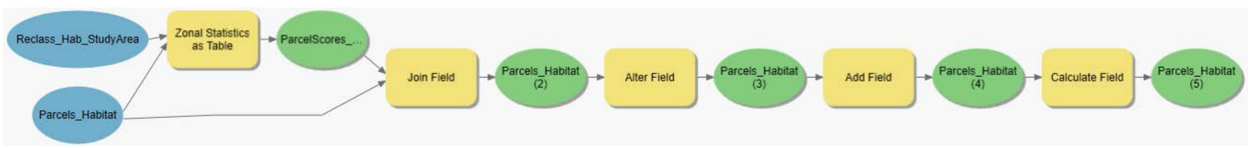


Figure B2. The ArcGIS Pro Model used to assign biodiversity and habitat connectivity scores to each parcel.

Appendix C: Development Vulnerability

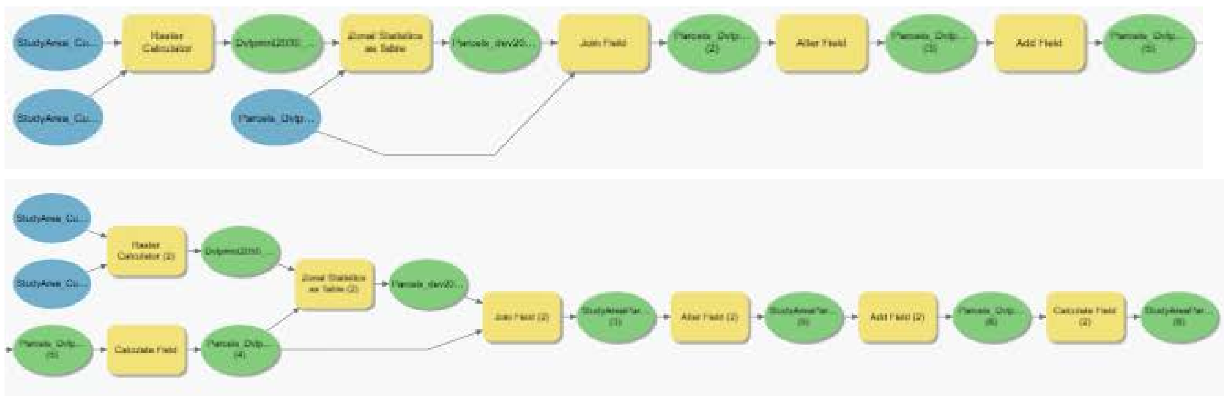


Figure C1. The ArcGIS Pro Model used to assign development vulnerability scores to each parcel, for both 2030 and 2050 projected development.

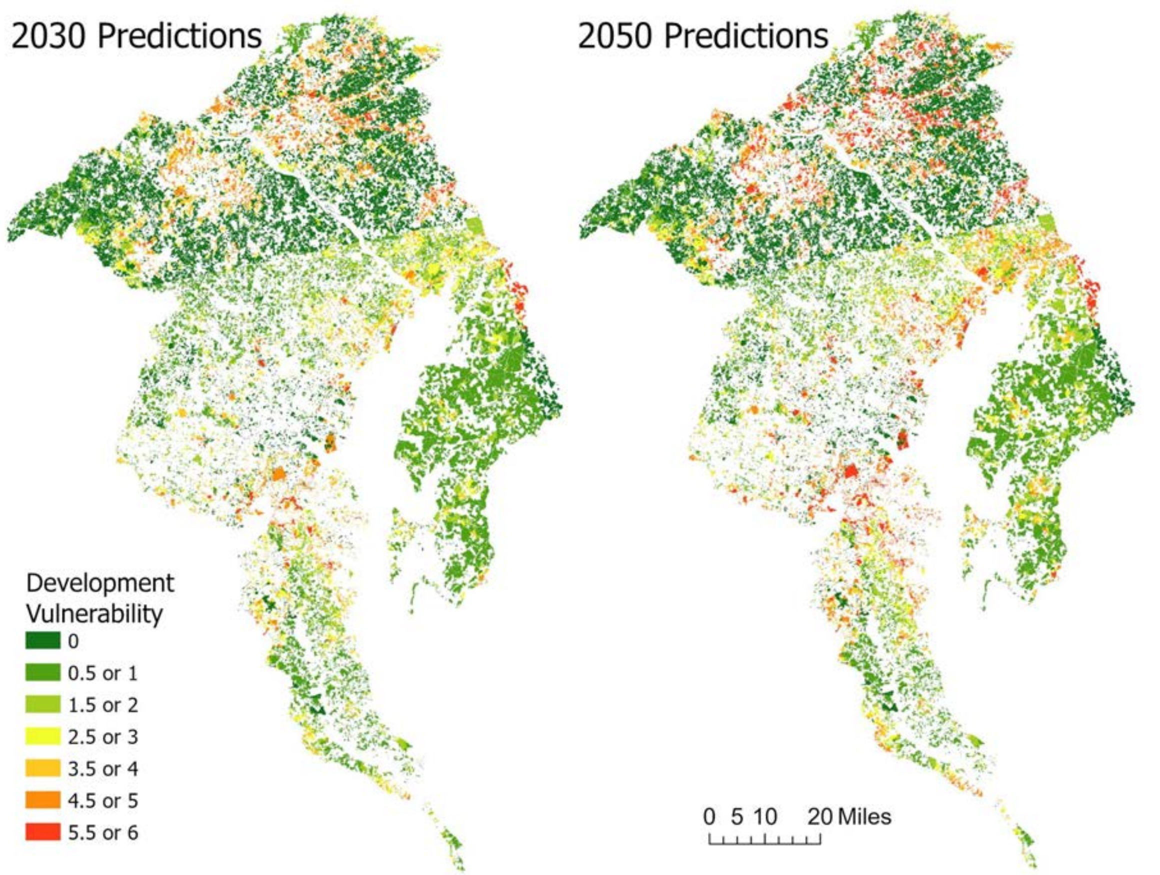


Figure C2. The 2030 development vulnerability predictions adjacent to the 2050 predictions. Our analysis incorporated the 2030 predictions for recommendations toward conserving 30% of the watershed by 2030. Regarding efforts for conserving 50% by 2050, the 2050 predictions would be better fitting. The 2030 development predictions and 2050 development predictions show similar regional trends with different intensities.

Appendix D: Human Access to Open Spaces

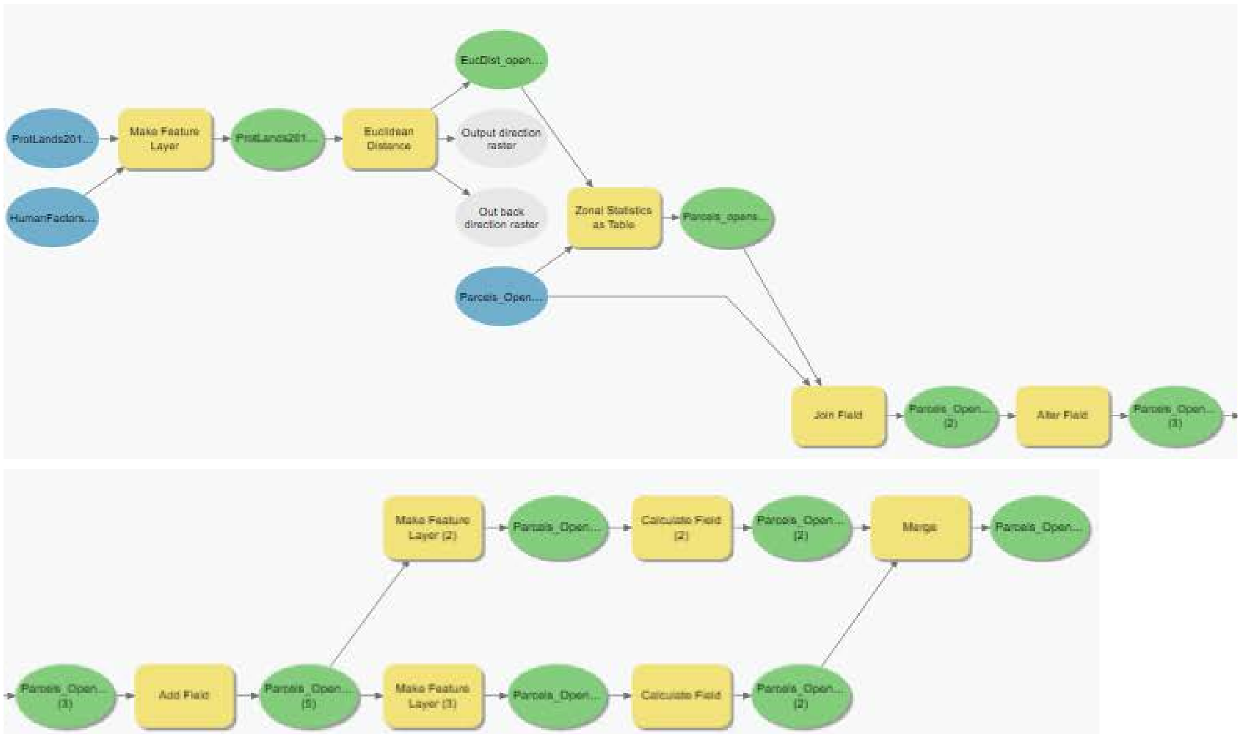


Figure D1. The ArcGIS Pro Model used to assign parcel scores for human access to open spaces.

Appendix E: Benefits to Underserved Communities

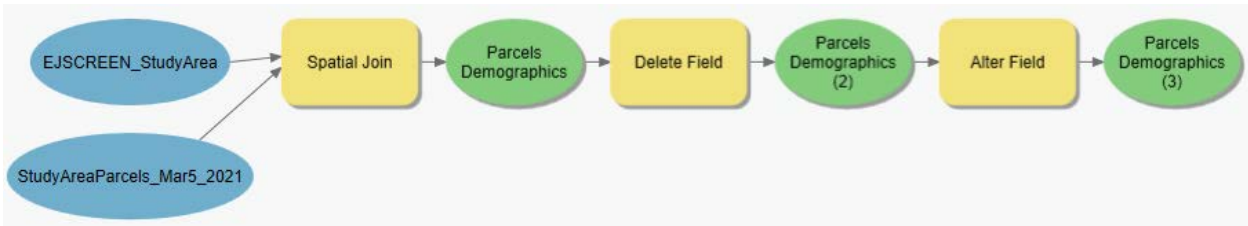


Figure E1. The ArcGIS Pro Model used to assign parcel scores for parcel demographics, incorporating the EPA's EJSCREEN data layer with census block group information.

Appendix F: Flood Risk Analysis

Table F1. Storm Design for InVEST Urban Flood Risk Mitigation Model.

Watershed(s)	Precipitation for 100-yr Storm (inches)	Precipitation for 100-yr Storm, rounded (mm)
Lower Susquehanna	7.5	190
Patuxent, Chester-Sassafras, Gunpowder-Patapsco, Servern	8.5	220

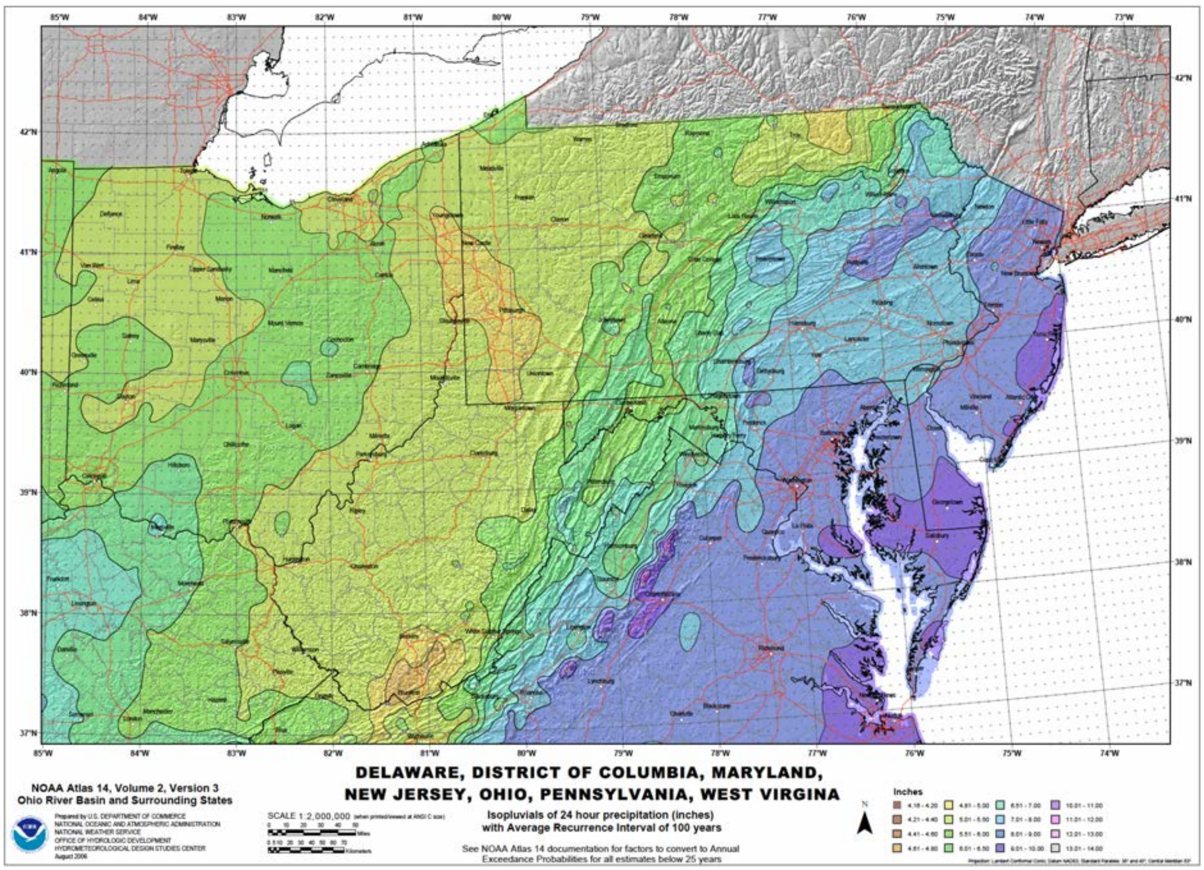


Figure F1. Map of precipitation ranges corresponding to a potential 100-year storm event for eastern region including the Chesapeake Bay Watershed. Source: NOAA Atlas 14.
https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=pa

Data Sources for Flood Analysis

Table F2. List of Data and Sources for Flood Mitigation Analysis and Scoring.

Data Layer	Source(s)	Publicly Available?	Raster or Feature	Analyses Used In	Processing Steps
100-year Floodplains	Pennsylvania Spatial Data Download, Maryland Open Data Portal, FEMA	Public	Feature	Parcel Scoring for Flood Mitigation Services	Clipped to the study area extent Dissolved to single feature
Land Cover	National Land Cover Dataset - Multi-Resolution Landscape Consortium (MRLC)	Public	Raster (30 by 30 meter)	InVEST Model	Clipped to the study area extent "No data" pixel values set to zero
HUC 12 Watershed Boundaries	National Watershed Boundary Dataset - United States Geological Survey (USGS)	Public	Feature	InVEST Model	Clipped to the study area extent
Soil Hydrologic Groups	Soil Survey Geographic Database (SSURGO) - United States Geological Survey (USGS)	Public	Raster (30 by 30 meter)	InVEST Model	Clipped to the study area extent See "Soil Hydrologic Group" below
Soil Drainage Class	Soil Survey Geographic Database (SSURGO) - United States Geological Survey (USGS)	Public	Raster (30 by 30 meter)	Pre-processing Soil Hydrologic Data	None - used to reclassify soil hydrologic groups
Building Footprints	OpenStreetMap	Public	Feature	InVEST	See "FEMA Hazus and OpenStreetMap Data" below
Damage estimates for buildings, in dollars	FEMA Hazus Program	Public	Feature	InVEST	See "FEMA Hazus and OpenStreetMap Data" below

Soil Hydrologic Group

The raw Soil Hydrological Group raster layer from USGS contained seven soil groups: A, B, C, D, A/D, B/D and C/D. Soils with mixed group classifications, such as A/D, are soils where the soil group changes depending on the drainage conditions of the soil. For instance, a soil of A/D group would be considered group A in a drained condition and group D in an undrained condition. The InVEST model requires that soils data have only four group values: A, B, C or D. Thus, soils in the SSURGO dataset with mixed groups had to be reclassified. Using a second SSURGO raster layer of soil drainage class, the team re-classified mixed soil groups to A, B, C, or D, according to soil drainage. If soil drainage class was unknown (null) for a particular area, mixed soil groups were assumed to be undrained and assigned to group D. The result of this cleaning was a 30 by 30 meter resolution raster data layer with four classes: Hydrologic Groups A, B, C, or D (Appendix F, Figure F2). In total, approximately 14% of the soils data had to be reclassified using this method.

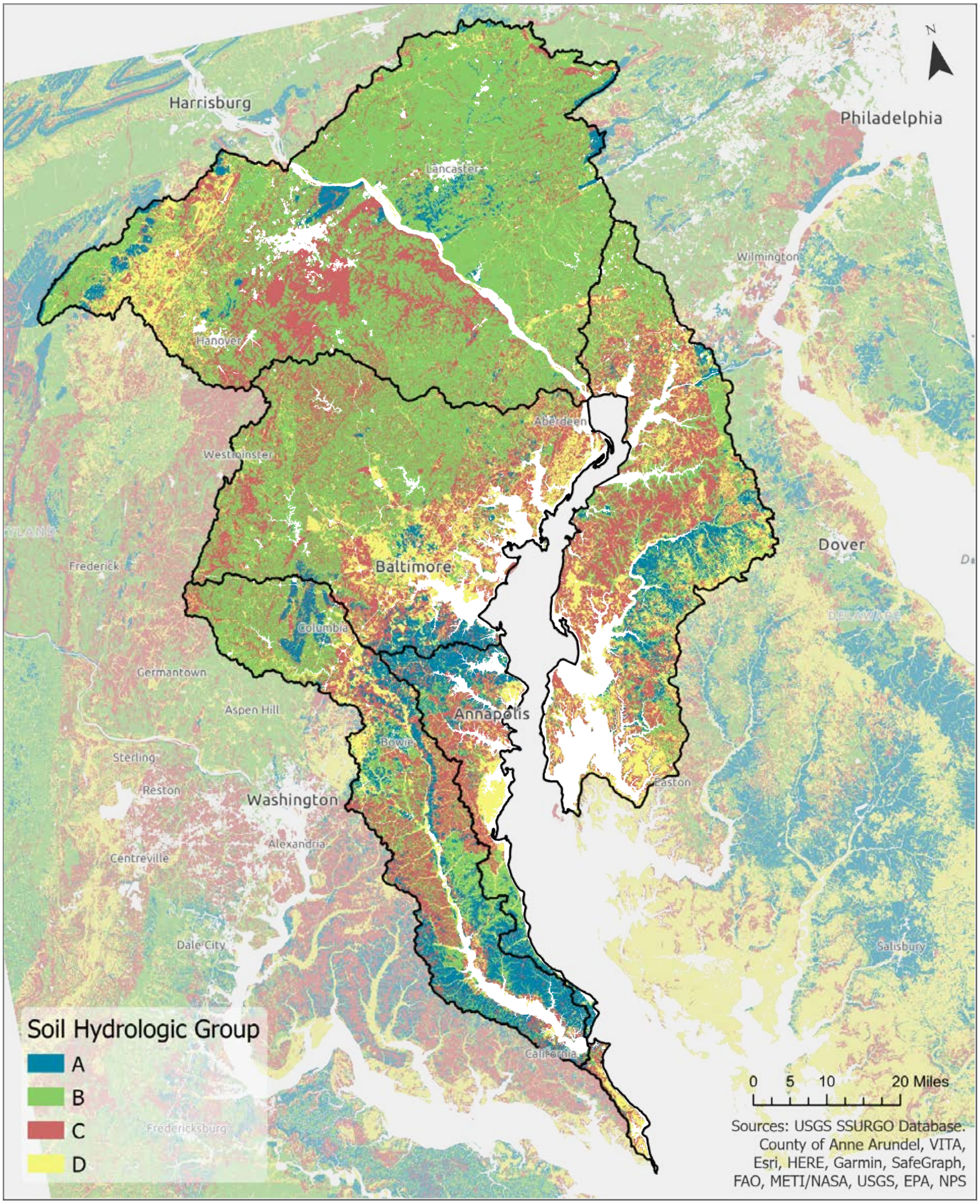


Figure F2. Soil Hydrologic Groups for the study area.

FEMA Hazus and OpenStreetMap Data

Table F3. Hazus classification scheme for census block "types" in the General Building Stock Data. 33 Classed were grouped into a "Final Building Type", and the replacement value for averages across the group.

HAZUS Census Block Occupancy Class	Final Building "Type"	Mean Replacement Value ($/m2)
RES1, RES2, RES3A, RES3B, RES3C, RES3D, RES3E, RES3F, RES4, RES5, RES6	Residential	1715.3
COM1 – COM10	Commercial	1980.5
IND1 – IND6	Industrial	1640.5
AGR1	Agriculture	1291.7
REL1, GOV1, GOV2, EDU1, EDU2 (Religion, Government, Education)	Public and Civic Services	2082.3

Included in Hazus is a General Building Stock (GBS) dataset of census block features with a variety of available attributes containing data on building count and type within a given census block. Building "type" in the GBS data follows a simple classification scheme with the following 7 types: Residential, Commercial, Industrial, Agriculture, Education, Religion and Government. The team grouped Education, Religion, and Government into a single type "Public/Civic Services" to create a 5 type classification scheme. Census blocks in the GBS are daysymetrically adjusted, meaning that areas of the census block layer which are unlikely to contain built structures based on land cover have been removed (Hazus 4.2 Flood Manual User Guidance). However, some census blocks without any buildings remain in the GBS dataset. Using R, the team removed census blocks from the GBS with a total building count of 0 (approximately 29% of the blocks) which were predominantly census blocks located on roads and highways. A "type" was assigned to each census block based on the most numerous building type in the block. For instance, in a census block with 10 residential buildings, 5 commercial and 3 industrial, the block would be assigned the "residential" type. In instances where two types of building "tied" for maximum count (true for 3.2% of census blocks) the block type was randomly selected.

Because InVEST calculates the potential damages in a watershed based on the area of built infrastructure, using the General Building Stock census block data in the InVEST model would have resulted in an unreliable overestimate of potential damages. To address this issue, the team acquired building footprint data from OpenStreetMap using the QuickOSM Plugin for QGIS 3.16. The Spatial Join tool was used in ArcGIS Pro to assign census block types to individual building footprints, based on the location of the footprints centerpoint (Appendix F, Figure F3). The resulting, final, building footprint data was classified by the 5 simple "types" derived from Hazus: Residential, Commercial, Industrial, Agriculture, and Public/Civic Service.

Prior to running the InVEST model, the building footprint data was clipped to include only footprints within 10 meters of 100-year floodplain, inclusive of footprints within the floodplain (Appendix F, Figure F3). Thus, only those buildings most likely to be impacted by a 100 year flood are included in the InVEST calculation of potential damages. The 10 meter buffer used around floodplains for this selection helps account for potential inaccuracies in OpenStreetMap data, which is estimated to have an average positional error of four meters (Fan et al. 2014). In addition to spatial data, FEMA's Hazus Program also provides estimates of the potential replacement value ($/m2). The InVEST model bases its calculation of potential damages within a watershed on these replacement costs by type ($/m2) and the total building footprint area (m2) within a watershed.

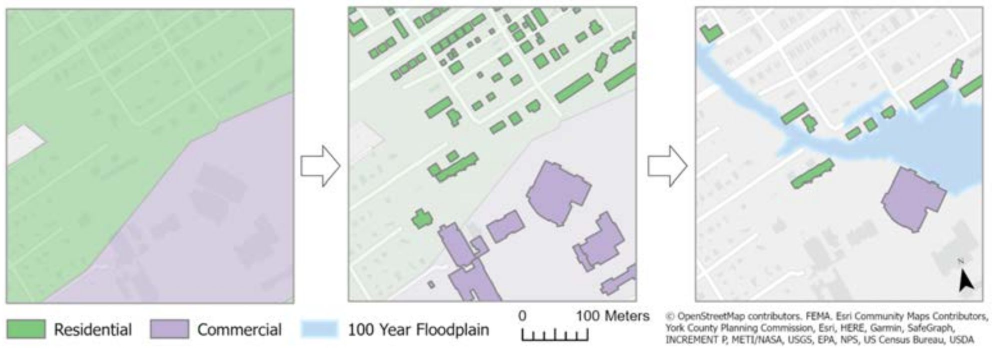


Figure F3. Example of workflow for processing OpenStreetMap building footprint data prior to input in InVEST.

In addition to spatial data, FEMA's Hazus Program also provides estimates of the potential replacement value ($/m^2) for 33 different building occupancy types. Replacement values were averaged across similar building types to correspond to the 5 type building classification scheme described above (Appendix F, Table F3). Building "type" was assigned based on the census block that contained the centerpoint of individual building footprints. Building footprints were then clipped with those within 10 meters of the 100 year floodplain. Note that only two of the five building "type" classes are shown in the example above, which maps several buildings in a southern suburb of York, PA (Figure F3). The InVEST model bases its calculation of potential damages within a watershed on these replacement costs by type ($/m^2) and the total building footprint area (m^2) within a watershed.

Curve Numbers

The InVEST Urban Flood Risk Mitigation model requires the user to set custom curve numbers for the input land cover and soil hydrological group data layers. These curve numbers are entered into the InVEST tool as a .csv table (Table F4). The team assigned curve numbers based on USDA recommended curve numbers for specific land covers, available in two documents: the USDA Technical Release 55 "Urban Hydrology for Small Watersheds" (TR-55) and an update to the TR-55 completed in October 2017 by the American Society of Civil Engineers (ASCE) and the American Society Agricultural and Biological Engineers (ASABE).

Table F4. Curve Numbers for Land Use / Soil Hydrological Group Pairings. Used in InVEST Model.

Land Use Code	Land Use Name	Curve Number: Soil Group A	Curve Number: Soil Group B	Curve Number: Soil Group C	Curve Number: Soil Group D
11	Open Water	99	99	99	99
12	Ice / Snow	99	99	99	99
21	Developed - open space	52	68	78	84
22	Developed Low	81	88	90	93
23	Developed Med	84	89	93	94
24	Developed High	88	92	93	94
31	Barren	70	81	88	92
41	Deciduous	30	55	70	77
42	Evergreen	30	55	70	77
43	Mixed Forest	30	55	70	77
52	Scrub/Shrub	30	42	55	62
71	Grassland/Herb	39	63	75	85
81	Pasture/Hay	40	61	73	79
82	Cultivated Crops	62	74	82	86
90	Woody Wetlands	86	86	86	86
95	Emergent Herbaceous Wetlands	80	80	80	80

Parcel Scoring

We log-transformed two attributes - floodplain area and potential watershed damages - prior to 0-1 scaling. Many parcels did not contain any of the 100-year floodplain area. Likewise, some parcels fell within HUC 12 watersheds that had potential damage estimates of $0, which were typically rural watersheds with insufficient building data. This large number of parcels with values of 0 created a rightward skew in both of these attributes. Without log-transforming these attributes to a semi-normal distribution, the 0-1 score for each would als be heavily right-skewed. (consider inserting plots of distribution before and after log transformation).

Table F5. Input Attributes for Urban Flood Mitigation Parcel Score.

Data	Unit, before scaling	Description	Weight
Average Runoff Retention Index	%	Average derived from 30 x 30 meter raster of percent runoff retained/attenuated (on 0-1 scale)	.6
Potential Damages in HUC 12 from a 100-year storm	$	Parcel is assigned the potential damages expected in it's HUC 12 (these damages will then be scaled 0-1)	.1
Area in 100-yr Floodplain	m^2	Area of the Parcel within the 100-year floodplain	.3

Additional Results from InVEST Model:

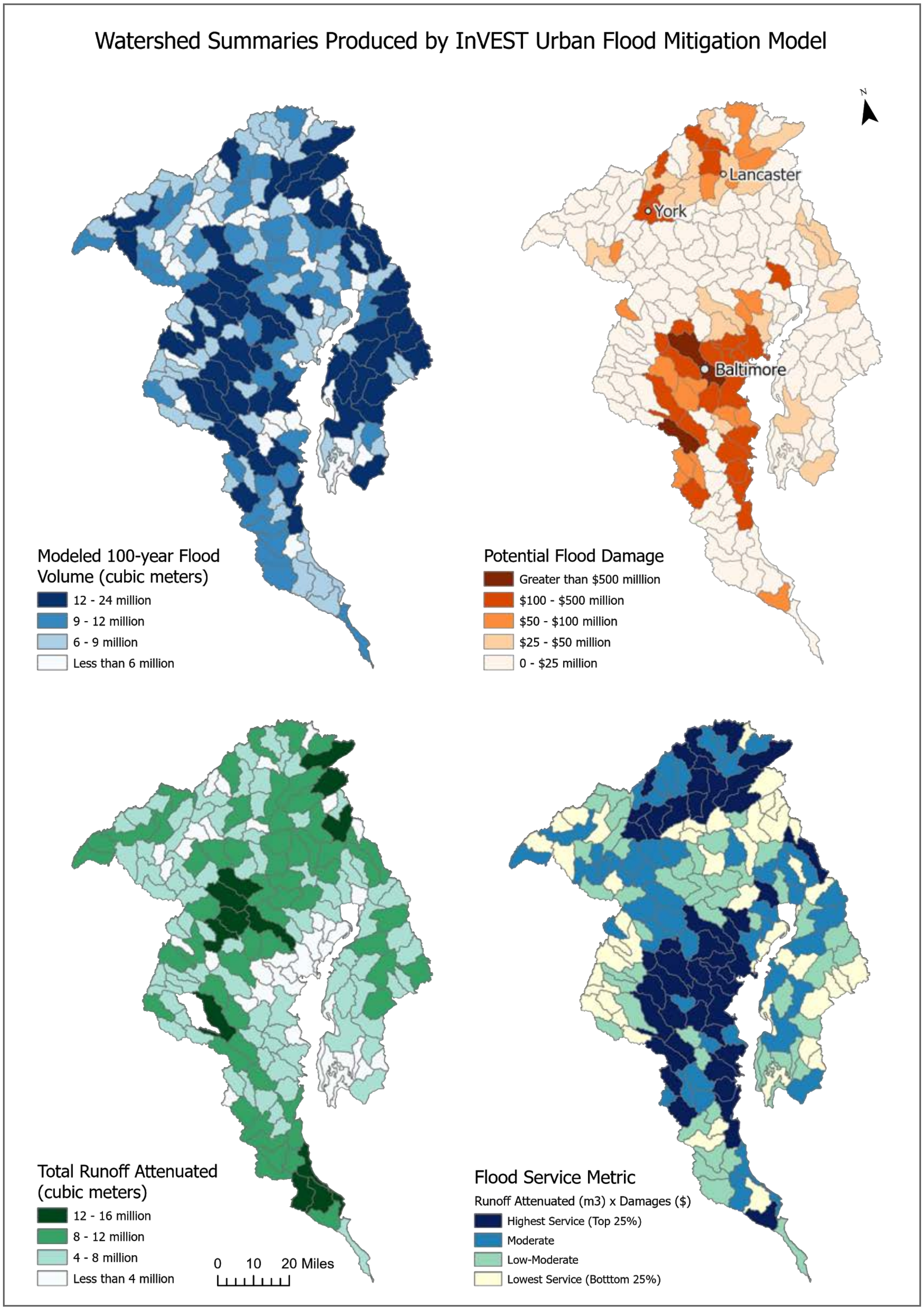


Figure F4. All watershed summaries of flood risk mitigation service for the study area.

Appendix G: Nutrient Retention

Seasonal Water Yield Model

Table G1. Parameters, datasets, and specifications for the InVEST SWY model.

Parameters	Datasets and/or Specifications
Monthly mean precipitation	0.5 x 0.5 degree grid aggregated and averaged for years 2000-2019, CRU TS4.04 Dataset, Climatic Research Unit
Monthly number of rain events	Tabulated .csv averaged for years 2000-2019, CRU TS4.04 Dataset, Climatic Research Unit
Monthly Reference ET	30 arc second grid averaged for years 2000-2019, Global Aridity Index and Potential Evapo-Transpiration (ET0) Climate Database, CGIAR
Digital Elevation Model	Hydrologic DEM (10m), National Hydrography Dataset (NHD), USGS
Land Use Land Cover	30m National Land Cover Dataset 2016, Multi-Resolution Land Characteristics (MRLC) consortium
Threshold Flow Accumulation	Set equal to 2,500 cells based on Hydrologic DEM (10m)
Soil Hydrologic Groups	Adapted from ggSurgo soils database, USDA
Biophysical Table	Includes CN (curve numbers) and Kc (crop coefficients) specified by LULC categories
Watershed Boundaries	HUC 8 (vector), National Hydrography Dataset (NHD), USGS
α, βi, and γ	InVEST default values

Table G2. Monthly average Kc coefficients used in the InVEST SWY model, informed by the InVEST Kc calculator.

Monthly average Kc coefficients													
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Growth stage/phenology of vegetation in each month		bare **	bare	bare	bare	planted (Kc ini)	growing canopy	full plant canopy	full plant canopy	decreasing plant canopy	decreasing plant canopy	harvested (Kc end)	bare
lucode	description	Kc_1	Kc_2	Kc_3	Kc_4	Kc_5	Kc_6	Kc_7	Kc_8	Kc_9	Kc_10	Kc_11	Kc_12
11	Open Water	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
21	Developed, Open Space	0.44	0.44	0.44	0.44	0.84	0.84	1	1	1	0.84	0.84	0.44
22	Developed, Low Intensity	0.395	0.395	0.395	0.395	0.72	0.72	0.85	0.85	0.85	0.72	0.72	0.395
23	Developed, Medium Intensity	0.3065	0.3065	0.3065	0.3065	0.484	0.484	0.555	0.555	0.555	0.484	0.484	0.3065
24	Developed, High Intensity	0.26	0.26	0.26	0.26	0.36	0.36	0.4	0.4	0.4	0.36	0.36	0.26
31	Barren Land (Rock Sand Clay)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
41	Deciduous Forest	0.5	0.5	0.5	0.5	1	1	1.2	1.2	1.2	1	1	0.5
42	Evergreen Forest	0.5	0.5	0.5	0.5	1	1	1.2	1.2	1.2	1	1	0.5
43	Mixed Forest	0.5	0.5	0.5	0.5	1	1	1.2	1.2	1.2	1	1	0.5
52	Shrub/Scrub	0.5	0.5	0.5	0.5	0.9	1	1.1	1.1	1	0.9	0.9	0.9
71	Grassland/Herbaceous	0.5	0.5	0.5	0.5	0.9	1	1.1	1.1	1	0.9	0.9	0.9
81	Pasture/Hay	0.4	0.4	0.4	0.4	0.4	0.675	0.95	0.95	0.95	0.9	0.4	0.4
82	Cultivated Crops	0.3	0.3	0.3	0.3	0.3	0.51	1	1	0.92	0.8	0.55	0.3
90	Woody Wetlands	0.5	0.5	0.5	0.5	0.5	0.85	1.2	1.2	0.85	0.5	0.5	0.5
95	Emergent Herbaceous Wetlands	0.5	0.5	0.5	0.5	0.5	0.85	1.2	1.2	0.85	0.5	0.5	0.5

Source: FAO (1998), InVEST KC Calculator, and embedded sources

Table G3. Complete biophysical table used in the InVEST SWY model.

lucode	CN_A	CN_B	CN_C	CN_D	Kc_1	Kc_2	Kc_3	Kc_4	Kc_5	Kc_6	Kc_7	Kc_8	Kc_9	Kc_10	Kc_11	Kc_12
11	99	99	99	99	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
12	99	99	99	99	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
21	52	68	78	84	0.44	0.44	0.44	0.44	0.84	0.84	1	1	1	0.84	0.84	0.44
22	81	88	90	93	0.395	0.395	0.395	0.395	0.72	0.72	0.85	0.85	0.85	0.72	0.72	0.395
23	84	89	93	94	0.307	0.307	0.307	0.307	0.484	0.484	0.555	0.555	0.555	0.484	0.484	0.307
24	88	92	93	94	0.26	0.26	0.26	0.26	0.36	0.36	0.4	0.4	0.4	0.36	0.36	0.26
31	70	81	88	92	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
41	30	55	70	77	0.5	0.5	0.5	0.5	1	1	1.2	1.2	1.2	1	1	0.5
42	30	55	70	77	0.5	0.5	0.5	0.5	1	1	1.2	1.2	1.2	1	1	0.5
43	30	55	70	77	0.5	0.5	0.5	0.5	1	1	1.2	1.2	1.2	1	1	0.5
52	30	42	55	62	0.5	0.5	0.5	0.5	0.9	1	1.1	1.1	1	0.9	0.9	0.9
71	39	63	75	85	0.5	0.5	0.5	0.5	0.9	1	1.1	1.1	1	0.9	0.9	0.9
81	40	61	73	79	0.4	0.4	0.4	0.4	0.4	0.675	0.95	0.95	0.95	0.9	0.4	0.4
82	62	74	82	86	0.3	0.3	0.3	0.3	0.3	0.51	1	1	0.92	0.8	0.55	0.3
90	86	86	86	86	0.5	0.5	0.5	0.5	0.5	0.85	1.2	1.2	0.85	0.5	0.5	0.5
95	80	80	80	80	0.5	0.5	0.5	0.5	0.5	0.85	1.2	1.2	0.85	0.5	0.5	0.5

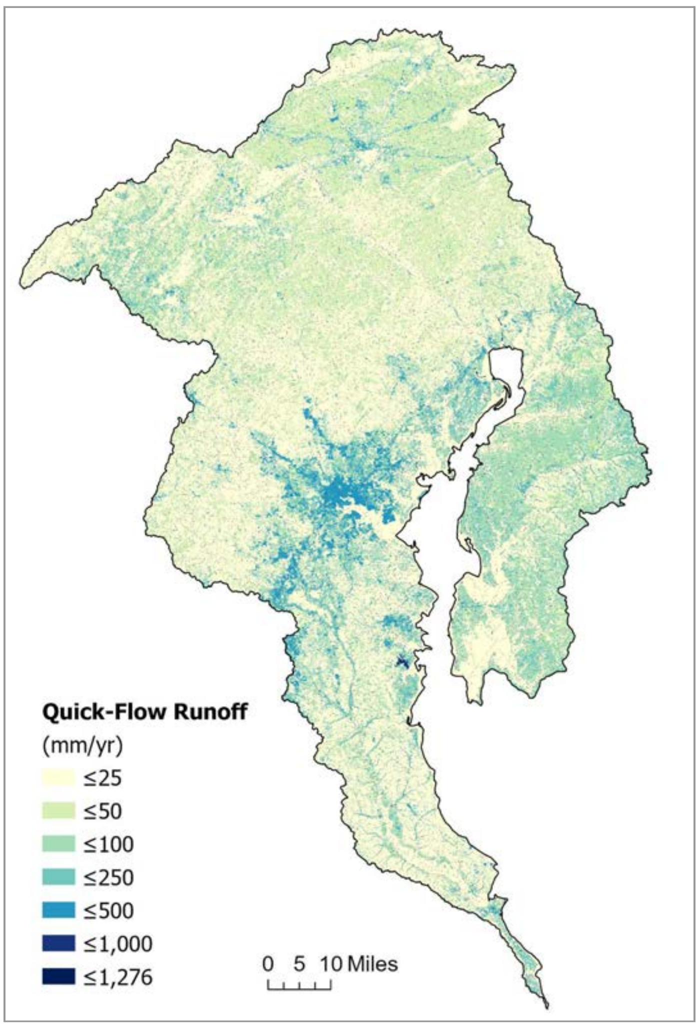


Figure G1. Raster surface of quick-flow runoff in the baseline scenario, which was used as the nutrient runoff proxy in the NDR model. Units are in mm/yr and represent surface runoff plus interflow.

Nutrient Delivery Ratio

Table G4. Parameters, datasets, and specifications for the InVEST NDR model.

Parameters	Datasets and/or Specifications
Biophysical Table	Average load values (kg/ha/yr) for N and P and retention ratio according to LULC category
Land Use Land Cover	30m National Land Cover Dataset 2016, Multi-Resolution Land Characteristics (MRLC) consortium
Digital Elevation Model	Hydrologic DEM (10m), National Hydrography Dataset (NHD), USGS
Nutrient Runoff Proxy	Quick-flow raster created in the SWY model
Watershed Boundaries	HUC 8 or HUC 12 (vector), National Hydrography Dataset (NHD), USGS
Threshold Flow Accumulation	Set equal to 2,500 cells based on Hydrologic DEM (10m)
Borselli k parameter	Set equal to default value of 2
Subsurface critical length (N)	Set equal to 200m
Subsurface critical length (P)	Set equal to 10m
Subsurface retention	Set equal to the maximum retention ratio in the biophysical table

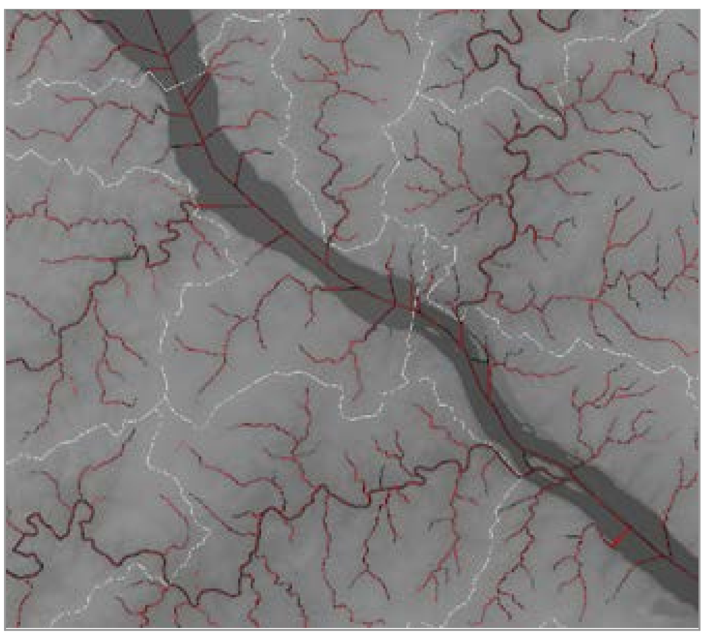


Figure G2. Visual comparison of streams raster created in NDR model with threshold flow accumulation based on 2,500 cells (red lines) overlaying the 10m resolution NHD hydrodem with burned-in streams (black lines). White boundaries represent NHD-level catchments.

Table G5. Average nitrogen loads used for the InVEST NDR model.

Nitrogen Biophysical Table									
lucode	*LULUC_desc*	*load_n_kg/ha*	*source*	*eff_n*	*source*	*crit_len_n*	*source*	*proportion_subsurface_n*	
11	Open Water	2.2	Han et al. 2021	0.1	Han et al. 2021	200	Mayer et al., 2007* *Gloal average retention rate that assumes 80% retention efficiency for vegetated buffers.	0	Ator et al., 2011* *The southeast has higher lateral flow than other regions due to high groundwater table and wet climate and it's estimated that half of all nitrate enters CBW through groundwater (Ator et al., 2011). Proportion subsurface values between 0.1-0.5 would probably be appropriate if an expert could confirm.
21	Developed, Open Space	15.5819	phase 6 developed land class average	0.3	Han et al. 2021	200		0	
22	Developed, Low Intensity	25.16	phase 6 developed reference	0.2	Han et al. 2021	200		0	
23	Developed, Medium Intensity	25.16	phase 6 developed reference	0.2	Han et al. 2021	200		0	
24	Developed, High Intensity	25.16	phase 6 developed reference	0.08	Han et al. 2021	200		0	
31	Barren Land (Rock Sand Clay)	3.7	Han et al. 2021	0.3	Han et al. 2021	200		0	
41	Deciduous Forest	1.88	phase 6 true forest reference	0.7	Han et al. 2021	200		0	
42	Evergreen Forest	1.88	phase 6 true forest reference	0.7	Han et al. 2021	200		0	
43	Mixed Forest	1.88	phase 6 true forest reference	0.7	Han et al. 2021	200		0	
52	Shrub/Scrub	2.75	phase 6 mixed open	0.6	Han et al. 2021	200		0	
71	Grassland/Herbaceous	8.4	Linker et al. 2000	0.54	Han et al. 2021	200		0	
81	Pasture/Hay*	13.2	phase 6 pasture reference	0.45	Han et al. 2021	200		0	
82	Cultivated Crops*	43.79	phase 6 cropland reference	0.15	Han et al. 2021	200		0	
90	Woody Wetlands	1.88	phase 6 wetland	0.85	Han et al. 2021 and Parn et al. 2012	200		0	
95	Emergent Herbaceous Wetlands	1.88	phase 6 wetland	0.72	Han et al. 2021 and Parn et al. 2012	200		0	
	*Could use a higher ag value, upward of 100 kg/ha/yr according to some literature, however that is inconsisent with recent Phase 6 documentation on average loads with removed effects.								

Table G6. Average phosphorus loads used for the InVEST NDR model

Phosphorus Biophysical Table									
lucode	*LULUC_desc*	*load_p_kg/ha*	*source*	*eff_p*	*source*	*crit_len_p*	*source*	*proportion_subsurface_p*	source
11	Open Water	0.1	Han et al. 2021	0.69	Han et al. 2021	200	Mayer et al., 2007* *Gloal average retention rate that assumes 80% retention efficiency for vegetated buffers.	0	Ator et al., 2011* *Lateral subsurface flow shown to be negligible for P, which is mostly exported at the surface (Ator et al., 2011)..
21	Developed, Open Space	0.19	20% of phase 6 developed reference	0.24	Han et al. 2021	200		0	
22	Developed, Low Intensity	0.46	49% of phase 6 developed reference	0.24	Han et al. 2021	200		0	
23	Developed, Medium Intensity	0.73	79% of phase 6 developed reference	0.24	Han et al. 2021	200		0	
24	Developed, High Intensity	0.93	phase 6 developed reference	0.24	Han et al. 2021	200		0	
31	Barren Land (Rock Sand Clay)	0.2	Han et al. 2021	0.24	Han et al. 2021	200		0	
41	Deciduous Forest	0.09	phase 6 true forest	0.7	Han et al. 2021	200		0	
42	Evergreen Forest	0.09	phase 6 true forest	0.7	Han et al. 2021	200		0	
43	Mixed Forest	0.09	phase 6 true forest	0.7	Han et al. 2021	200		0	
52	Shrub/Scrub	0.48	phase 6 mixed open	0.6	Han et al. 2021	200		0	
71	Grassland/Herbaceous	1.68	Han et al. 2021	0.7	Han et al. 2021	200		0	
81	Pasture/Hay	0.91	phase 6 pasture reference	0.8	Han et al. 2021	200		0	
82	Cultivated Crops	2.1	phase 6 crop reference	0.15	Han et al. 2021	200		0	
90	Woody Wetlands	0.09	phase 6 wetland	0.38	Han et al. 2021	200		0	
95	Emergent Herbaceous Wetlands	0.09	phase 6 wetland	0.35	Han et al. 2021	200		0	

Table G7. Complete biophysical table used in the NDR model.

lucode	LULUC_desc	load_n	eff_n	crit_len_n	proportion_subsurface_n	load_p	eff_p	crit_len_p	proportion_subsurface_p
11	Open Water	2.2	0.1	200	0	0.1	0.69	200	0
21	Developed, Open Space	15.5819	0.3	200	0.1	0.19	0.24	200	0
22	Developed, Low Intensity	25.16	0.2	200	0	0.46	0.24	200	0
23	Developed, Medium Intensity	25.16	0.2	200	0	0.73	0.24	200	0
24	Developed, High Intensity	25.16	0.08	200	0	0.93	0.24	200	0
31	Barren Land (Rock Sand Clay)	3.7	0.3	200	0	0.2	0.24	200	0
41	Deciduous Forest	1.88	0.7	200	0	0.09	0.7	200	0
42	Evergreen Forest	1.88	0.7	200	0	0.09	0.7	200	0
43	Mixed Forest	1.88	0.7	200	0	0.09	0.7	200	0
52	Shrub/Scrub	2.75	0.6	200	0	0.48	0.6	200	0
71	Grassland/Herbaceous	8.4	0.54	200	0.1	1.68	0.7	200	0
81	Pasture/Hay	13.2	0.45	200	0.2	0.91	0.8	200	0
82	Cultivated Crops	43.79	0.15	200	0.3	2.1	0.15	200	0
90	Woody Wetlands	1.88	0.85	200	0	0.09	0.38	200	0
95	Emergent Herbaceous Wetlands	1.88	0.72	200	0	0.09	0.35	200	0

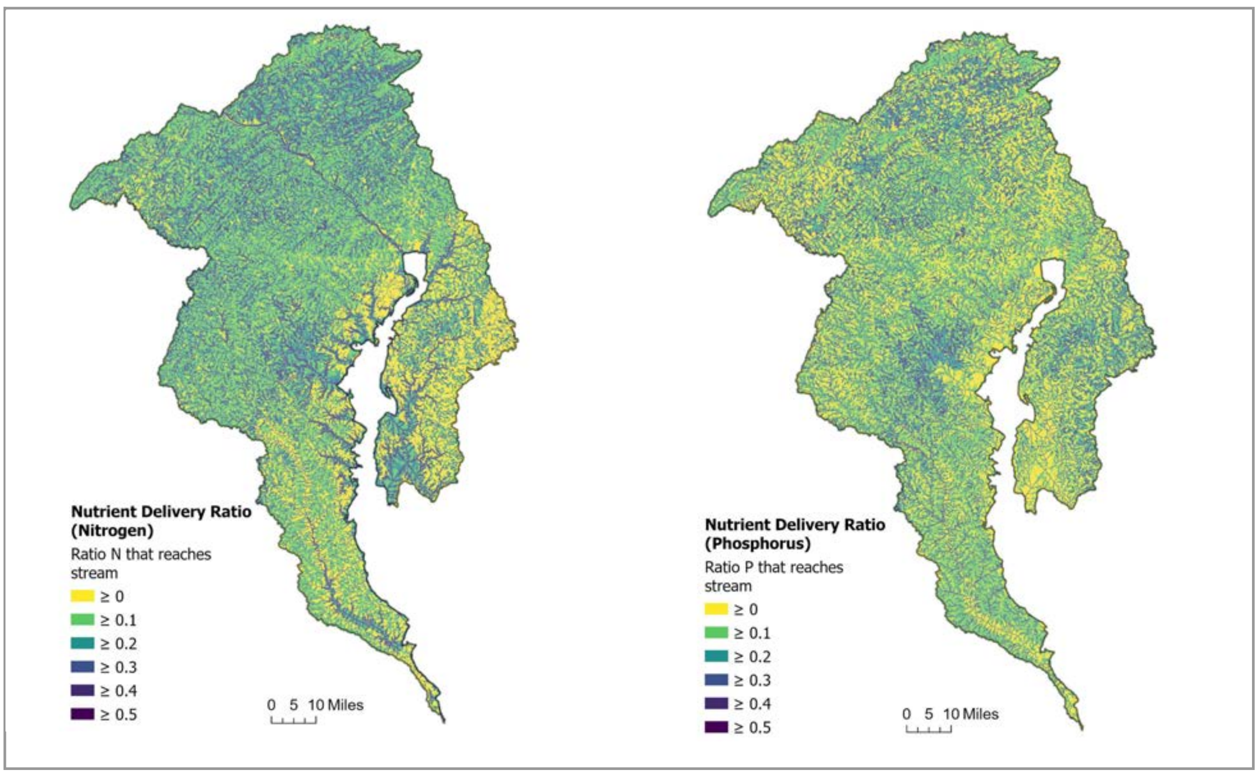


Figure G3. Nutrient delivery ratio for both nitrogen and phosphorus under baseline conditions. Values reflect the proportion of the nutrient from a 10m cell that actually reaches a stream or waterbody.

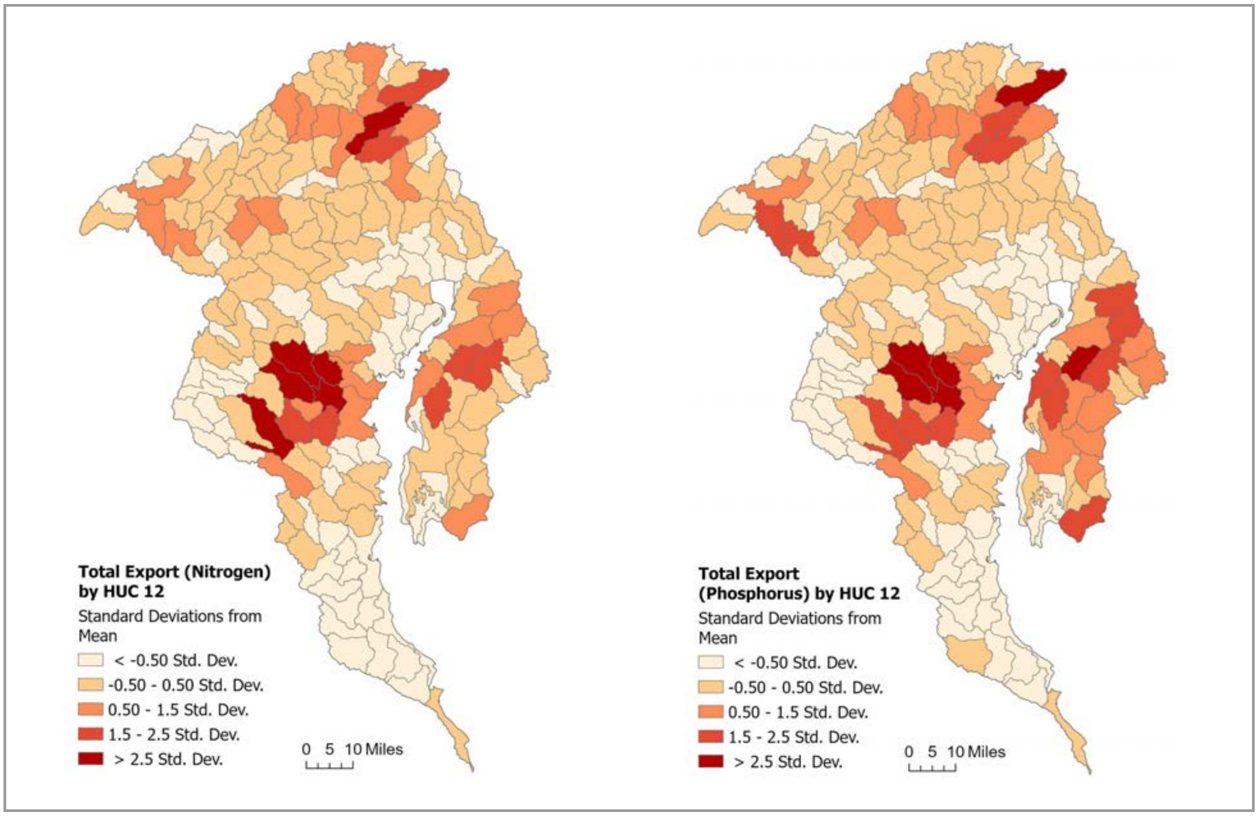


Figure G4. Total export of nitrogen and phosphorus under baseline conditions, summarized by HUC 12 watershed boundaries and symbolized by standard deviations from the mean. Darker shaded HUC 12's indicate higher relative export. There is some spatial variance in nitrogen and phosphorus export.

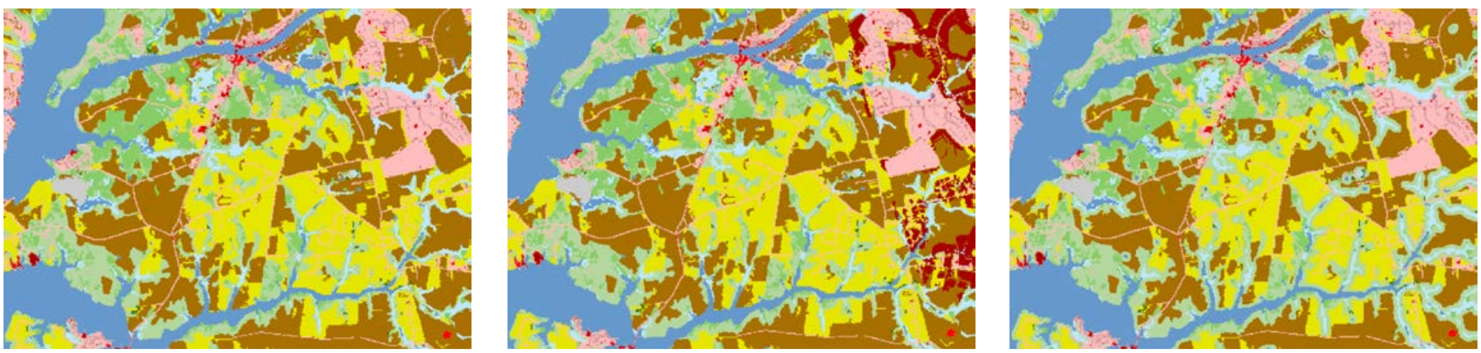
Table G8. CAST 2019 Progress Report load categories used to calculate total export of nitrogen and phosphorus (kg/yr) across the study area. Point sources, septic, and sewer were removed from the summary calculations.

CAST 2019 Progress Report Minor Source - All Agencies	
Sector	**Load Source**
Agriculture	Hay
Agriculture	Pasture
Agriculture	Riparian Pasture
Agriculture	Row Crops
Developed	Impervious Developed
Developed	Pervious Developed
Natural	Forest
Natural	Open Space
Natural	Shoreline
Natural	Stream
Natural	Wetland

Proximity-Based Scenario Generator

Table G9. Parameters, datasets, and specifications for the Proximity-Based Scenario Generator.

Parameters	Datasets and/or Specifications
Land Use Land Cover	30m National Land Cover Dataset 2016, Multi-Resolution Land Characteristics (MRLC) consortium
Study Area Boundaries	HUC 8 (vector), National Hydrography Dataset (NHD), USGS
Max Area of Convertible Landcover Code(s)	Set equal to 5% or 10% of the total area (hectares) of the Convertible Land Cover code(s)
Focal Landcover Code(s)	The LULC class(es) that serve as the basis for distance to/from edge calculation. In this case, the distance from hay, pasture, cultivated crops, streams, or wetlands.
Convertible Landcover Code(s)	The LULC class(es) allowed to be converted. In this case, based on hay, pasture, cultivated crops, or forest cover.
Replacement Landcover Code	Specifies the new LULC (can only be a single LULC class)
Nearest or Farthest from Edge	Calculates proximity based on nearest or farthest from distance of focal class(es)



Baseline Development 2030 Stream Buffers

Figure G5. Examples of land use change for individual land use change scenarios (middle and right maps) compared to the baseline 2016 NLCD (left map).

Appendix H: Ecosystem Service Valuation

Literature used in Delaware Estuary Watershed case study

- Cecil County green infrastructure study by the Conservation Fund, Annapolis, Md. (2007).
- New Jersey Department of Environmental Protection with the University of Vermont (2007)
- Ecosystem services value of forests by the Wilderness Society (2001)
- Ecosystem services value of Peconic Estuary watershed by University of Rhode Island (2002)
- U.S. National Wildlife Refuge System by University of Maryland and Nature Conservancy (2008)
- Economic value of ecosystem services in Massachusetts by the Audubon Society (2003).

Methods Used in Ecosystem Service Valuation

Table H1. Land Use Translation for Current Land Use.

NLCD Land Cover Class	Revised Land Use Used in Present Study
11 Open Water	Open Water
21 Developed, Open Space	Urban
22 Developed	
23 Developed, Medium Intensity	
24 Developed, High Intensity	
31 Barren Land	Barren land
41 Deciduous Forest	Forest
42 Evergreen Forest	
43 Mixed Forest	
52 Shrub/Scrub	
71 Grassland/Herbaceous	
81 Pasture/Hay	Farmland
82 Cultivated Crops	
90 Woody Wetlands	Forest
95 Emergent Herbaceous Wetlands	Wetland

Table H2. Land Use Translation for future land use projection.

Historical Trends Scenario 2025	Revised Land Use Used in Present Study
Commercial	Urban
Residential	
Mixed	
Forest	Forest
Scrub	
Farmland	Farmland
Barren	Barren
Water	Open Water
Wetland	Wetland
Developed Open Space	Urban
Low-density Development	
Medium-density Development	
High-density Development	

Ecosystem Service Value Results

Table H3. Ecosystem Service Value for different Land Use 2025 (Historical Trends Scenario).

Revised Land Use	Area (acres)	$/acre/year 2021	$/year in 2021 dollars (millions)	NPV($, millions)
Open Water	397,363	2694	1,070.49	35,683
Urban	980,721	473	463.88	15,462.67
Barren land	12,534	0	0	0
Forest	1,313,496	2738	3596.35	119,878.33
Farmland	1,416,455	4450	6303.23	210,107.67
Wetland	40,348	18855	760.78	25,359.33
Total	4,160,919		12194.73	406,491

Table H4. Ecosystem Service Value for different Land Use in 2016.

Revised Land Use	Area (acres)	$/acre/year 2021	$/year in 2021 dollars (millions)	NPV($)
Open Water	344,501	2694	928.09H	30936.33
Urban	867,387	473	410.75	13691.67
Barren land	11,853	0	0	0
Forest	1,419,892	2738	3887.66	129588.67
Farmland	1,486,893	4450	6616.68	220556
Wetland	29,379	18855	553.96	18465.33
Total	4,160,908		12397.14	413238

Discussion of Ecosystem Service Value

Table H5. Change in Area from 2016 to 2025, by land use.

Revised Land Use	Projected 2025 Area (acres)	Baseline Area (acres)	Change in Area (acres)
Open Water	397,363	344,501	52,862
Urban	980,721	867,387	113,334
Barren land	12,534	11,853	681
Forest	1,313,496	1,419,892	-106,396
Farmland	1,416,455	1,486,893	-70,438
Wetland	40,348	29,379	10,969
Total	4,160,919	4,160,908	

Table H6. Area changes in HUC 12 experiencing the highest decrease in ecosystem service value (Unit: acres).

HUC 12	Open Water	Urban	Barren	Forest	Farmland	Wetland
20503061103	2601982	5399686	93085.07	-1063491	-7047977	8109.517
20503061202	3866407	2944587	185468.5	2031935	-9051366	14407.23
20503061106	5668220	2771700	44135.59	283146.8	-8763310	-2688.77
20600020204	4105126	2902133	119760.1	-2442797	-4276836	-412705
20503060502	945177.2	3647131	-8095.24	1262427	-5752855	-119644
20503060303	331459.6	5240506	41407.04	-1378260	-4228335	9054.82
20600020202	1846826	4219456	-6298.67	-2107463	-3866576	-97078.4
20503060602	2730059	4503549	50409.52	-2728996	-4611661	53117.51

Table H7. Area changes in HUC 12 experiencing the highest increase in ecosystem service value (Unit: acres).

HUC 12	Open Water	Urban	Barren	Forest	Farmland	Wetland
20600030204	-485156	555431.9	-80004.6	-2007033	-94326.4	2124897
20600030602	604810.9	1328172	98317.19	-4208042	-72364	2256971
20600030105	609297.6	1288875	11734.64	-4213453	95152.51	2208549
20600020302	-315726	1881313	-327484	-4873526	1623827	2032738
20600020411	-910297	2411169	2713.705	-2777230	-480395	1767841
20600020410	-1047556	2394910	-5391.05	-2942434	-107555	1712973
20600020408	-354829	1788967	-3594.29	-2589156	-477427	1649336

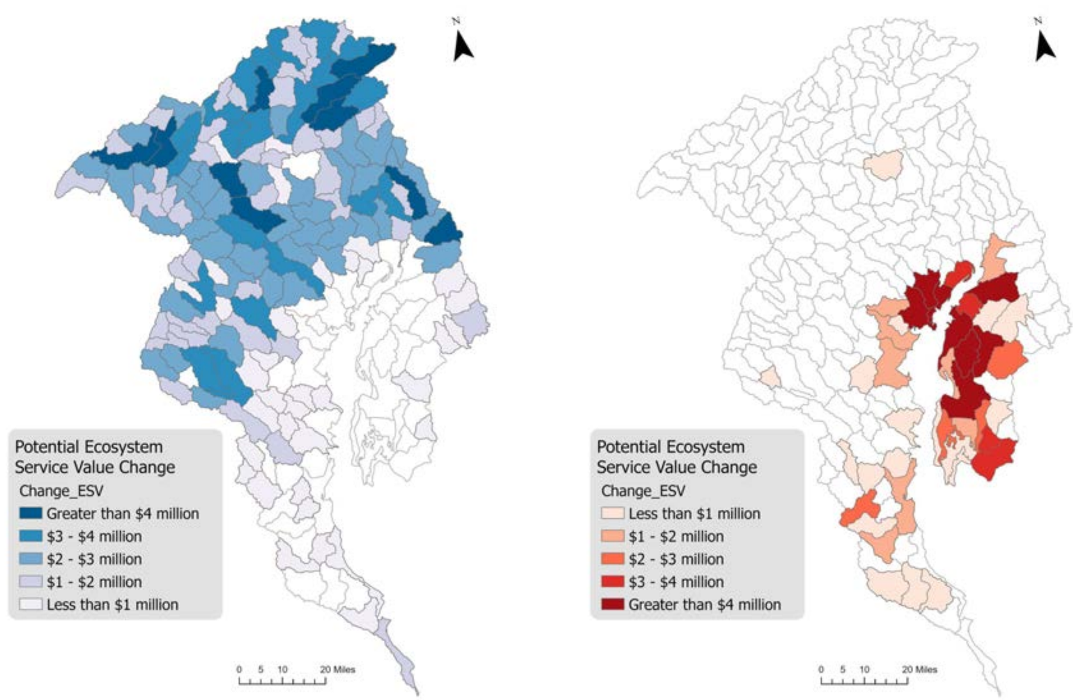


Figure H8. HUC 12 regions experiencing a potential ecosystem service value loss (left) and potential ecosystem service value gain (right) across the study area from 2016 to projected land use in 2025 under Historical Trends Scenario.

Appendix I: Scoring and Weighting Scenarios

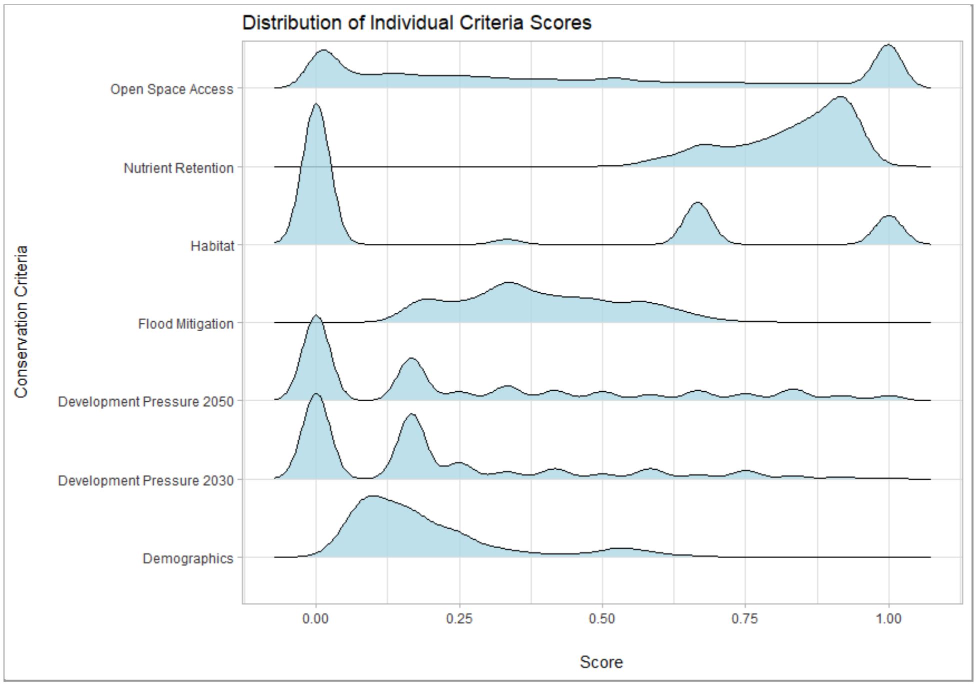


Figure I1. Distribution of each individual criteria scores.

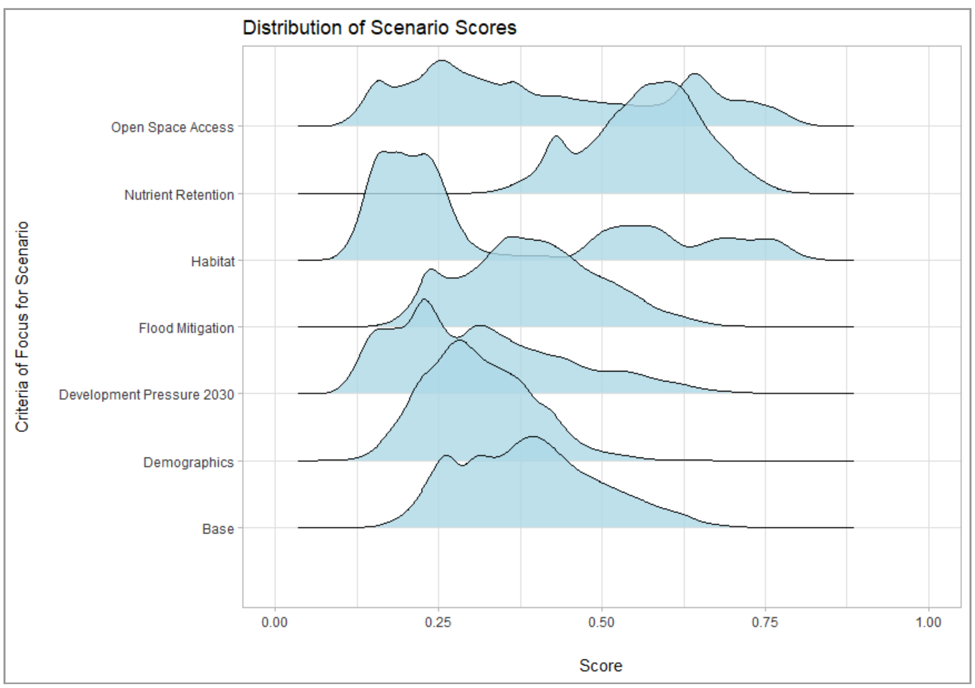


Figure I2. Distribution of each scenario's scores, where the criterion on the y-axis is the characteristic weighted at 50%, and the remaining criteria were all set to 10%. The base scenario weights all criteria equally at 16.67% each.