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The Impact of Projected Land Use Changes on the Availability of Ecosystem Services in the Upper Flint River Watershed, USA

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Abstract: The conversion of forestlands to alternative land uses is a growing worldwide concern, given the wide range of provisioning and regulating ecosystem services (ES) provided by forests. We applied a scenario-based land-use/land-cover (LULC) projection technique integrating societal preferences, conservation policies, and socio-economic factors to the Upper Flint River Watershed in the Atlanta, Georgia (USA) metropolitan area. We employed the InVEST modeling toolset to assess the impact of anticipated LULC changes on ES under each development scenario. Our simulations projected a consistent conversion from Deciduous/Mixed Forests to either Urban or Evergreen forests across all scenarios, leading to a significant decline in ES. We quantified the economic impacts of this ES loss, conservatively estimated as representing millions of dollars per year under a Business as Usual scenario in just carbon and water services alone. Integrating social and policy drivers into our projection approach yielded policy-relevant results and identified the need for conservation policy instruments to protect forested ecosystems with higher conservation values. Existing conservation policies are unlikely to stem the loss of important ES, and there may be a need to consider more aggressive policies to prevent further degradation of watersheds, such as the one analyzed here.

Keywords: urbanization; deforestation; carbon sequestration; water quality

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1. Introduction

The ecosystem service (ES) concept has become widely employed as a means to describe the environment-society relationship and the benefits humans receive from nature [1,2]. An ES is any benefit that ecosystems provide people to enable and support physiological, social, and economic well-being [3]. Forestlands play a crucial role in supporting human well-being through provisioning and regulating services [4]; for example, by sequestering carbon in the form of woody biomass, forests serve as a terrestrial carbon sink during most stages of forest development [5–7]. Forest vegetation not only stabilizes soil and prevents erosion, but tree roots also aerate and condition the soil so that rainwater can be easily absorbed, filtered, and transported into nearby lakes, rivers, and underground aquifers, thus helping to mitigate damage from floods, droughts, and stormwater pollution [8,9]. Moreover, forestlands provide habitat for the majority of the planet's terrestrial species, including wild plants, animals, and important pollinators [10].

In spite of the many contributions to human well-being provided by forests, forestland degradation and conversion have increased in recent decades, even as the demand for forest-related ESs continues to grow [11]. Due to economic and demographic pressures encouraging urban expansion, deforestation is widespread in many forests close to metropolitan areas. More than half of the forestlands in the southeastern U.S. are owned and managed by private entities, mostly families and individuals [12]. Although these forestlands are recognized for the numerous benefits they provide to human societies [5,13–15], private owners are rarely compensated for the ESs provided by their lands [16,17]. Consequently, it is often

in landowners' financial interest to convert forests to other land uses [17–19]. Such land-use changes have considerable impacts on the provisioning of forest ESs as well as on the well-being of the growing human population relying on these ESs [14,20].

Developments in remote sensing, machine learning, and GIS technologies can help to better conceptualize and analyze the ES consequences of land use and land cover (LULC) changes. Several modeling toolsets have been developed to visualize and quantify ES dynamics [21,22]. The complexity associated with assessing non-market values of ESs is a common obstacle in environmental economics [20], but platforms such as the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) toolset enable users to estimate ES economic values across large spatial areas [21]. Substantial research effort has utilized InVEST models to calculate the dynamics and value of biodiversity, land connectivity, and species habitat [20,23,24], to model the hydrological impacts of land-use changes [13,25,26], to evaluate carbon stocks and sequestration [13,14], to estimate provisioning and regulate ESs under alternative scenarios, and to support management decision-making [13,20,27,28].

In this research, we aim to (1) analyze the pattern of deforestation and urban expansion in the Upper Flint Watershed (UFW), Georgia, USA, over the past two decades; (2) integrate socioeconomic and policy factors into our scenario-based projection approach to examine future LULC changes in the UFW under various hypothetical development scenarios with different levels of conservation policies effectiveness and market pressures for LULC change; (3) evaluate and estimate the economic values of ESs of concern within the UFW, drawing a comparison between various development scenarios with regard to ES of special concern; and (4) assess the effectiveness of current conservation policies and address policy gaps to maintain important ES. The approach applied in this study is applicable to other regions experiencing similar development and conversion pressures. In this research, the approach was employed to predict the availability of ES in the future, aiming to provide a solid basis to inform development and conservation plans within the UFW and assess the potential of various conservation policies in stemming the loss of important ES.

1.1. Ecosystem Services

The ES concept was developed to better account for and quantify the wide range of goods and services provided by natural systems that directly or indirectly contribute to human well-being [29,30] as a means of raising public awareness and interest in biodiversity conservation [11,31–36]. Following the introduction of the concept, there was a surge in research designed to develop methodologies and models for measuring ES [37–42], attribute economic values to ES [1,24,43–46], elevate the concept on the policy agenda [3,4,47], incorporate it into decision-making processes [48,49], encourage market development for ES [4,37,43,46,50,51], and understand land owners' motivations to participate in ES conservation and compensation programs [4,34,43,52–54].

While some scholars have embraced the ES concept, others have leveled criticisms against ES as a potentially problematic and "value-laden" conservation concept [55,56]. One line of argument critiques the reduction of complex and intricate ecological functions to individual "services" [55,57–59], while others view the ES concept as commodifying nature and raising equity issues related to unequal access to the benefits and burdens from ES protection [37,56,58–61]. Despite these ethical issues, many consider the ES concept to be important for highlighting the critical role ecosystems and biodiversity play in sustaining life, human well-being, and long-term economic sustainability [55,62]. Others see it as a conceptual tool with the capacity to make environmental externalities explicit and as the basis for the design of policy mechanisms intended to internalize the value of such externalities in market transactions and decision-making processes [29,63].

The common core point in all these various perspectives around the ES subject is the failure in conservation practices to properly recognize the value of natural systems [1,30,37,59,63–66], whether these are difficult to quantify intrinsic values [59] or values assigned through the commodification of ecosystem functions [43,45,46,67]. This "accounting failure" has arguably contributed to the widespread degradation of natural

ecosystems [68]. In light of this "accounting failure," calculating the economic values of specific ESs can be an important component in communicating the importance of ES, quantitatively comparing alternative scenarios, and ensuring that ES is not discounted in decision-making processes [62].

Over two decades of research on ESs calls for the integration of the ES paradigm into policy development to inform land-use planning for sustainable economic development and the conservation of important landscapes [38,69,70]. Scenario-based approaches, or "what if" situations, help to develop and test assumptions regarding factors such as demographic change trends or shifts in attitudes, behaviors, or policies. Scenarios are not characterized by relative probabilities; instead, they are designed as alternative pathways to contrast against one another and to serve as a tool to contemplate possible consequences for the future [71]. Incorporating these scenarios into LULC projections allows researchers to explore and map the ES implications of modeled changes in the studied system [72].

Forested watersheds near growing metropolitan areas are a particularly important focal area for ES analyses, given the ongoing loss of forests to housing, infrastructure, and other urbanized uses. Understanding how to maintain important ESs even as the human population increases has become a growing concern in planning for sustainability [24,29,30]. An in-depth study of particular social-ecological systems and their ESs is required to pinpoint conservation priorities in specific landscapes and halt the further degradation of forestlands with important ESs [73]. The UFW is one example of a highly forested area experiencing development pressures, forest conversion, and the loss of important ESs.

1.2. Study Area

The UFW ranges from 82 m to 410 m in elevation [74] with average annual precipitation of 1337 mm and a mean annual temperature of 17.3 °C [75]. More than half of the UFW is covered by forestlands: 25% of the watershed is categorized as evergreen forest, 20.3% as deciduous forest, and 6.3% as mixed forest (Figure 1). The Flint River and its tributaries offer numerous provisioning ES, including water for agricultural, industrial, and municipal purposes, as well as various regulating, supporting, and cultural ESs. The watershed hosts a diverse array of flora and fauna, including several species classified as endangered or threatened at state, federal, and global levels [76].

With a total area of 682,188 hectares, the UFW covers portions of 19 counties, including Clayton, Coweta, Crawford, Fayette, Fulton, Harris, Henry, Lamar, Macon, Marion, Meriwether, Monroe, Peach, Pike, Talbot, Taylor, Schley, Spalding, and Upson Counties [35,36]. The Atlanta Metropolitan Area overlaps the northern extent of the UFW with over 46 miles of major transportation corridors and the site of Hartsfield-Jackson Atlanta International Airport and its supporting businesses [77]. The Atlanta Metropolitan Area is experiencing one of the fastest population growth rates in the United States, and the predominant medium-to-low-density urbanization model has led to extensive conversion and development of forestland [78–80]. Urbanization, inadequate stormwater controls, and deforestation have limited the provisioning of some important ESs within the watershed [77,81]. Recent local reports note a drop in groundwater levels and streamflow coupled with rising water demands, leading to reduced water availability and exacerbated pressure on water resources [82,83]. Additionally, the region has experienced more frequent and intense precipitation events in recent years, which may have consequences for water quality and ecosystem health [82].

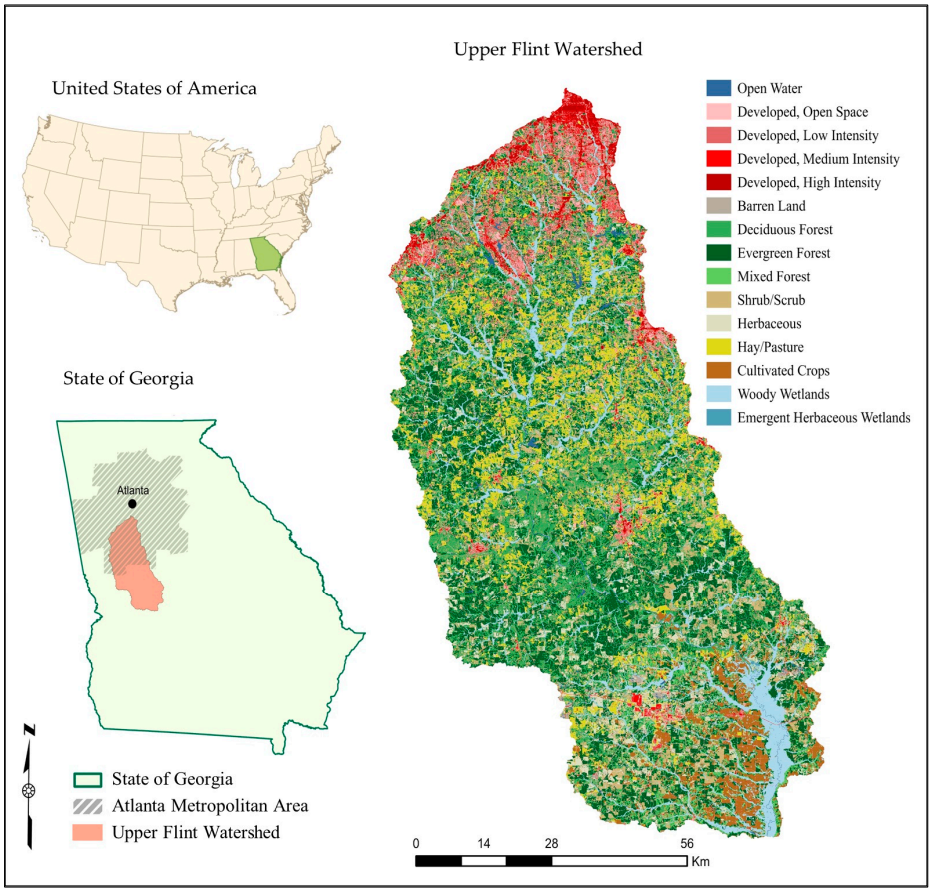


Figure 1. The Land-use and Land-cover map of the Upper Flint Watershed in 2019 is based on the National Land Cover Database (NLCD) produced by the US Geological Survey [37] (p. 6). Reprinted/adapted with permission from Ref. [78]. 2023, Abbasnezhad, B., Abrams, J.B., and Hepinstall-Cymerman, J.

2. Materials and Methods

This part is divided into three subsections. In the first section, we investigate the historical trend of LULC changes in the UFW and describe the projection approach we employed to project LULC to the year 2040. The second subsection explains our assumptions about future LULC change trends under four different development scenarios. The third subsection describes steps taken for modeling selected ES and determining their economic value. Figure 2 provides a brief description of the methods and approaches employed in this research.

2.1. Land Use and Land Cover Projection

Based on their biophysical characteristics, different natural and modified ecosystems have the potential to offer various goods and services to human societies. Hence, LULC acts as the fundamental indicator of the available ES within a landscape; projecting LULC changes is useful for estimating the future availability of ES, driven by the demands of a changing population, human activities, and the impacts of climate change [84]. In this study, we used the US Geological Survey National Land Cover Database (NLCD) layers from 2001, 2011, and 2019 to generate the baseline for projecting the LULC map of the UFW for 2040 [85]. We modified the number of NLCD original land-use classes from 15 to 9 to focus on major LULC conversions and improve accuracy.

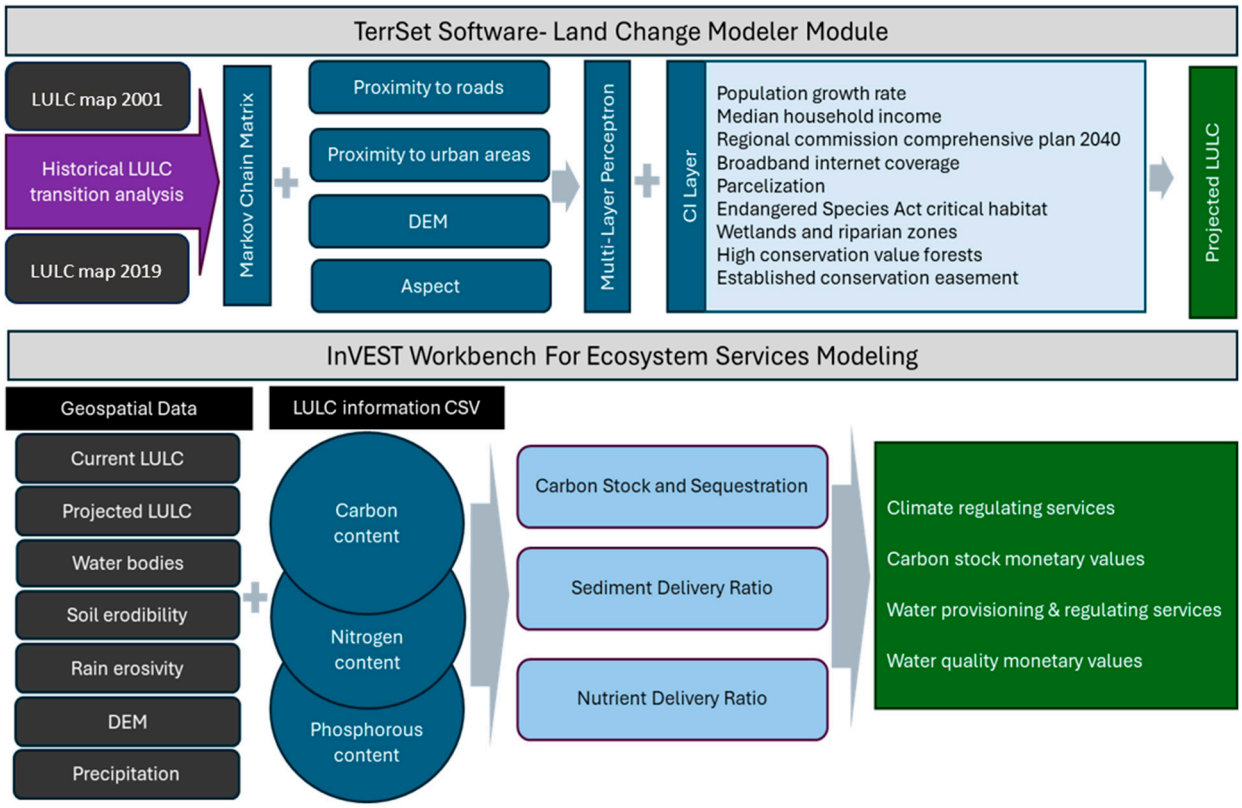


Figure 2. The methodology scheme for LULC projections and ES analysis.

The Land Change Modeler module (LCM) embedded in the software TerrSet 19.0.6 was used to project LULC maps of the UFW for 2040 under different scenarios. The module runs land change detection on two LULC maps from different years to identify historical land-cover changes. LCM requires a set of explanatory variables such as elevation, aspect, population growth rate, distance to urban areas, and distance to roads, highways, and railroads to develop a pragmatic model defining the relationship between land cover transitions and independent explanatory variables and to calculate the conversion possibility of each pixel from one land cover class to another [78,86].

In this study, we used a combination of Multi-Layer Perceptron (MLP) and Markov Chain (MC) analysis. MC generates a matrix of land-cover transition probabilities over time based on an analysis of historical land-cover changes [87]. Since the MC does not incorporate the causes of land-use change, nor is it sensitive to the spatial and geographical characteristics of the site [88,89], the MLP calculations were used to integrate major LULC change driving forces to create a robust model [90]. We used the Constraints and Incentives (CI) panel in LCM to integrate socio-economic factors and policies into our projection method. This allowed us to project the LULC map of the UFW in 2040 across four development scenarios explained in the following subsection.

In this study, development incentives included broadband internet coverage, median household income, population growth rate, future potential development areas according to regional commission comprehensive plans, and land parcelization. Development constraints included the habitats of endangered species protected under the Endangered Species Act, lands identified for conservation purposes in regional commission comprehensive plans, established conservation easements, and high conservation value forests (HCVFs). In the CI layers, values of zero indicate an absolute development constraint and can reflect protected zones or established conservation easements, while values above one can represent strong pressures toward land conversion. Details on LULC projection methods are provided in [78].

2.2. Development Scenarios

In this study, we characterized potential future changes under four main scenarios, assuming the population growth rate remains constant in all scenarios.

2.2.1. Business as Usual

The Business as Usual scenario assumes that forthcoming changes in land use within the UFW will mirror the patterns observed during the transitions from 2011 to 2019. In this scenario, all development constraints and incentive factors integrated into the CI layer carry equal weight and equally influence future development decisions. However, there are exceptions made for established conservation easements and regional commissions' conservation plans, which are assigned a zero value in the CI layer, indicating no potential for conversion (Table 1).

Table 1. Land-use change driving forces incorporated into the development Constraints and Incentives (CI) layer under various development scenarios [34] (p. 8).

	Contributing Factors	Scenarios			
		Business as Usual	**Urbanization**	**Conservation**	**Maximum Forest Protection**
Incentives	Population growth rate	x 1 *	x 2 *	x 1	x 1
	Median household income	x 1	x 2	x 1	x 1
	Regional commission comprehensive plan 2040 (development plans)	x 1	x 1	x 1	x 1
	Broadband internet coverage	x 1	x 2	x 1	x 1
	Parcelization	x 1	x 2	x 1	x 1
Constraints	Endangered Species Act habitat	x 1	x 1	x 2	Constant = 0
	Wetlands and riparian zones	x 1	x 1	Constant = 0	Constant = 0
	HCVFs	x 1	x 1	x 2	Constant = 0
	Regional commission comprehensive plan 2040 (conservation plans)	Constant = 0	x 1	Constant = 0	Constant = 0
	Established conservation easement	Constant = 0	Constant = 0	Constant = 0	Constant = 0

* x 1 shows that no weight was given to the contributing factor in the CI layer calculation. * x 2 shows that the contributing factor was given twice the weight in the CI layer calculation.

2.2.2. Urbanization

This alternative scenario projects an accelerated urban growth rate relative to the Business-as-usual scenario. In this setting, a loosening of existing conservation policies or increased market-driven pressures for development encourages shifts from various land uses to urban areas. Consequently, the development incentive factors in the CI layer are given twice the weight of the development constraints. While some studies recommend examining all pairs of available NLCD maps to pinpoint the timeframe with the highest urban growth rate for initiating the MC matrix [13], we have decided to maintain the same MC matrix as in the baseline scenario. This decision was made to prevent biases due to substantial changes from occasional projects, such as the expansion of the Hartsfield-Jackson Atlanta International Airport and the establishment of Lake McIntosh in the UFW. Unlike the Business as Usual scenario, areas within regional commission conservation plans can undergo conversion to urban development in this scenario. However, established conservation easements are still valued as zero (Table 1).

2.2.3. Conservation

The Conservation scenario prioritizes forestland protection and restoration. This scenario assumes that the implementation of incentive programs encourages landowners

with HCVFs to maintain their properties undeveloped. The scenario posits that land-use policies grounded in conservation principles concentrate on riparian zones, enhancing buffer areas along main rivers to 100 m and secondary rivers to 30 m. In this scenario, urban development within buffer areas is strictly prohibited. While using the same MC matrix as the baseline, this scenario assigns double weight to development constraints as compared to development incentives in the CI layer (Table 1).

2.2.4. Maximum Forest Protection

This scenario illustrates an especially high level of forest protection within the UFW. Despite socio-economic influences that typically drive urban expansion, this hypothetical scenario envisions strong protections for all existing forestland, eliminating any conversion from forestland to urban areas. Additionally, forests with higher conservation values, particularly those situated in riparian zones, would remain forest with no possibility for conversion to any other non-forest land uses. While acknowledging that this scenario would be a sharp departure from prevailing policy trends in Georgia, it serves as a point of comparison for the other (more realistic) scenarios.

2.3. Ecosystem Services Modeling

We used the InVEST® (Integrated Valuation of Ecosystem Services and Tradeoffs) 3.13.0 Workbench to quantify the ES implications of past and possible future land use trajectories. InVEST was developed over many years by the Natural Capital Project at Stanford University as an open-source platform that produces spatially explicit ES models based on spatial and non-spatial input data (https://naturalcapitalproject.stanford.edu/software/invest accessed on 22 August 2023). InVEST uses LULC maps as the basis for its ES quantification processes [29,91] and for the economic evaluation of ES using various non-market valuation techniques [29,42,51]. Drawing from prior studies that highlighted concerns over the provisioning of water and climate regulation services in the Apalachicola-Chattahoochee-Flint River Basin, the focus of this research is on modeling-related ES [13,28,77,83,92]. We used InVEST Carbon Storage and Sequestration models for carbon modeling and Sediment Delivery Ratio (SDR) and Nutrient Delivery Ratio (NDR) as indicators of erosion avoidance and water purification services. We utilized the NLCD maps for the years 2001 and 2019, along with projected LULC maps for 2040 [85], to assess changes in the availability of selected ES over the past two decades and project change patterns for the next 20 years under different development scenarios. In addition to LULC maps, these models require ancillary spatial data and biophysical factors for accurate simulations [13,40]. For detailed information on data requirements and potential data sources, see Supplementary Materials.

2.3.1. Carbon Storage and Sequestration

This model estimates the amount of carbon currently stored over time in four major carbon pools, including aboveground and belowground biomass, soil, and dead organic matter. For the economic valuation of carbon stocks in the UFW, we employed the social cost of carbon (SCC), which represents the economic damage incurred due to carbon emissions. We used an SCC value of USD $7.26/tC/year (2020 $), which is estimated according to domestic (USA) climate change damages at a three percent discount rate. As the impacts of carbon emissions extend beyond the confines of the UFW, we did not include population density in our calculations [24].

2.3.2. Water Quality

InVEST's SDR model was employed to assess and map the UFW's capacity to retain sediments, control erosion, and manage the generation and delivery of overland sediment to water bodies. Sediment dynamics on a watershed scale are predominantly influenced by climatic factors (especially precipitation intensity), soil characteristics, topography, and vegetation, alongside human-induced factors [93].

The InVEST NDR model was employed to assess the retention and delivery of nitrogen and phosphorus in the UFW in order to depict alterations in nutrient export and retention patterns under different scenarios. The model maps the movement of nutrients from catchment sources to the stream network [94]. Land use changes can impact the nutrient cycle through the alteration of anthropogenic nutrient sources, including both point sources like industrial sewage or water treatment plant discharges and non-point sources such as fertilizers used in agriculture and residential areas [95]. Nutrient retention is one of the most frequently modeled services in urbanized watersheds and can be assessed in economic terms using factors like avoided treatment costs or enhanced water security achieved through access to clean drinking water [96]. In this study, subsurface nutrient delivery was not included due to the model's associated uncertainties [40,94].

Ultimately, we aggregated all InVEST outputs associated with water quality (SDR and NDR models) into a single layer, representing the contribution of each pixel in the watershed to water quality. We also computed population density and distance to surface water intakes and water bodies within the UFW. The outputs were then normalized to a range between 0 and 1. The value transfer technique was used to determine economic values associated with regulating water flow in Georgia, estimated at $7755/ha/year (2020 $) based on previous studies [10,13,97]. This value includes annual flood damage protection, water quality improvement due to lower sediment and nutrient transfer to water bodies, and assurance of water supply. Finally, we multiplied this economic value by the normalized combined layers, emphasizing higher economic values in areas with greater contributions to water quality, proximity to surface water intakes with elevated water withdrawal, proximity to water bodies, and situated in regions with higher population density [10,13,97].

3. Results

The 2001 and 2019 NLCD maps were used to analyze LULC change patterns within the UFW. These same maps were employed in the MLP-MC analysis to anticipate potential future land-use changes and to project LULC maps for 2040 under four development scenarios. Focusing on land-use categories undergoing prominent changes, including Deciduous Forest, Evergreen Forest, Shrubland/Herbaceous, Urban, and Hay/Pasture, models project a declining trend in the Hay/Pasture and Deciduous/Mixed Forest classes across all development scenarios. The overall extent of Evergreen Forest is projected to either remain relatively constant or experience growth in all future scenarios. However, a substantial reduction in the overall extent of Evergreen Forest over the last two decades was noted, coinciding with a rise in the total area of the Shrubland/Herbaceous class. During the 2019–2040 period, urban areas are projected to continue to exhibit remarkable expansion across all scenarios. Even in the Maximum Forest Protection scenario, the model anticipates the conversion of over 5000 hectares of land, predominantly under Hay/Pasture and other non-forest land uses, into urban areas (Table 2).

Table 2. Changes in the total area under each LULC category between 2001 and 2019 are projected under four scenarios to 2040, where values represent a change in hectares.

LULC	2001–2019	2019–2040			
	Historical Trend	Business as Usual	Urbanization	Conservation	Maximum Forest Protection
Water	619	139	139	139	139
Urban	13,155	14,492	17,655	12,787	5257
Barren	325	395	370	13	−104
Deciduous/Mixed Forest	−9778	−9943	−10,680	−8176	−5947
Evergreen Forest	−12,573	1332	290	1844	5400
Shrubland/Herbaceous	19,369	3469	2859	4085	4942
Hay/Pasture	−11,180	−10,580	−10,829	−9932	−9932
Cultivated Crop	221	200	200	241	241
Woody Wetlands	−159	−3	−3	2	3

The carbon sequestration model was employed to assess the effects of projected LULC changes on carbon stock and sequestration within the UFW. The historical trend observed from 2001 to 2019 reveals a decline of over 23,000 tons in carbon stock. Simulation results for future scenarios indicate that the carbon stock continues to decrease most sharply in the Urbanization scenario and decreases only slightly in the Maximum Forest Protection scenario compared to the historical trend (Figure 3).

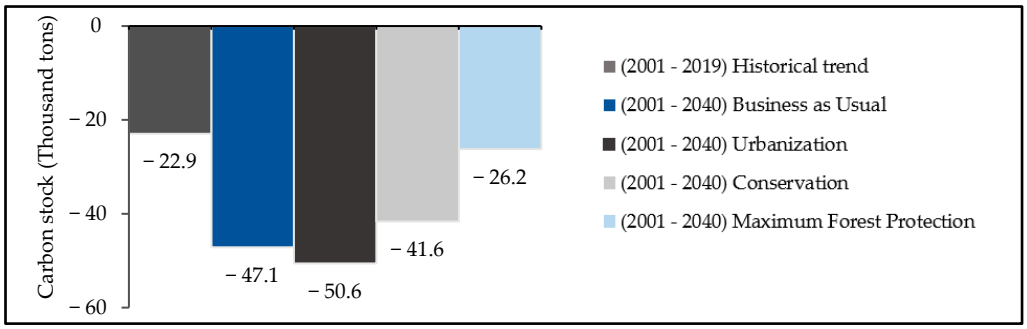


Figure 3. Changes in the carbon stock within the UFW, with values in thousand tons of carbon sequestered.

The results of the SDR model, including the amount of sediment deposition, avoided erosion and avoided sediment export, are presented in Figure 4. The historical trend spanning from 2001 to 2019 illustrates a decline in the landscape's capability to stabilize soil and avoid water erosion, implying more sediment deposited in waterbodies and on land. Projecting the SDR model for development scenarios indicates the persistence of this historical trend even under the Maximum Forest Protection scenario. Under the Urbanization scenario with its considerable decrease in Deciduous/Mixed Forest and Hay/Pasture land-use classes, we expect an annual increase of 1.9 kg/ha in the sediment delivered to water bodies, 16.8 kg/ha in soil deposited on land, and an annual decline of 36.7 kg/ha in avoided erosion from 2019 to 2040. Avoided erosion represents ecosystems' capability to stabilize the soil. The Conservation scenario shows similar outcomes to the historical trend, suggesting that this relatively "realistic" conservation scenario only modestly ameliorates sedimentation (Figure 4).

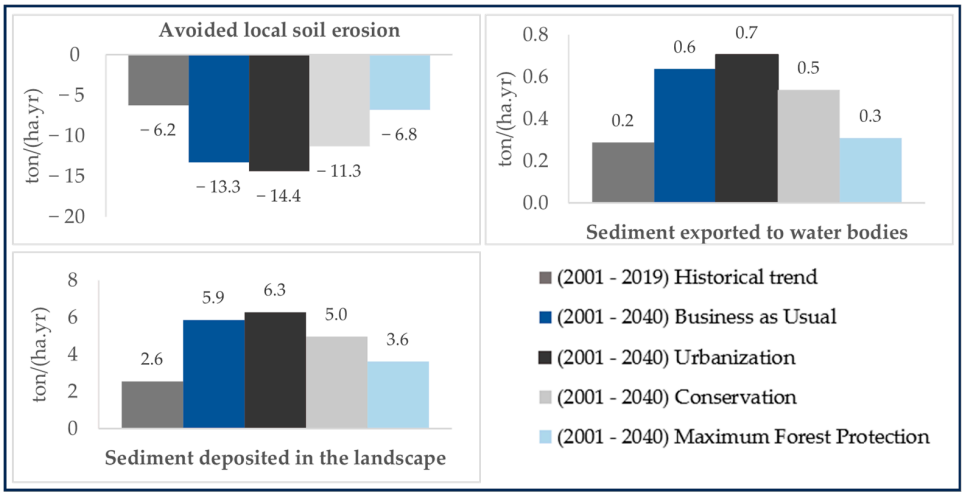


Figure 4. The results of the Sediment Delivery Ratio model where values represent the impact of LULC changes on landscape capabilities to avoid erosion and capture sediments.

The outputs of the NDR model, including estimates of phosphorous and nitrogen surface load and surface export, are shown in Figure 5. Surface load represents the total nutrients liberated into the watershed from all land covers without considering the natural

landscape's contribution in filtering the water, while surface export represents the total amount of nutrients that eventually reach water bodies by surface flow [40]. NDR results for the UFW indicate that from 2001 to 2019, both the nutrient load and nutrient export increased. In other words, while the amount of nutrient load increased as a result of agricultural and forestry practices, urban storms, and other point and non-point source pollution, the natural landscape's capability to retain nutrients and avoid nutrients export to water bodies decreased. Projected results for 2040 represent an increasing nutrient delivery pattern under all scenarios. Even under the Maximum Forest Protection scenario, nitrogen load, and nitrogen export are high, which reflects the use of nitrogen-rich fertilizers in pine plantations and the conversion of other LULCs to open-space developments.

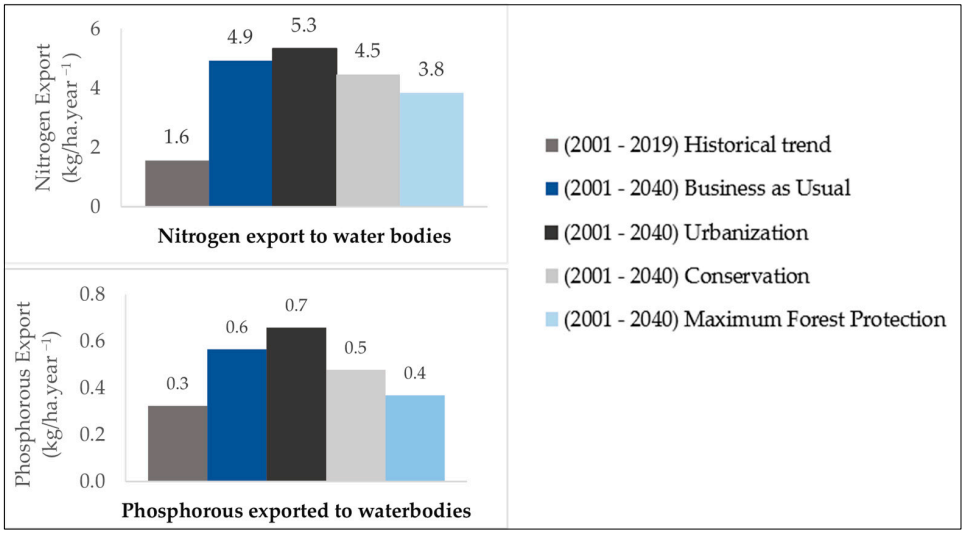


Figure 5. Changes in annual nitrogen and phosphorous export from the UFW.

The monetary values of selected ES within UFW and the economic costs of losing them due to LULC changes are shown in Table 3. Economic calculation results reveal that LULC changes between 2001 and 2019 resulted in a diminishment of ES calculated at $10.6 million USD/per year on average. Projected results suggest that if LULC changes follow the same trend as in the past from 2001 to 2019 under the Business as Usual scenario, the costs of losing these ES would be tripled by 2040. Estimates under the Maximum Forest Protection scenario suggest that avoiding any LULC changes in the HCVF regions and riparian zones, as well as avoiding urbanization in forestlands within the watershed, can reduce the annual costs of losing ESs considerably compared to other scenarios. Note that our estimates are substantially less than those calculated by [13], which is not surprising given the greater development pressures on the northern edge of the Atlanta metropolitan area.

Table 3. The monetary value of selected ES within the UFW and annual average costs of loss (values are in million USD).

Ecosystem Services Type	2001	2019	2040			
			Business as Usual	Urbanization	Conservation	Maximum Forest Protection
Climate Regulating Services	198.8	195.6	191.6	191.1	192.4	194.8
Water Provisioning and Regulating Services	441.4	434.0	412.5	408.7	417.3	429.2
Total	640.2	629.5	604.1	599.8	609.8	624.0
	2001–2019		**2001–2040**			
Average annual cost of lost ES	−10.6		−36.1	−40.4	−30.4	−16.2

4. Discussion

Incorporating socio-economic and policy factors into the LULC projection approach was suggested in previous studies to provide a more reliable anticipation of the significant changes within a landscape [13,78,98]. In this research, we integrated all of the effective conservation and development policies within the UFW, along with influential socio-economic factors, into our LULC projection computational algorithms to project the LULC of UFW by 2040. Benefiting from the CI panel in the LCM module, we projected LULC in the UFW under four development scenarios with different levels of conservation policy effectiveness and market pressure for development.

Projection results suggest that the Deciduous/Mixed Forest and Hay/Pasture classes continue to decline, while the overall extent of lands under the Evergreen Forest class is projected to remain relatively stable or grow across all future scenarios. This result is explained in part by the continued conversion of Deciduous/Mixed Forests to intensive pine plantations. Assuming that conservation policies and urban development pressures follow the same historical LULC changes trend under the Business as Usual scenario, we expect more than 14,000 ha of natural landscapes, mostly representing Deciduous/Mixed Forests and Hay/Pasture land use, to become converted to urban areas by 2040 [78]. The ES analysis of the projected scenarios demonstrates that these changes lead to loss of carbon stock in both soil and biomass, more soil erosion, and elevated levels of nutrients and sediments in the water. The continuation or expansion of 2001–2019 trends portends increased erosion and declining water quality; a moderate forest conservation intervention under the Conservation scenario ameliorates this trend only slightly, and substantial improvement is only seen in the most aggressive forest protection scenario with an absolute prohibition on forest conversion to urbanized land uses.

Similar patterns are noted for carbon sequestration, with only the Maximum Forest Protection scenario substantially slowing the loss of carbon uptake capability while continued urbanization threatens to more than double the loss of carbon storage by 2040. The annual average economic cost estimates of losing these ES range from $10.6 million USD in the 2001–2019 period to over $40 million USD in Urbanization projections.

Comparing the two LULC maps from 2001 to 2019, we noted a significant decrease in Deciduous/Mixed Forest, followed by reductions in Hay/Pasture and Evergreen Forest, respectively. At least some of the movement between Evergreen Forest, Hay/Pasture, and Shrubland/Herbaceous categories represents distinct stages of the predominant practices of even-aged forest management in pine-dominated Evergreen Forest. Conversely, there is a remarkable increase in the Shrubland/Herbaceous, Barren, and Urban classes. The reduction in Evergreen Forest during the 2001–2019 period is also attributed to the creation of Lake McIntosh near Peachtree City. However, the rise in the Urban and Barren Classes can be attributed to mining activities, road construction, the establishment of transportation infrastructure, and urban expansion.

Under the hypothetical Urbanization scenario, characterized by a loosening of current conservation policies and heightened market pressure promoting urban development, Evergreen Forest still undergoes expansion (although to a comparatively lesser degree than in other scenarios) while Deciduous/Mixed Forest declines sharply. Both forest types are subject to conversion, especially in the upper regions of the UFW, and the overall area of Evergreen Forest remains steady or experiences growth in the lower parts. The diminished rate of Evergreen Forest expansion in the upper parts of the UFW under the Urbanization scenario is likely attributed to parcelization, where forestry practices in small parcels struggle to compete with the intense development market pressures near the Atlanta Metropolitan Area, primarily due to economies of scale [99,100]. Our findings align with other studies focusing on Georgia's forest cover transitions, indicating an increase in Evergreen Forest in exurban and rural areas but a decrease in proximity to urban areas [13,24]. Extensive urban expansion in forestlands and pastures in the upper parts of the UFW, accompanied by conversion of Deciduous/Mixed Forest and Hay/Pastureland uses to monoculture pine plantations, reduces the landscape's ability to avoid erosion

and adds more nutrients to water bodies due to urban stormwater and use of fertilizers in pine monocultures [101]. The Urbanization scenario suggests that accelerating urban expansion [95,102] can increase the costs of lost climate and water regulating services to over $40 million USD per year.

Comparing our Conservation scenario with Business as Usual reveals that even employing a relatively realistic conservation strategy fails to control the pace of conversion of Deciduous/Mixed Forest and Hay/Pasture classes to urban areas. We find that parcels smaller than 20 ha of Deciduous/Mixed Forest situated near densely developed areas are prone to conversion into urban spaces due to urban growth dynamics. Conversely, the reduction of larger Deciduous/Mixed Forest parcels in rural areas, distant from metropolitan zones, stems from a preference to optimize revenue through conversion to intensive pine plantations. However, InVEST results for carbon stock and sequestration (Figure 3), SDR (Figure 4), and NDR (Figure 5) represent better conservation of ES, which indicates that even small-scale conservation interventions can exhibit landscape-level impacts on securing selected ES.

Under the hypothetical Maximum Forest Protection scenario, with the assumption of no forest conversion in HCVFs or riparian zones and no forest conversion to urban areas across the watershed, it becomes evident that Deciduous/Mixed Forests gradually become converted to Evergreen Forests. Further, ES models represent some level of degradation in natural landscape potential to provide ES due to the conversion of Deciduous Forests to Evergreen Forests as well as the loss of other non-forest land uses to urban areas. Despite these changes to ES provisions related to the replacement of deciduous/mixed forests with monoculture evergreen forests, this scenario nevertheless conserved the highest levels of ES. This suggests that introducing policies to discourage LULC conversions in HCVFs can sharply reduce the associated costs of losing ES.

The LULC projections for the UFW suggested that small parcels (less than 20 ha) of forestlands within proximity to urban areas are highly prone to urban development as forestry practices in smaller parcels are costly and struggle to compete with development market pressures. On the other hand, many of these forests are located in the Flint River headwaters, and therefore, their importance is not just limited to the ES we included in this research. Previous studies and technical reports also noted that deforestation in the region has led to urban storm runoff, soil erosion, and low water quality [77,81,83,103].

5. Conclusions

This research aimed to enhance our comprehension of how land-management decisions, influenced by conservation policies and socio-economic factors promoting urban development, impact the availability of some climate and water regulating ES necessary to human societies' well-being. Building on prior studies highlighting the importance of incorporating socio-economic variables in LULC projection approaches [98,104–106], we sought to project complex human-natural dynamics and integrate human-making processes into computational projection algorithms.

The comparison of four contrasting development and conservation scenarios enabled us to project the future LULC of the UFW under various levels of conservation policy effectiveness and development pressure. LULC projection results coupled with InVEST ES models enhanced our ability to model and quantify the effects of LULC changes on the availability of climate regulating and water provisioning/regulating services. Calculating the economic values of these ES can benefit land managers, stakeholders, and policymakers by providing a clearer understanding of the monetary and non-monetary costs and benefits of their decisions.

Even with a greater emphasis on development constraint factors in the Conservation scenario, a consistent decline in the Deciduous/Mixed Forest calls for more effective conservation strategies and policy tools if maintaining the same level of available ES in the future is desired, especially in watersheds facing high urbanization pressures [13,97,107]. Moreover, as Deciduous/Mixed Forests continue to convert to monoculture pine plantations,

the Maximum Forest Protection scenario suggests that new conservation strategies discouraging LULC changes in forestlands with higher conservation values could help measurably conserve important ES.

Introducing new policy instruments and incentive plans to encourage smaller forest owners to keep their lands forested seems urgent, as policies that only marginally improve forest conservation outcomes will do little to stem the loss of important ES. A mix of increased funding for ES payments, targeted acquisition and easement purchases in HCVFs, and restrictions on development in the most sensitive areas could come closer to achieving the improvements represented in the most aggressive conservation scenario modeled here.

6. Limitations

Like all research, this study has some important limitations. Given that the main objective of this research was to investigate the impact of LULC changes on the availability of several ES, we only incorporated policies that impede land-use conversions into our LULC projection approach. However, there are other rules and regulations in Georgia associated with the use of fertilizers in agricultural fields and water consumption [108] that were not integrated into our ES modeling process. We utilized the most plausible datasets for each, incorporating parameters as inputs to ES models, ensuring that assessments derived from these models represent the best estimates. We acquired our data from open-source publicly available databases for the entire conterminous United States. While such large data sets provide the opportunity to replicate the analysis in other regions within the U.S., there might be some level of error at smaller scales. Moreover, as our understanding of underlying LULC change drivers is limited and some of the factors are not spatially representable in GIS layers, there are inherent limitations with the accuracy level of projected LULC maps. These limitations have been addressed across previous studies [13,14,28,88]. Moreover, despite the prevalent application of InVEST models in the literature [13,21,28,94,109] and efforts to validate some of these models [26], there are uncertainties associated with the models that should be acknowledged [40].

The economic values assigned to ES in this study are the minimum estimated values associated with each ES. As there were inconsistencies in suggested discount rates in the literature, we decided to use a single (3%) discount rate for simplicity purposes and to calculate the minimum annual costs of losing ES. However, there are several economic factors, such as inflation, that can affect the discount rate, and future research could explore the use of different rates.

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