Comprehensive Analysis of Water Quality and Land Use Dynamics within Connecticut's Mystic River Watershed

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Introduction

A watershed is a section of land that gathers and conducts all runoff from streams, rivers, and watercourses to a common endpoint, such as a reservoir's discharge point, the mouth of a bay, or any specified location along a stream (Lei-Parent and Arnold 2022). Watersheds range in size from small, like the drainage area of a duck pond, to large, like the basin flowing into Long Island Sound. Figure 1 displays the Mystic River Watershed, nestled in southeastern Connecticut, serves as a vital natural and socioeconomic resource in the region. Spanning through the sovereign territories of the Mashantucket and Eastern Pequot Tribal Nations, alongside the municipalities of Ledyard, North Stonington, Stonington, and Groton, the watershed encompasses an intricate network of water bodies, wetlands, forests, and urban areas ("Our Watershed | Alliance for the Mystic River Watershed" n.d.). The relationship between land use practices and water quality in the Mystic River Watershed has received a lot of attention because of the implications for ecosystem health, human well-being, and sustainable development.

Commissioned by the Alliance for the Mystic River Watershed, this report aims to provide a comprehensive examination of the relationship between land use patterns and water quality dynamics in the Mystic River Watershed, recognizing its importance as a critical natural and socioeconomic resource in southeastern Connecticut. Because the watershed crosses multiple regions and municipalities, understanding the effects of climate change and human activity on its ecological integrity is critical.

To aid this analysis, I used the University of Connecticut's CLEAR (Center for Land Use Education and Research) watershed assessment tool. Using its features, I can effectively examine various land uses in the watershed such as agricultural practices, urbanization, industrial activities, and conservation efforts, shedding light on the complex interactions that shape the health in this region. This tool allows us to combine spatial data and model simulations to provide a solid foundation for our study of the Mystic River Watershed. Recognizing the relationship between land use and water quality, this analysis will offer insight into how climate change-induced changes and human activities affect the delicate balance of the Mystic River Watershed. Using UConn CLEAR's watershed assessment tool, the report aims to create actionable insights that will influence decision-making processes and assist the implementation of sustainable watershed management and conservation practices.

Through interdisciplinary collaboration and community participation, the report plans to contribute to informed decision-making processes prioritizing the sustainable use and care of water resources in this biologically diverse and culturally significant area. By encouraging dialogue and advocating evidence-based solutions, I hope to build resilience and safeguard the Mystic River Watershed's long-term viability for current and future generations.

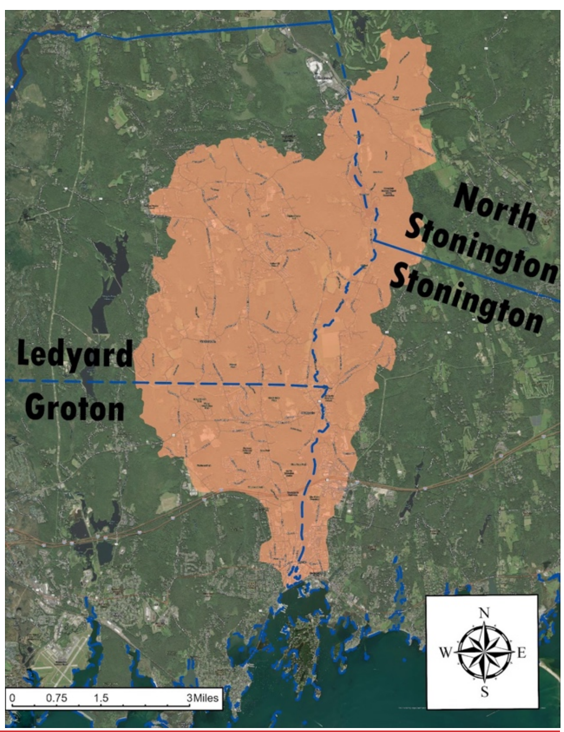

Figure 1. Map of the Mystic River Watershed

Variables and Indicators

The features of UConn CLEAR's Watershed Assessment Tool offer a comprehensive approach to analyzing land use patterns and water quality dynamics within the Mystic River Watershed. Several variables that were collected and displayed in the tool were used for this report. The main feature of the tool is the Combined Condition Index (CCI) Dashboard. CCI is an index that describes the projected health of a basin within a watershed. The CCI of a basin is calculated using the ratios of natural, impervious, and agriculture-like land cover from the National Oceanic and Atmospheric Administration's (NOAA) C-CAP High Resolution Land Cover dataset for the 100-foot riparian zone and upland region within the watershed. CCI ranges from 0 to 1. Each basin is then assigned to a recovery category, which specifies the recommended land use strategy for a watershed based on its existing CCI rating.

The recovery categories are the following:

- **Conservation** if CCI ≥ 0.75. This suggests that the watershed is likely to be healthy and should be protected through land conservation and riparian protection techniques.
- **Recovery** if 0.43 ≤ CCI < 0.75. This suggests that the watershed's health is likely to decline but it can potentially be improved with conservation and reforestation, as well as riparian restoration efforts.
- **Mitigation** if CCI < 0.43. This indicates that the watershed's health is significantly impacted, but it can be restored by focusing on restoration initiatives in the riparian zone and projects such as those aimed at increasing urban tree canopy.

Furthermore, alongside the CCI, the report considered enrichment factor (EF) land uses within riparian zones and upland watersheds as additional variables observed in the CCI Dashboard. The Enrichment Factor (EF) is a measure of how much nitrogen (N) is anticipated to be in the basin's waters relative to a theoretical baseline level for a completely untouched watershed. Nitrogen pollution is a major threat to many watersheds that drains into large bodies of water such as the Long Island Sound. EF is a ratio, therefore an Enrichment Factor of 3 would suggest that the nitrogen load produced by the watershed is three times that of a pristine watershed.

Riparian zones are ecosystems that form at the boundary of terrestrial and freshwater habitats along flowing waterways as shown in Figure 2. Even though riparian zones make up a small area of the landscape, they contribute significantly to the region's biodiversity and provide several ecological services, owing mostly to the dynamic “edge effect" of the aquatic/terrestrial transition zone following flooding pulses (González et al. 2017). As a result, riparian zones are modest natural features that play an ecological significant role beyond their borders. Riparian zones offer numerous critical functions and benefits, encompassing habitat provision for diverse wildlife, assistance in preserving water quality by facilitating the removal of excess nutrients and sediment from surface runoff, stabilization of stream banks, and reduction of floodwater velocity due to the presence of riparian vegetation (“Riparian Areas | Elbow River State of the Watershed” n.d.). Human and urban development are putting riparian zones at risk through land use changes and climate change. On the other hand, upland watersheds are the areas of the watershed that do not encounter regular flooding from a stream.

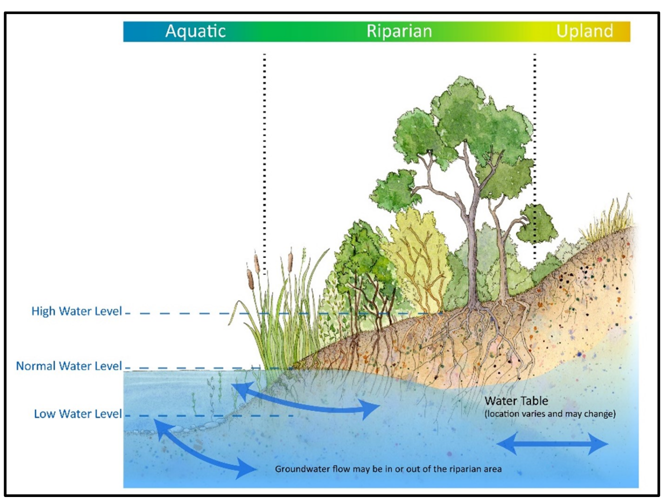

Figure 2: Diagram of Riparian Zone and Upland Regions along a Waterway. Accessed from Elbow River Watershed Partnership

Methods

The Mystic River Watershed and its sub-regions were defined using the UConn CLEAR (Center for Land Use Education and Research) watershed assessment program. Williams Brook, Haleys Brook, Mystic River, and Whitford Brook constitute the four main sub-regions that make up the Mystic River Watershed. To represent the larger hydrological environment, five extra basins consisting of Pequotsepos Brook, Noank, and Mystic Harbor were also included in the analysis shown in Figure 3. Moreover, NOAA's 2016 C-CAP Connecticut Land Use Cover dataset was downloaded and mapped on ArcGIS Pro concerning the Mystic River Watershed.

Following the delineation process, shapefiles and data including variables mentioned in the previous section related to the Mystic River Watershed were downloaded from the watershed assessment tool. These datasets were combined and examined using ArcGIS Pro to provide spatial representations and maps that show the dynamics of water quality, land use patterns, and other pertinent factors distributed throughout the watershed. In Figures 5 and 6, as well as Figure 7, the land use maps and enrichment maps utilized a method known as natural breaks, also called Jenks natural breaks classification. This classification method divides the data into meaningful categories based on natural groupings in the data distribution.

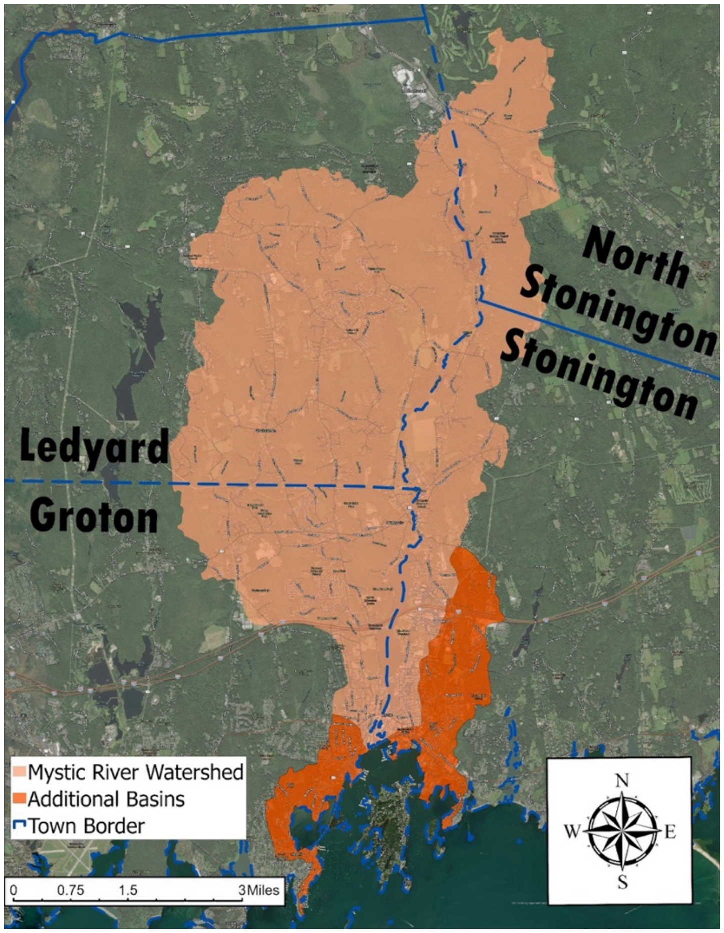

Figure 3: Map of Mystic River Watershed plus the additional five basins used for the analysis.

Limitations

Mason's Island was left out of the analysis, which is a significant study restriction. Figure 4 shows a map Mason's Island that was excluded from the analysis. The reason for this exclusion was the lack of CCI data for this particular location, which restricted our capacity to fully evaluate the dynamics of water quality and land use patterns on Mason's Island. Moreover, the analysis centered on the 2016 land cover set, despite efforts to use the most recent datasets available. Given the dynamic nature of changes in land cover and use, an updated dataset would give a more accurate picture of the state of affairs in the Mystic River Watershed presently.

Figure 4: Map of Mason's Island

Key Findings

UConn CLEAR's watershed assessment tool unveiled significant spatial patterns in both land uses and the health of the watershed. The spatial distribution of land uses within the riparian zones of the Mystic River Watershed reveals a prominent pattern characterized by higher concentrations of agricultural-like and impervious cover land uses south of the Connecticut-184 (CT-184) highway. There is a noticeable decrease in natural cover within the riparian zones in the southern basins, highlighting the potential ecological implications of intensified human development in these areas. Figure 6 shows similar patterns in terms of land uses in the upland watershed. Figures 7 and 8 provide further insight into the observed spatial patterns of land use within the riparian zones of the Mystic River Watershed. Specifically, these figures illustrate the distribution of land use cover types, offering context regarding the prominent concentrations of agricultural-like and impervious cover land uses observed in Figures 5 and 6.

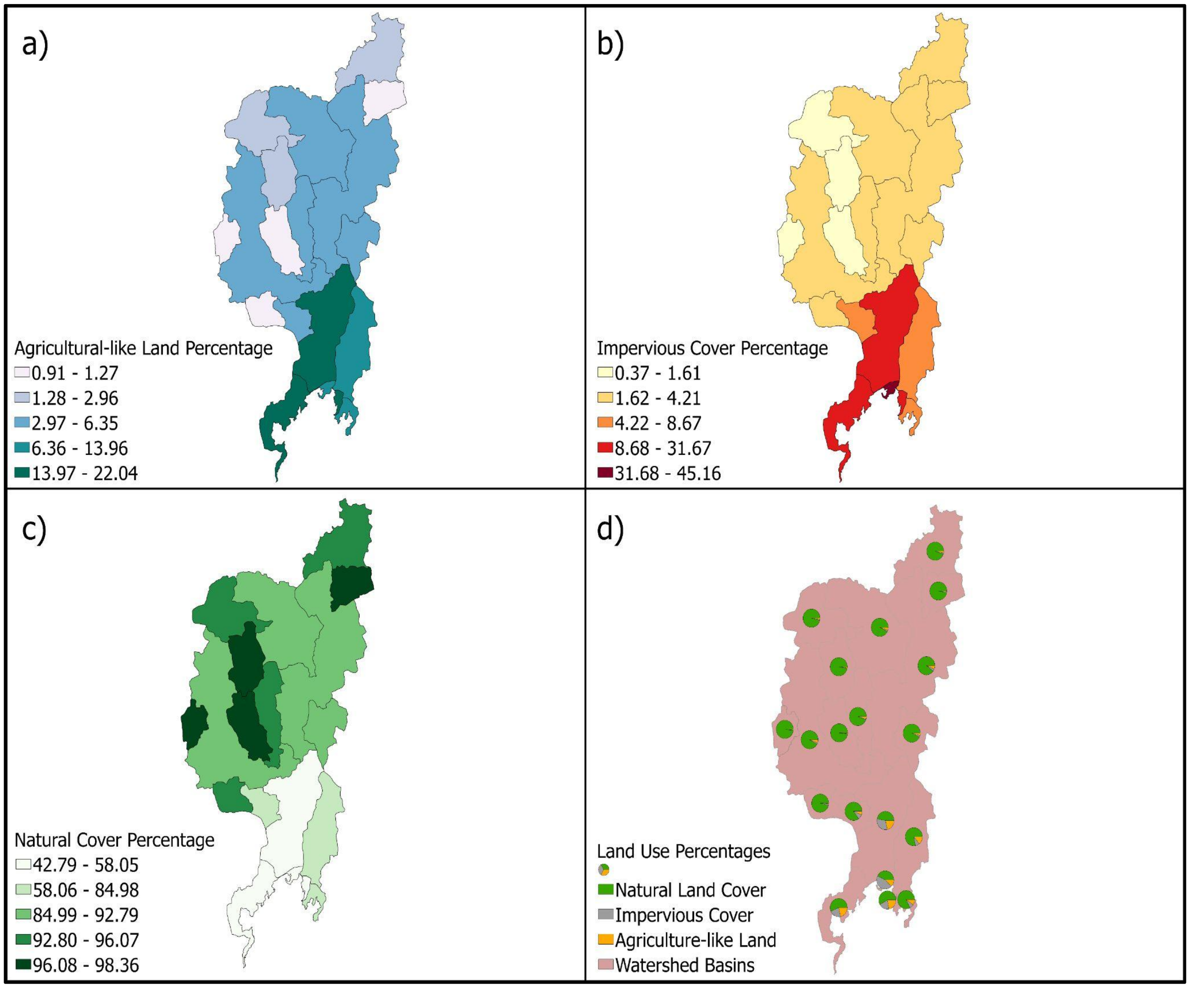

Figure 5: Land Use Distribution within Riparian Zones (**a**) Agriculture-like land. (**b**) Impervious Surface. (**c**) Natural Land. (**d**) Percentage of land use in each basin.

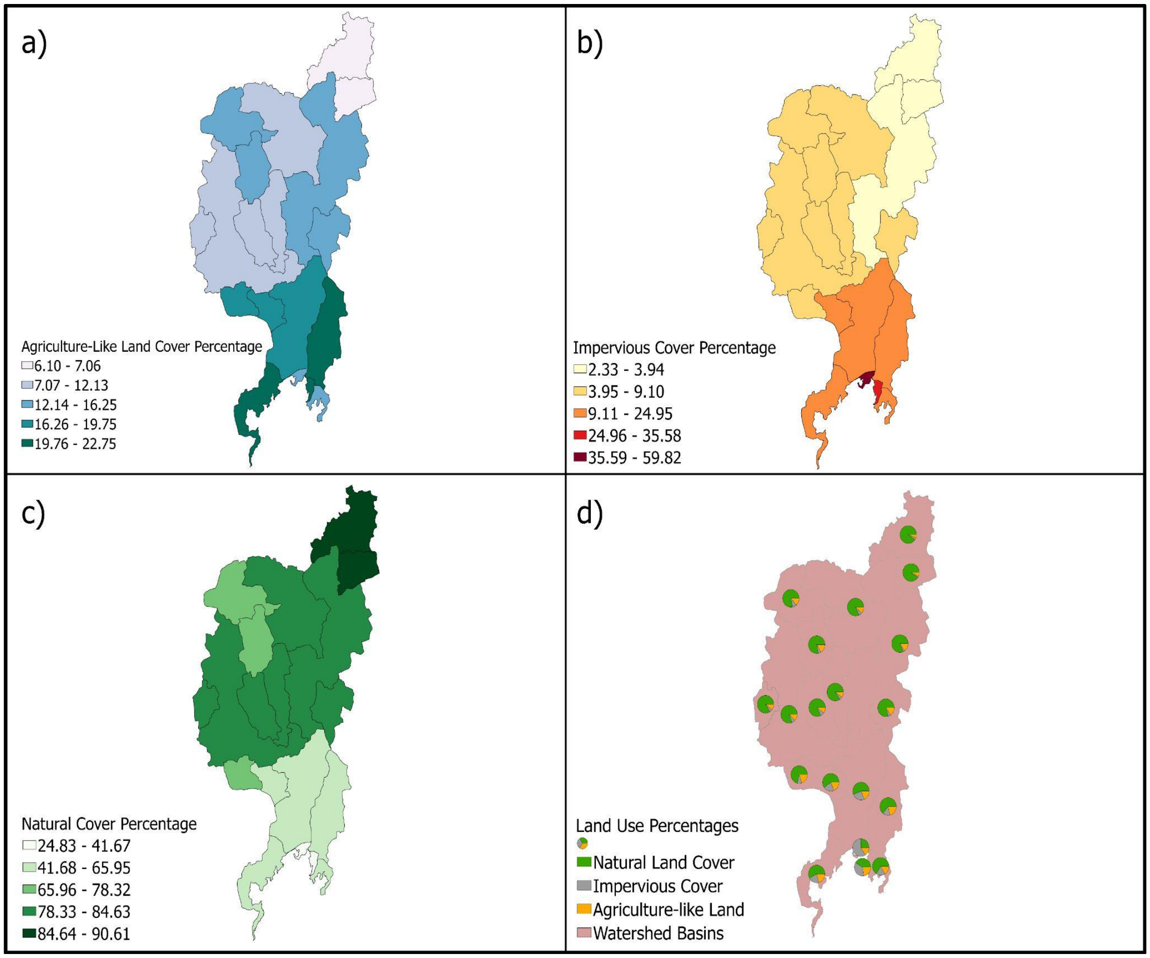

Figure 6: Land Use Distribution within Upland Watershed (**a**) Agriculture-like land. (**b**) Impervious Surface. (**c**) Natural Land. (**d**) Percentage of land use in each basin.

Figures 7 and 8 illustrate substantial areas of impervious cover in the southern portion of the watershed. This observation is consistent with the high economic activity and concentration of businesses in the area, requiring extensive urban expansion and infrastructure. The high proportion of impervious cover and developed land signifies the urbanized nature of the Mystic Harbor region. Additionally, the spatial distribution of low CCI scores and high EF near the mouth of the Mystic River shown in Figure 7 is consistent with the patterns observed in Figures 3-6, emphasizing the pattern of impervious cover and agricultural lands leading to worse watershed health. The proliferation of impervious surfaces potentially presents a pressing environmental and health concern in the Mystic and Noank area.

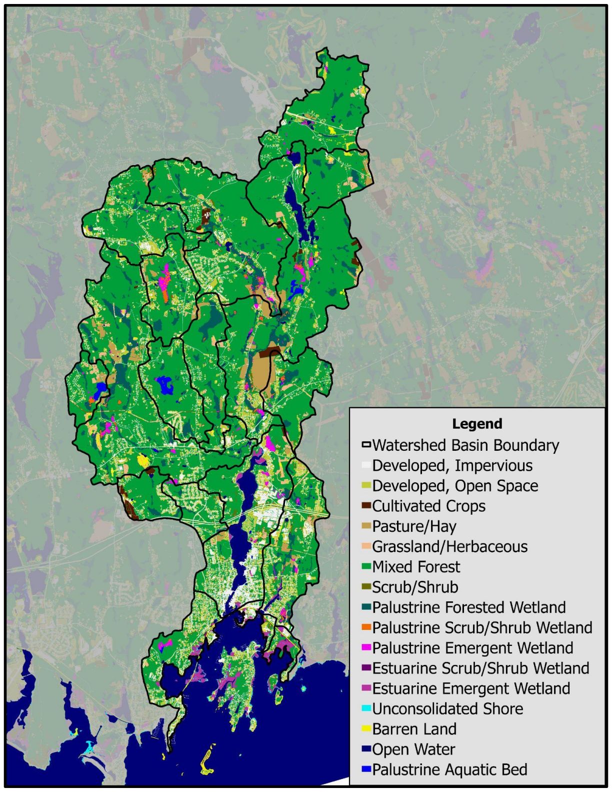

Figure 7: Map of Land Cover Uses in the Mystic River Watershed from NOAA's 2016 Connecticut C-CAP land cover dataset

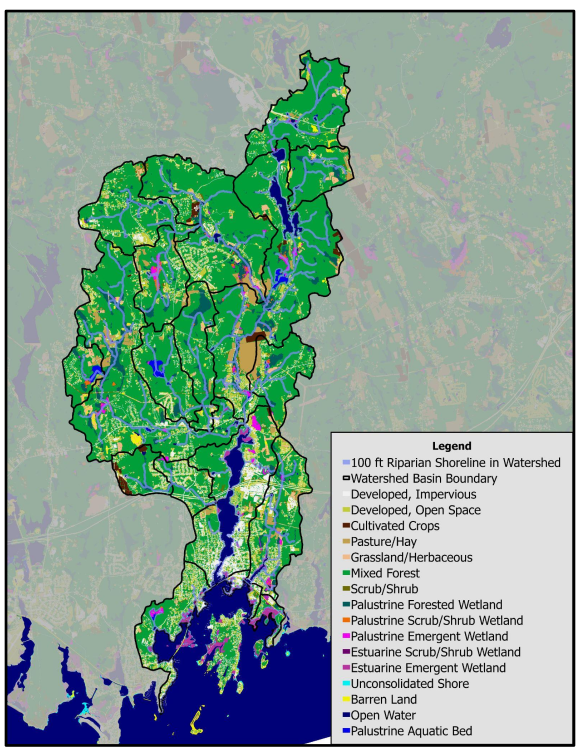

Figure 8: Map of Land Cover Uses in the Mystic River Watershed from NOAA's 2016 C-CAP land cover dataset with 100 ft riparian shoreline

In Table 1, out of the nineteen basins observed, nine were in the recovery category, seven were in the mitigation category, and only three were in the conservation category. As expected, the mitigation category contains a larger EF, agricultural and impervious cover average, while having a lower CCI and natural land cover percentage average compared to the other categories. The large amount of area that is environmentally impacted shown in Figure 9 as seen in the yellow and red basins by human development shows concern for the health of the watershed. Many of the riparian zones in the red basins are susceptible to environmental harm due to them being adjacent to impervious cover or developed space. This would result in a low CCI score as stormwater runoff or non-point pollution from buildings and farms can travel more easily into these important ecosystems, emphasizing the need for restoration measures in the riparian zone.

Table 1: Mystic River Watershed Health Categories

	Mitigation	**Recovery**	**Conservation**
Number of Basins	7	9	3
Average Impervious Cover Percent	20.49%	2.30%	1.45%
Average Agricultural-Land Like Cover Percent	15.31%	3.40%	1.71%
Average Natural Cover Percent	64.20%	94.3%	96.8%
Average CCI	0.24	0.67	0.80
Average EF	8.71	2.56	0.63

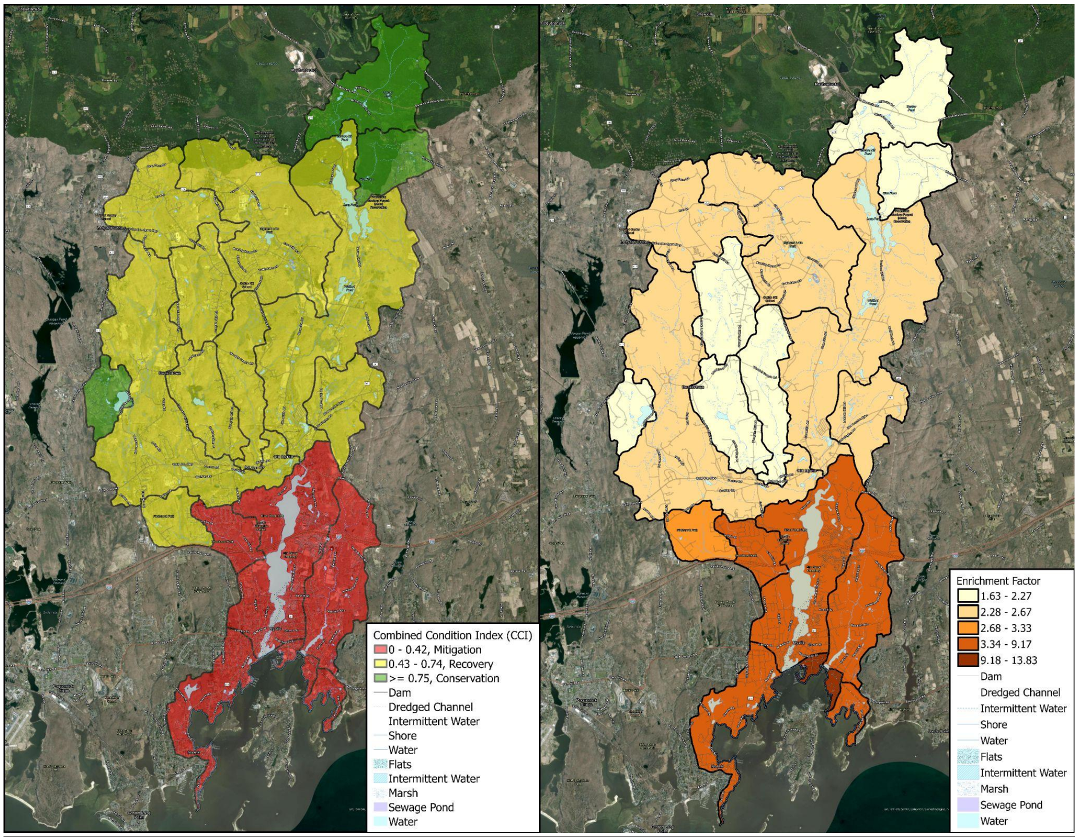

Figure 9: Map of the Combined Condition Index (left) and Enrichment Factor (right) of the Mystic River Watershed

Because there is more urban development around Mystic Harbor, the large amount of impervious surfaces reduces rainwater infiltration, leading to higher storm runoff volumes and a negative impact on streams. Urbanization can impact stream habitats by altering low flows. Urban streams experience both increased low flows from faulty water supply pipes and sewers during storm events and decreased flows due to impervious surfaces reducing infiltration, water table level, and groundwater flow rates (Bell et al. 2019). Urban impervious surfaces have a significant impact on watershed hydrology, but their linkage to stream networks via drainage channels and storm sewers also influences peak discharge and runoff. Drainage networks bypass biologically active zones, limiting urban ecosystems' ability to remove excess nutrients from the watershed caused by atmospheric deposition, imported food, and applied fertilizer (Bell et al. 2019).

The rapid transport of pollutants, facilitated by impervious surfaces and agricultural land uses that are prominent in the southern areas of the watershed, poses significant risks to human health aquatic ecosystems, and water quality. Non-point source pollution, including pathogens, nutrients, toxic contaminants, and debris, is particularly concerning, as it accumulates in water bodies via runoff, further exacerbating environmental degradation and health risks (Arnold and Gibbons 1996). Agricultural land use's negative impact on eutrophication extends beyond present farming methods, including historical nutrient inputs and management strategies prioritizing output over environmental protection. Significant amounts of nitrogen (N) and phosphorus (P) are susceptible to direct wash-off into surface waters, especially after fertilizer and manure applications or livestock grazing periods (Withers et al. 2014).

While these events may occur infrequently, their cumulative impact is exacerbated by the deposition of N and P in groundwater, soils, and sediments as a result of previous agricultural activities (Withers et al. 2014). This continuing flow of nutrients into the watershed due to increased development around the mouth of the Mystic River considerably contributes to eutrophication, posing a serious threat to the ecosystem's general health and leading to the high EF spatial distribution in the area as seen in Figure 9.

Figures 10, 11, and 12 show scatterplots of the relationship between the three different land uses: impervious cover, agricultural-like cover, and natural cover. In Figure 10, there is a moderate negative correlation between impervious cover percentage and natural land cover percentage with one outlier deviating further away from the regression line. Figure 11 shows a moderate negative correlation between agricultural land cover percentage and natural land cover percentage. Lastly, Figure 12 highlights a relatively weak positive correlation between agricultural-like land cover percentage and impervious land cover percentage. These relationships suggest that a decrease in natural land cover, coupled with an increase in agricultural and impervious surfaces can lead to various environmental stressors such as reduced biodiversity, degraded water quality, and heightened flood risks. The loss of natural land cover diminishes ecosystem services such as habitat provision, water filtration, and flood regulation, exacerbating the vulnerability of the watershed to environmental degradation and compromising its long-term resilience.

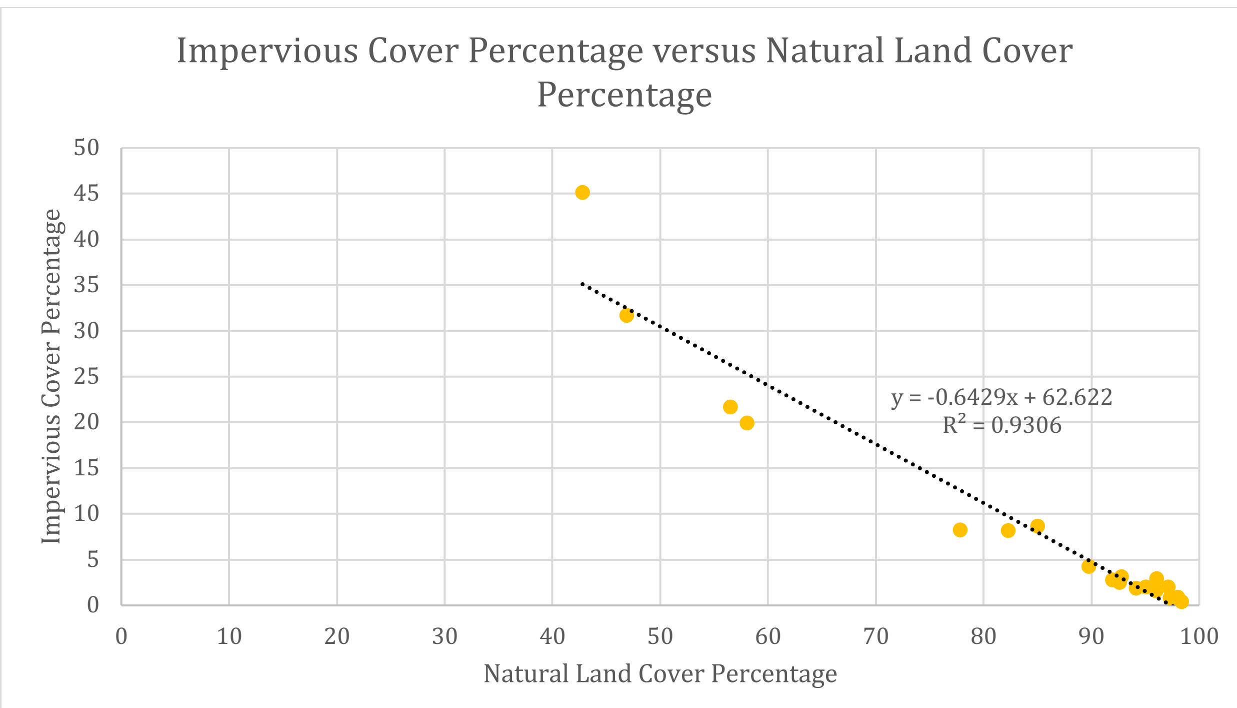

Figure 10: Scatterplot of Impervious Cover and Natural Land Cover Percentages

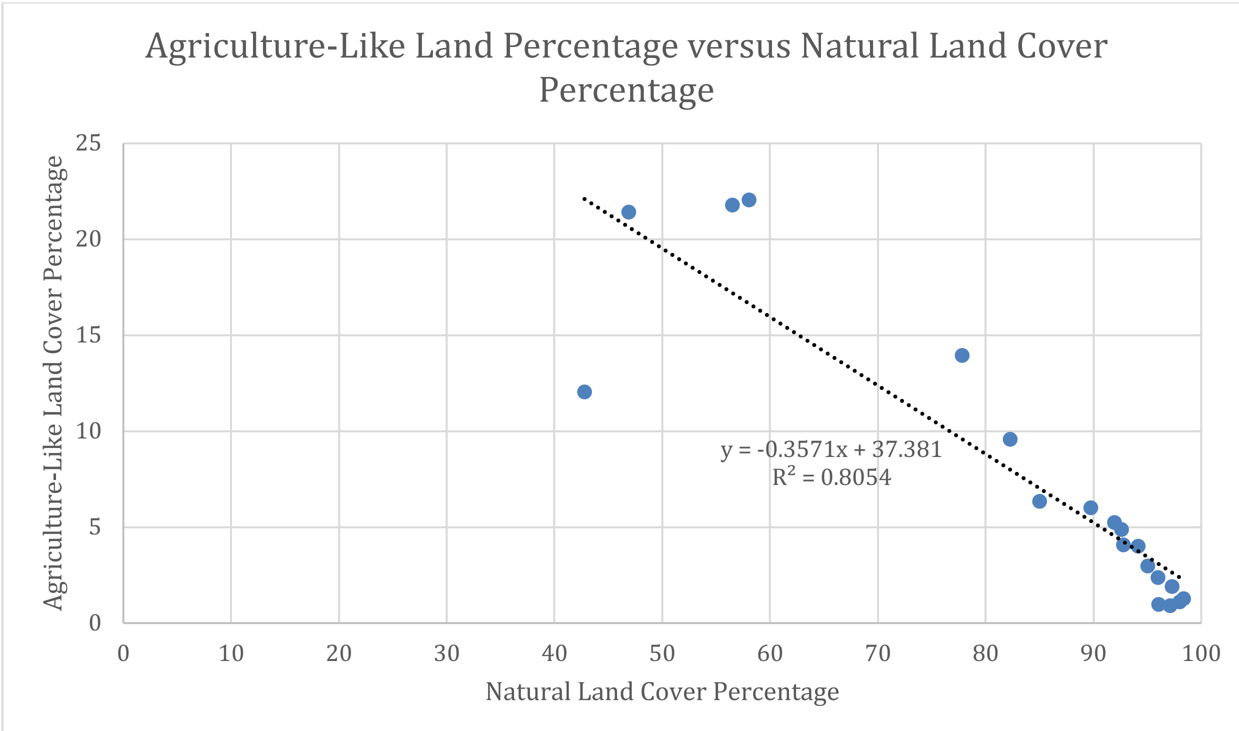

Figure 11: Scatterplot of Agricultural-Like Land Cover and Natural Land Cover Percentages

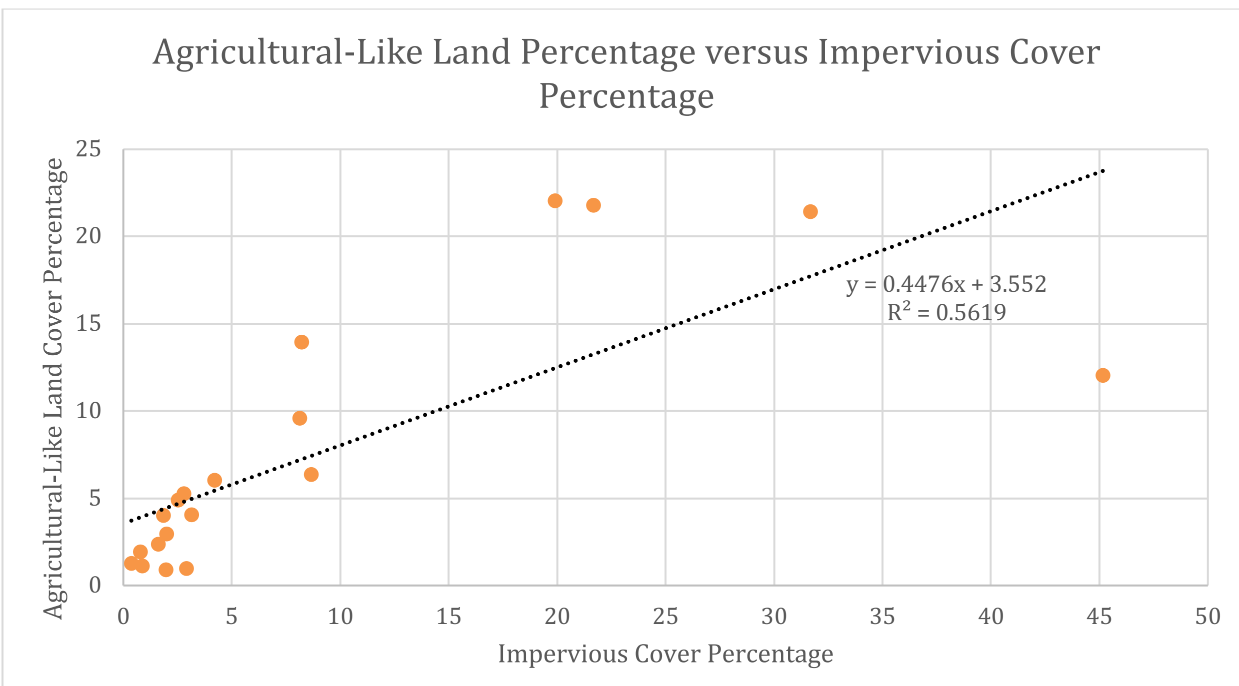

Figure 12: Scatterplot of Impervious Cover and Agricultural-Like Cover Percentages

Overall, the results show that the health of the majority of the Mystic River Watershed can be improved. Areas south of CT-184 are important to focus on due to the larger proportions of impervious cover and agriculture which are contributing to the degradation of watershed health. Conservation practices should primarily focus on improving watershed health should be focused in the mitigation basins.

Strategies to Improve Watershed Health

With the majority of the Mystic River watershed in the 'Recovery' and 'Mitigation' category, improving its health is vital for the overall human health and environmental integrity in the watershed. Western Connecticut Council of Government (WestCOG) wrote a report focusing on strategies for riparian corridor protection that have the potential to be implemented in the Mystic River watershed. One of the main strategies that the report mentioned was vegetative and forest buffer zones to reduce pollution. The report referred to a study done in the Chesapeake Bay where several studies conducted over the last three decades have shown the benefits of constructing and maintaining vegetative and forest buffer systems to reduce surface runoff and the subsequent release of pollutants (Chesapeake Bay Program Forestry Working Group 2003). The Chesapeake Bay watershed has served as a focus point for such research due to tremendous development in the area over the last fifty years, providing a platform for evaluating innovative water quality preservation techniques that can be used in the Mystic Harbor. The main finding was that forest buffer systems are successful at reducing pollutants, according to EPA and Chesapeake Bay Program research.

For example, a 1995 research by Richard Lowrance and colleagues, which expanded on the U.S. Department of Agriculture's Riparian Forest Buffer System, is especially important for places with significant agricultural and forested holdings. Soil composition, geography, hydrology, root systems, vegetation, and the presence of woody debris all play a role in determining the required width of a riparian buffer ("The Case for Riparian Corridor Protections" 2021). A vegetated buffer intercepts and filters runoff, allowing greater percolation to recharge groundwater. In addition, the buffer functions as a living filter for sediments and pollutants ("A Planting Guide for Riparian Sites Along the Connecticut Coast", n.d.).

The Connecticut Department of Environmental Protection recommended a standardized 100-foot riparian buffer width in 1991, citing numerous scientific studies linking such widths to lower levels of nitrogen, phosphorus, and suspended solids in water bodies (Moulton 1991). This recommendation inspired the formation of the 100-foot upland review area, which serves as the legal foundation for the Inland Wetland Agency's jurisdiction outside of controlled wetlands.

In response to these findings, municipalities that contain the Mystic River watershed and the Southeastern Council of Government (SECOG) should set similar goals such as establishing buffers ranging at least 100 feet to achieve comprehensive water quality improvements. While bigger buffers may provide extra benefits such as conserving wildlife habitats and migratory patterns, landowner interests and public education initiatives must be considered when supporting wider buffer zones. While riparian buffer development is critical for protecting water bodies, it should be performed carefully to maximize its influence on lowering phosphate and nitrogen levels ("The Case for Riparian Corridor Protections" 2021). Instead of implementing buffers everywhere, planning and zoning commissioners focusing on projects near the Mystic River watershed should prioritize streams and rivers where they will have the greatest impact on water quality. Efforts should focus on creating contiguous forested stream corridors, safeguarding headwater streams, and targeting areas with heavy nitrogen and phosphorus inputs.

Local land use rules are critical in controlling non-point sources of pollution such as roadway runoff, agricultural fields, erosion sites, and poor waste management. To successfully address these challenges, zoning regulations should include more thorough stormwater management guidelines, as well as suitable fertilizer and pesticide usage guidelines ("The Case for Riparian Corridor Protections" 2021).

Improving riparian ecosystem health can be done in the individual level. If you own a property within a riparian zone, there are strategies to help you with riparian water quality and watershed health. To properly manage coastal property, it is critical to prevent actions that can impair delicate ecosystems and water quality. Excessive lawn maintenance, such as frequent mowing, overfertilization, and overwatering, should be avoided to minimize nutrient-rich runoff that can harm coastal ecosystems (Barrett and Cleveland 2009). Clear-cutting or drastically modifying vegetation density near the water should also be avoided, as this can speed erosion and make the shoreline more vulnerable to flood damage. Additionally, actions such as blowing leaves and brush into the water or building multiple access paths to the sea should be avoided to prevent further damage to coastal habitats and shoreline stability. Rather, property owners should take proactive measures to manage their coastal areas, such as creating riparian buffers with native coastal plants and reducing grass size to lessen maintenance requirements (Barrett and Cleveland 2009). Maintaining an unmown buffer zone near to a coastal resource improves habitat and water quality, with larger buffers advised for properties with steep slopes adjacent to riparian regions to improve runoff mitigation efficiency.

Another strategy that municipalities can implement to improve watershed health is rain gardens. Rain gardens are shallow depressions in an area that usually contains plants and a layer of mulch or ground cover (CLEAR 2022). In addition to improving groundwater recharge, these gardens are intended to treat contaminants. The treatment process involves processes such as adsorption, breakdown, ion exchange, and volatilization. Rain gardens are frequently used in residential settings to regulate runoff from roofs and other impervious surfaces. In commercial settings, bioretention zones mimic rain gardens but are frequently larger and designed differently (CLEAR 2022). Rain gardens address the issue of runoff from impermeable surfaces such as roofs, driveways, and roads, which accumulate pollutants and greatly contribute to water pollution. Areas within the ‘Mitigation’ category can incorporate rain gardens to improve overall watershed health.

Several zoning approaches can be utilized to reduce the influx of nutrients and pollution into Connecticut's Mystic River watershed, thereby safeguarding Long Island Sound. One comprehensive approach is to restrict impermeable development throughout the watershed, acknowledging that all rainfall eventually contributes to contaminated stormwater runoff. However, this strategy may fail to successfully target the watershed's priority areas that pose the greatest danger to water quality. Another popular technique in New England is to build Riparian Corridor Protection zones along rivers, streams, and brooks. These zones serve several functions, including protecting water quality, reducing toxins, controlling erosion, and improving stormwater management (“The Case for Riparian Corridor Protections” 2021). While Connecticut's planning and zoning commissions are responsible for protecting the water quality of Long Island Sound, legislation supports the creation of multi-purpose riparian corridor protection zones. Furthermore, low-impact building options such as green roofs and pervious pavements can reduce stormwater runoff and recharge groundwater. These solutions supplement standard stormwater management practices and should be incorporated into a comprehensive management plan for Long Island Sound and its tributaries ("The Case for Riparian Corridor Protections" 2021).

Next Steps

The next stage in improving the health of the Mystic River Watershed that a future Climate Corps member can take on is to identify important regions that contribute the most to pollution and are most impacted by runoff. The watershed assessment tool also provides a scenario feature that allows users to simulate various land use scenarios and calculate the amount of land use change required to shift a basin's recovery category, providing significant insights into viable mitigation techniques. Conducting extensive geospatial assessments to identify specifically where high-impact zones are located would provide useful information for developing targeted initiatives. Once identified, measures can be targeted to address specific issues in these locations, such as establishing riparian buffer zones, using low-impact development approaches, and improving stormwater management practices. Collaboration among stakeholders, including local communities, government agencies, and environmental organizations, will be critical in successfully implementing these initiatives and producing demonstrable improvements in water quality and ecosystem health throughout the Mystic River Watershed.

Conclusion

In conclusion, this report emphasizes the complex relationship between human activities and environmental health. The spatial and qualitative data of different land uses such as agricultural methods, urbanization, and impervious surface coverage demonstrates that land use decisions have a substantial impact on the watershed's ecological integrity and sustainability. There is a necessity for focused conservation efforts and sustainable land management methods in mitigating and adapting to the negative effects of urbanization, agricultural runoff, and habitat fragmentation on water quality, wildlife habitat, and overall ecosystem health. Moving forward, interdisciplinary collaboration, community participation, and evidence-based decision-making will be critical for adopting effective watershed management plans that prioritize the Mystic River Watershed's long-term health and resilience for current and future generations.

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