APPLE COUNTRY NATURAL CLIMATE SOLUTIONS PROJECT REPORT

Bolton Mass. Incorporated 1738
Town of Harvard, Mass. Incorporated June 29, 1732
BSC Group
Regenerative Design Group
Devens Enterprise Commission
MVP Municipal Vulnerability Preparedness
Linnean Solutions
Woodwell Climate Research Center

ACKNOWLEDGMENTS

Apple Country Land Acknowledgment

We wish to acknowledge that the land where the Apple Country Natural Climate Solutions Project is taking place is on the traditional lands of the Nipmuc Tribal People. Nipmuc means the People of the Fresh Water. Faced with the dual challenges of climate change and biodiversity loss, we encourage, and endeavor to seek, collaboration with the Nipmucs and other Indigenous Peoples to work towards enhancing climate resilience and supporting biodiversity, consistent with the holistic and reciprocal relationship that Indigenous Peoples traditionally maintain with Nature.

Ecosystems Acknowledgment

We would like to acknowledge the contributions to our health and well-being from the Apple Country forests, wetlands, meadows, farms, open spaces and biodiversity including the people of Apple Country. This web of life, our common wealth, creates ecological and climatic balance and provides the basis for our resilience to climate change and other challenges.

MVP Acknowledgment

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For more information about the Massachusetts MVP Program, visit https://www.mass.gov/municipal-vulnerability-preparedness-mvp-program

Core Team and Stakeholders Acknowledgement

The Apple Country Natural Climate Solutions Project was a collaboration between the three Apple Country communities, the success of which would not have been possible without the generous contributions of time, energy, ideas and thoughts from the many community members who participated in the Core Team and Stakeholder meetings and site walks/site tours. We would like to thank everyone who participated for their generous contributions.

Photo Credits

The photos found in this report are courtesy of Rebecca Longvall, Gillian Davies, Casey-Lee Bastien, Katie Kemen, Keith Hannon, Keith Zaltzberg-Drezdahl, Eric Toensmeier, and Jim Newman. Thank you for your photographic prowess and contributions.

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The project website provides the following information and materials:

1. Home Page
2. Project Story Tab
    - Project StoryMap
    - Community Meeting Video Recording
    - Project Reports and Reference List
    - About the Forests & Trees Greenhouse Gas Inventory Tool
    - Community Survey Results
3. Field Tour Tab
    - Apple Country Self-Guided Field Tour: Bolton, Devens, Harvard
4. Data Viewer Tab
    - Interactive data viewer with map layers
5. Wetlands Tab
    - Wetlands, Climate Change + Biodiversity
    - Sustainable Development Goals
    - Rights of Wetlands
    - Links to Wetlands Organizations
    - Wetlands + Climate Change Report
    - Wetlands + Climate Change StoryMap
    - Apple Country Self-Guided Field Tour
    - Toolkit for Educators
6. Forests Tab
    - Forests + Climate Change Resources
7. Natural Solutions Tab
    - Infographic & Definitions
    - Bolton Nature-based Solutions
    - Devens Nature-based Solutions
    - Harvard Nature-based Solutions
8. Global Context Tab
    - Global Context Report
9. More Tab
    - Other Educational Resources
        - Including regional climate projections, climate science and healthy soils resources, NbS tools + fact sheets
    - Contact Us
    - Project Team: password needed
    - Project Schedule: password needed
    - Shared Documents: password needed

KEY TERMS & DEFINITIONS

Nature-based Solutions
Nature-based Solutions (NbS) refers to actions that work with nature to meet the challenges of climate change (both mitigation and resilience) and decline/loss of biodiversity, while providing benefits to humans that support sustainable development and human well-being (Seddon et al 2020). NbS is a comprehensive term that includes Natural Climate Solutions, Green Infrastructure, and Low Impact Development.

Natural Climate Solutions
Natural Climate Solutions (NCS) refers to conservation, ecological restoration and land management practices that protect, restore or enhance ecosystem carbon banks and carbon sequestration capacity in ecosystems such as forests, wetlands, grasslands and agricultural lands (Griscom et al 2017).

Green Infrastructure
Green Infrastructure (GI) is a cost-effective, efficient approach to managing water, particularly stormwater, that protects, restores, or mimics the natural water cycle and uses elements of nature to absorb and treat stormwater in proximity to where rain falls, rather than utilizing traditional "grey" built infrastructure to convey stormwater away as quickly as possible.

Low Impact Development
Low Impact Development (LID), similar to GI, refers to cost-effective, efficient development practices that mimic or utilize nature to maximize the stormwater infiltration, evapotranspiration, air quality, wildlife habitat and ecological resilience potential of a developed site.

Carbon Sequestration
Carbon sequestration refers to the process whereby atmospheric carbon dioxide is converted into living plant material and then becomes soil organic matter after the plant material dies and begins to decompose, effectively sequestering the carbon out of the atmosphere and storing it in plant and soil material.

Evapotranspiration
Evapotranspiration is a term describing the combined processes of 1) transpiration: plants, through physiologic and metabolic processes, absorbing water through their roots and moving the water up through stems, into their leaves, and then releasing water vapor through leaf stomata (similar to pores) into the atmosphere and 2) evaporation: liquid water on the surfaces of plants and land converting to gaseous form and moving into the atmosphere.

Land Cover
Land cover refers to how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water *types*.

Land Use
Land use shows how people *use* the landscape – whether for conservation, cultivation, recreation, restoration, development, or other (and potentially mixed) uses.

Apple Country

In the context of this project, "Apple Country" refers to the project study area, which includes the Towns of Bolton and Harvard and the Devens Regional Enterprise Zone. In general parlance, a larger geographical area surrounding these communities is often referred to as "Apple Country", due to the historical and current day presence of many apple orchards.

Project Purpose

Facing the global challenges of climate change and biodiversity loss and regional development pressures, the Town of Bolton, the Devens Regional Enterprise Zone and the Town of Harvard are collaborating with Nature to identify and deliver Nature-based Solutions that will increase the resilience of our communities and ecosystems. Nature-based Solutions provide cost-effective climate resilience by providing multiple co-benefits, including reduction of greenhouse gas emissions, improved water quality and water supply, reduced flooding, improved air quality, cooler local temperatures, fish and wildlife habitat and support for biodiversity, recreational and aesthetic opportunities, and improved physical and mental public health.

More specifically, this project assesses the existing natural resource assets within the project area to evaluate their climate vulnerability and/or resilience and analyzes their capacity to support the climate resilience goals of the Apple Country communities through the development of specific Nature-based Solutions. The Apple Country communities' climate resilience goals were identified during their MVP planning process.

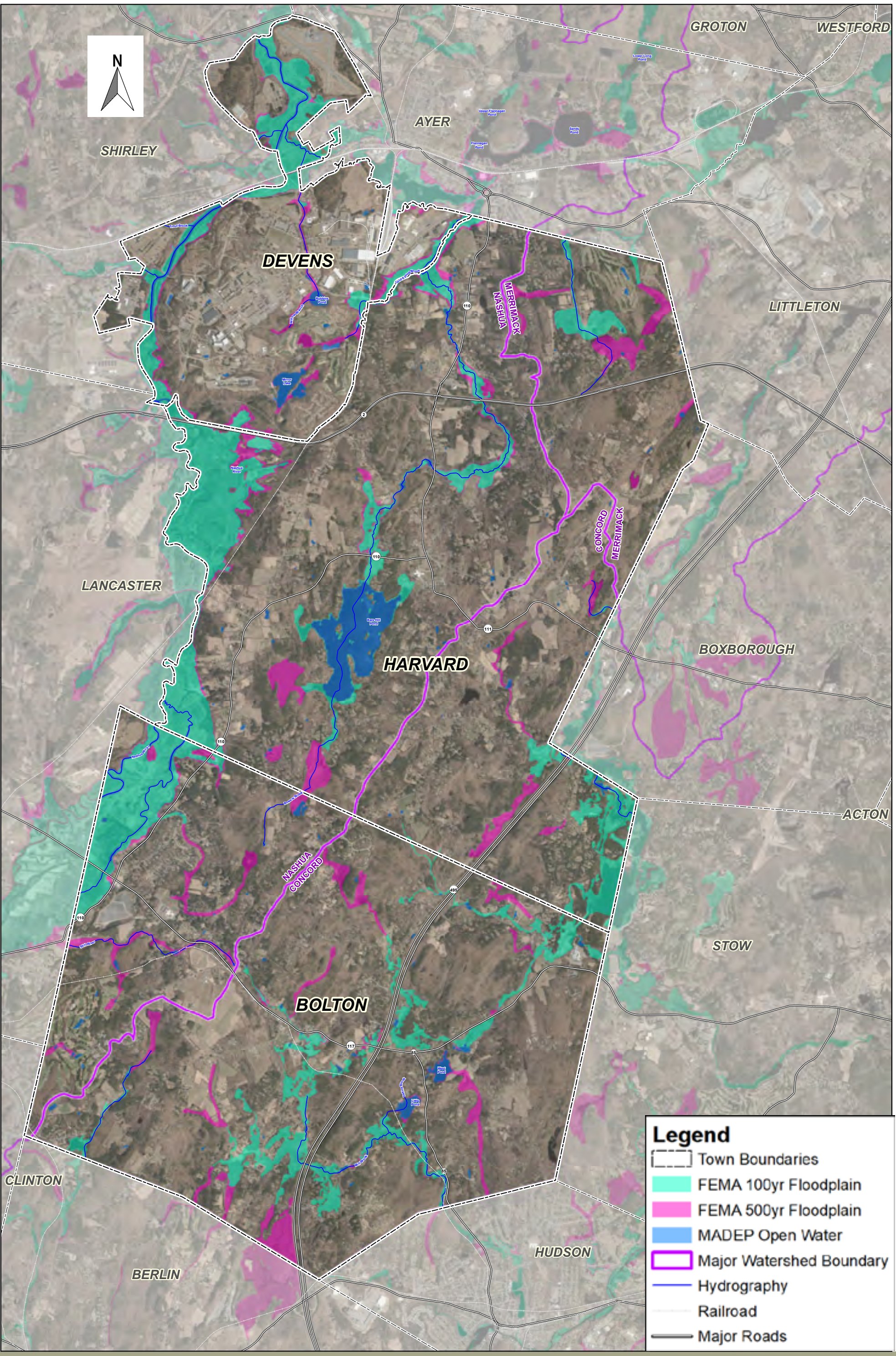

Figure i.
Apple Country Communities

Project Goals

1. Expand communities' capacity to 1) protect, 2) restore, and 3) enhance: A. **ecological climate resilience** (including biodiversity); and B. **ecosystem services** (including carbon sequestration and long-term storage) using **Nature-based Solutions**.
2. Develop and provide durable **educational materials and opportunities** for community members, leaders and organizations.
3. Provide a **replicable model for community-driven assessment** of natural resources and their capacity for climate resilient Nature-based Solutions and co-benefits, particularly ecosystem carbon sequestration and long-term storage and support for biodiversity. This model relies on a robust community engagement and outreach process that integrates outreach to, and inclusion of, under-represented groups such as Environmental Justice and Climate Vulnerable groups.

How to Use this Report

This report includes a Regional Assessment and Analysis which considers the three participating communities as a whole. Following this, the reader will find community-specific Assessment and Analysis sections, one for each of Bolton, Devens, and Harvard. While the former section highlights recommendations best implemented at the regional scale and those that are equally applicable to all of the communities, the latter sections contain recommendations applicable to the unique characteristics and existing conditions in each individual town, including soils, agriculture, forests, wetlands, turf and ornamental landscapes, and detailed site-specific recommendations for Nature-based Solutions.

A substantial amount of information is included in the report appendices, including maps; detailed discussions of data assessment and mapping methodologies and interpretations of the data and maps; downscaled climate data and information; site-specific Nature-based Solutions spreadsheets, maps, and memoranda; detailed information on the public engagement process; results from the Apple Country survey; detailed information on the Apple Country greenhouse gas assessment for forests; discussion about the Massachusetts Healthy Soils Action Plan; and a report on the global context for local Apple Country climate resilience and carbon conservation action, including explanations about, and links to, various relevant global frameworks and initiatives.

The project website (see links and menu above) provides easy access to much of the information generated by this project, and is intended to be a useful tool for the citizens of Apple Country, Apple Country leaders and staff who may be implementing many of the recommendations, educators, and citizens and staff from other communities who may find the information useful or wish to use this project as a model.

The observations and recommendations herein are intended to be relevant for a wide range of audiences, and directly actionable for community leaders and decision-makers who will be primarily responsible for implementing them. Municipal staff and volunteers, local landowners and land managers, advocates, educators, and researchers will find information and strategies geared toward supporting and furthering their ongoing work. This includes enhancing and providing education about ecological climate resilience, ecosystem services including carbon accumulation, and community awareness and involvement in land-based stewardship and planning for a resilient climate future in Apple Country.

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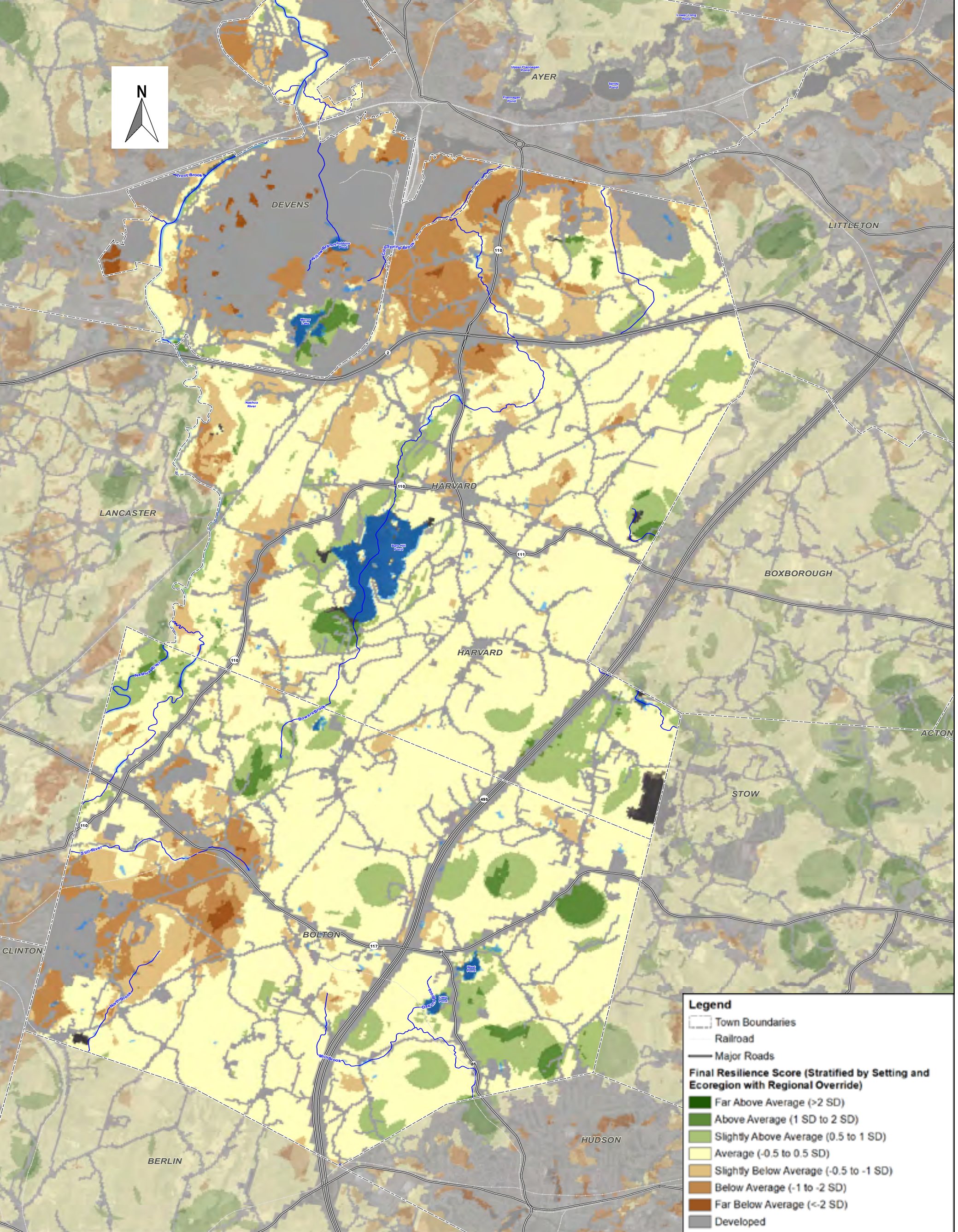
EXECUTIVE SUMMARY

Avoiding land use change for existing natural lands is the most crucial Nature-based Solution in order to ensure robust ecological climate resilience and ecosystem services in Apple Country, as it is in most of the world. Prioritizing Apple Country areas where ecological climate resilience is above, or far above, average for conservation will help ensure continued ecosystem health and delivery of ecosystem services as the century unfolds and climate changes accelerate (See Figure ii. on page 18 and Figure 1.4 on page 42, and other TNC maps in Appendix 4). Targeted ecosystem restoration, broad adoption of better land management practices, and better development processes and patterns have additional important roles to play in protecting and enhancing regional resilience as well as in conserving ecosystem carbon and supporting biodiversity. The key recommendations that emerge from this project, therefore, are grouped into four categories consisting of 1. Protect, 2. Restore, 3. Manage Better, and, 4. Develop Better. Supporting recommendations include outreach and education actions as well as research and data collection efforts.

Bolton and Harvard have a discrete window of opportunity to conserve the significant remaining healthy ecosystems as land conversion/development pressures increase. The Devens Regional Enterprise Zone (Devens), although largely developed, has some remaining natural lands that can be prioritized for conservation. Expanded application of best management practices can make a modest but important contribution, yet certainly pales in comparison to the protection of forests and wetlands from development. In general, with regard to forest and tree management, allowing existing forests and trees outside of forests, especially large-diameter trees and stands, to continue to grow and accumulate carbon is the best way to maximize carbon drawdown from the atmosphere, given that the next 10 - 30 years are critically important for removing as much



Resilience Score: A site's Resilience Score estimates its capacity to maintain species diversity and ecological function as the climate changes. It was determined by evaluating and quantifying physical characteristics that foster resilience, particularly the site's landscape diversity and local connectedness. The score is calculated within ecoregions based on all cells of the same geophysical setting and is described on a relative basis as above or below the average.

Figure ii. **Apple Country Ecological Climate Resilience Map**

carbon as possible from the atmosphere. Avoiding disturbance of high-carbon soils, particularly wetland high-carbon soils, is the best way to avoid release of soil carbon from these areas into the atmosphere. Protection of the buffer zone is important so that wetland that converts to upland during a dry period can reclaim the converted area when wetter conditions return, and so that wetland functions are protected in general. Protecting intact, connected lands, such as riparian corridors and floodplains (both existing and future floodplains) and large forested tracts (see Forests, below) contributes to hydrologic connectivity and supports biodiversity, which increases resilience to flooding, storm damage and drought, improves habitat, and protects water quality and water supply.

Degraded and disturbed wetlands, forests, floodplains and soils on agricultural land and turf/ornamental areas offer opportunities for restoration of ecosystem functions and services, including restoration of the capacity to store and accumulate carbon and support biodiversity. Areas where ecological climate resilience is rated as average or slightly below average may offer opportunities for ecological restoration and removal of existing stressors so that these areas can become more climate-resilient (see Figure ii. (left) and Figure 1.4 on page 42, and other TNC maps in Appendix 4).

Recommendations to increase the value of ecosystem services focus on:

- Implementing site-specific Nature-based Solutions as identified and explained in Town-specific sections for Bolton, Devens, and Harvard, Appendices 10, 11, 12, and on the project website NbS page.

- Planting trees and/or facilitating natural regeneration of areas that are currently lacking tree cover,
- Restoring hydrologic connections and river/stream/floodplain/wetland health and connectivity,
- Restoring soil health, including increasing soil organic carbon, for all land cover types where soils have been degraded.

In order to achieve a "no net loss of forests and farms" and "no net loss of soil organic carbon" a strong effort to convert paved landscapes to planted landscapes will be necessary. Bolton and Harvard have a window of opportunity to restore and conserve significant degraded ecosystems before land conversion/development pressures increase. Devens is a leader in sustainable development and has great opportunities and capacity to implement ecological restoration projects, in addition to conserving remaining healthy ecosystems. Other communities in the region may wish to look to Devens as a model for sustainable development that integrates ecological restoration into development projects.

Increasing resilience on the farms of Apple Country requires a four-fold approach consisting of:

- Protection from development (see Protect, above),
- Education and technical assistance to help farmers implement management practices that address climate vulnerabilities,
- Improved access to equipment and financial assistance to remove barriers to changing practices,
- Cooperation with local and state governments to ensure climate resilient farm management practices are allowed.

The benefits of local food production should be weighed carefully with the carbon costs and watershed impacts of the conversion of forests to agriculture when making land use decisions in the coming decades.

Key Statistics

- The UMass Donahue Institute projects the population of Harvard and Bolton to increase by roughly 23% by 2040, requiring the development or redevelopment of many acres in Apple Country.
    - Data suggest that a minimum of 2,000 acres of land are likely to be developed between 2021 and 2050 in Apple Country, the majority of which will replace both actively managed and less managed lands including forests or pastures with low-density residential housing.
- The estimated carbon content of Apple Country soils is approximately 2.9 million metric tons (equal to 10.8 million tons of CO_2).
    - Wetland soils are the most carbon-dense soils; occupying 16% of Apple Country land, wetlands contain 27% of Apple Country SOC.
    - Forests are major carbon banks as well. They occupy 49% of Apple Country land, and contain 53% of Apple Country SOC. In addition, forested lands, including wetland forests, contain the largest quantity of above-ground biomass carbon of all land cover types.
- Carbon flux in the living landscapes of Apple Country results in an estimated annual net gain of 4,300 tons of CO_2 equivalent.

    - Total ecosystem-based carbon sequestration, primarily in trees, wetlands, and soils, is estimated by this team to be roughly equivalent to 75% of town-based emissions for Bolton and Harvard. For Devens, it has been estimated to be approximately 25% of community-based emissions.
- Within Apple Country there are a combined 13,286 acres of soils of agricultural importance. Only ten percent, or 1,383 acres, of these more productive soils are actively farmed.
    - Apple Country Total Estimated Soil Organic Carbon (SOC) Stocks: 2.8 Million Metric Tons
        - Forest SOC: 1,573,332 t
        - Wetland SOC: 758,288 t
        - Turf, lawn, and ornamental landscape SOC: 114,729 t
        - Agricultural SOC: 80,133 t
        - Other SOC: 270,116 t

Key Observations

- Land use change (development) is, and always has been, the biggest threat to forests and wetlands functions including climate resilience and ecosystem carbon, both above and below ground.
    - While there has been strong development pressure in the broader region, the Town of Harvard has experienced very little forest loss to development over the past 15 years. The reasons for this should be investigated and understood so as to ensure continued avoidance of conversion of forests to development.
- The Nashua and Still Rivers and Bowers Brook/Cold Spring Brook and adjacent floodplains, wetlands and forests connect all three Apple Country communities and present an opportunity to protect and enhance regional resilience and ecosystem services.
    - Apple Country's FEMA 100-year and 500-year floodplain mapping correlates strongly with areas that are highly ranked in TNC Ecological Climate Resilience, BioMap2 Core and Critical Natural Landscapes, Index of Ecological Integrity mapping, and as priorities for soil regeneration mapping.
- Many opportunities for Nature-based Solutions (NbS) exist in Apple Country. This project has identified and analyzed many NbS in each of the Apple Country Communities. Appendices 10, 11, 12, and the project NbS website page provide specific details in this regard, including:
    - An NbS spreadsheet that identifies and prioritizes specific NbS that are appropriate at several specific sites in each community
    - Aerial photography maps showing where the identified NbS can be implemented
    - Memoranda that provide scalable thumbnail project scopes and costs for each type of NbS and one that outlines typical project planning and permitting processes.

On June 10, 2021, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Intergovernmental Panel on Climate Change (IPCC) released a joint report recognizing that neither climate change nor biodiversity loss can be resolved successfully unless they are addressed together.

Key recommendations from the report (Portner et al 2021) are:

- **"Stopping the loss and degradation of carbon- and species-rich ecosystems on land and in the ocean, especially forests, wetlands, peatlands...**
- **Restoring carbon- and species-rich ecosystems. The authors point to evidence that restoration is among the cheapest and quickest nature-based climate mitigation measures to implement... thus enhancing resilience of biodiversity in the face of climate change, with many other benefits...**
- **Increasing sustainable agricultural and forestry practices to improve the capacity to adapt to climate change, enhance biodiversity, increase carbon storage and reduce emissions."**

Key Recommendations

Regional recommendations prioritize protection and conservation of key landscapes of high climate value. Restoration and regeneration strategies can help to reclaim ecological functioning and associated climate benefits, including ecological resilience and carbon sequestration. Next, managing natural landscapes using innovative strategies and Best Management Practices can maximize their potential to adapt to a changing climate and continue to thrive and provide healthy habitat and ecosystem services. Development practices can maintain and enhance the functions of natural systems, or they can degrade and destroy them. Regenerative development principles offer a lens through which better development can be realized.

Below are the key recommendations for each of the major categories identified (Protect, Restore, Manage Better, Develop Better). Supporting the report's regional recommendations are strategies for outreach, education, research, and data collection that can engage and inform communities, and enable leaders and stakeholders in Apple Country to demonstrate the effectiveness and replicability of their approaches. See the full Regional Recommendations section for more information.

Protect

Accelerate conservation of areas with high climate value, prioritizing areas at highest risk of development.

Where "climate value" can be understood as the overlap of:

- Areas of high ecological climate resilience; and
- Areas of high ecosystem services value (e.g. carbon sequestration and storage, stormwater management).

See Figure 1.9 (page 46) for a map of key carbon banks and Figure 1.4 (page 42) for an overview of ecological climate resilience in Apple Country.

Restore

Prioritize restoration efforts that connect existing healthy ecosystems.
Connectivity is a key ecological principle and priority for climate resilience. Strategies for increasing connectivity include reforestation, pocket forests, verge and ornamental plantings, agroforestry, and floodplain, hydrologic and wetland restoration.

Restore native species and resilient tree cover strategically where opportunities exist.
Limit tree planting to native species and consideration of some slightly more southern species that will not become invasive, as a hedge against warming conditions. Plant

climate-threatened trees where microclimate conditions create an advantage such as higher elevations, northeast exposures, or cooler, shaded ravines.

Manage Better

Evolve management practices for forests, wetlands, agricultural and ornamental lands.
This should include invasive species management, planting species strategically to enhance climate resilience, supporting threatened native species and ecosystems (such as vernal pools), and mimicking native ecosystems in landscaped areas. Adopting climate-smart farming practices that protect and build soils, maintain clean waterways, support biodiversity, and ensure a consistent food supply will also contribute to ecological climate resilience and ecosystem services provisioning.

Expand management planning and explore new funding mechanisms.
Engage in proactive planning for watershed and sub-watershed resilience (including floodplain restoration) at the regional scale. Develop land cover management plans and guidance documents that prioritize conservation of ecosystem carbon, climate resilience ecosystem services, and biodiversity while also addressing landowner goals. Establish a Healthy Soils Program to reward management practices that preserve and enhance ecosystem health. Direct investments in regional agriculture and food systems to assist farmers with training and equipment costs for transition to practices which increase soil health.

Develop Better

Direct solar development toward previously developed sites and degraded soils.
Develop local programs to incentivize solar development on already developed lands where co-benefits are high such as parking lots, flat roofs, roadsides, and brownfields. Create or update local bylaws for siting ground mounted solar energy production facilities.

Update wetlands regulations and performance standards.
Explicitly recognize climate resilience and carbon accumulation (sequestration and storage) as contributions of wetlands. Develop climate resilience and ecosystem carbon performance standards for each type of wetland that is protected by state and local regulations. Establish conversion fees and penalties for damaged or converted wetlands that account for value of services provided for ‘impact period’ until full carbon stocks are restored.

Expand general climate resilience performance standards and incentives.
Create a comprehensive Soil Protection and Post-Construction soil performance standard to protect and maximize soil health during and after site development. Require that green infrastructure and other Nature-based Solutions are integrated into development and redevelopment projects to mitigate or regenerate loss of ecosystem services.

Explore the potential for regional Transfer of Development Rights.
Explore the potential to institute an inter-municipal Transfer of Development Rights framework, emphasizing areas in Harvard and Bolton with high climate values as the sending regions and establishing Devens as the receiving area. There is sufficient infrastructure to support additional density and growth in Devens, provided it incorporates Nature-based Solutions and other sustainable development approaches.

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PROJECT OVERVIEW

Introduction

The Town of Bolton (Bolton), the Devens Regional Enterprise Zone (Devens) and the Town of Harvard (Harvard) communities (Apple Country communities), located in a part of central Massachusetts that historically has been known for its orchards, agriculture, rivers and forests, and where current development pressures are high, initiated the Apple Country Natural Climate Solutions Project (Apple Country Project) through a Massachusetts Executive Office of Energy and Environmental Affairs (EEA) Municipal Vulnerability Preparedness (MVP) Action Grant to identify and assess potential Nature-based Solutions (NbS) and Natural Climate Solutions (NCS) within the project area.

In contributing to achieving climate resilience goals, the Apple Country Project identified and assessed potential Nature-based Solutions (NbS)/Natural Climate Solutions (NCS) that help offset hazards from our changing climate, such as increased flooding, increased extreme and variable weather, increased disease vectors and increasing extreme heat and drought. Re-establishing a stable climate, and preventing catastrophic climate destabilization, depends in part upon conserving, protecting and restoring the ecosystems, and the biodiversity that comprises those ecosystems, that support human well-being by storing and purifying water, supporting food production, storing carbon, protecting against severe storms and floods, providing shade and localized cooling, improving air quality, mitigating pollution, and providing habitat for fish and wildlife. Because biodiversity is an essential element of our ecosystems and their functioning, the Apple Country Project includes supporting and enhancing biodiversity as a climate resilience and climate mitigation strategy.

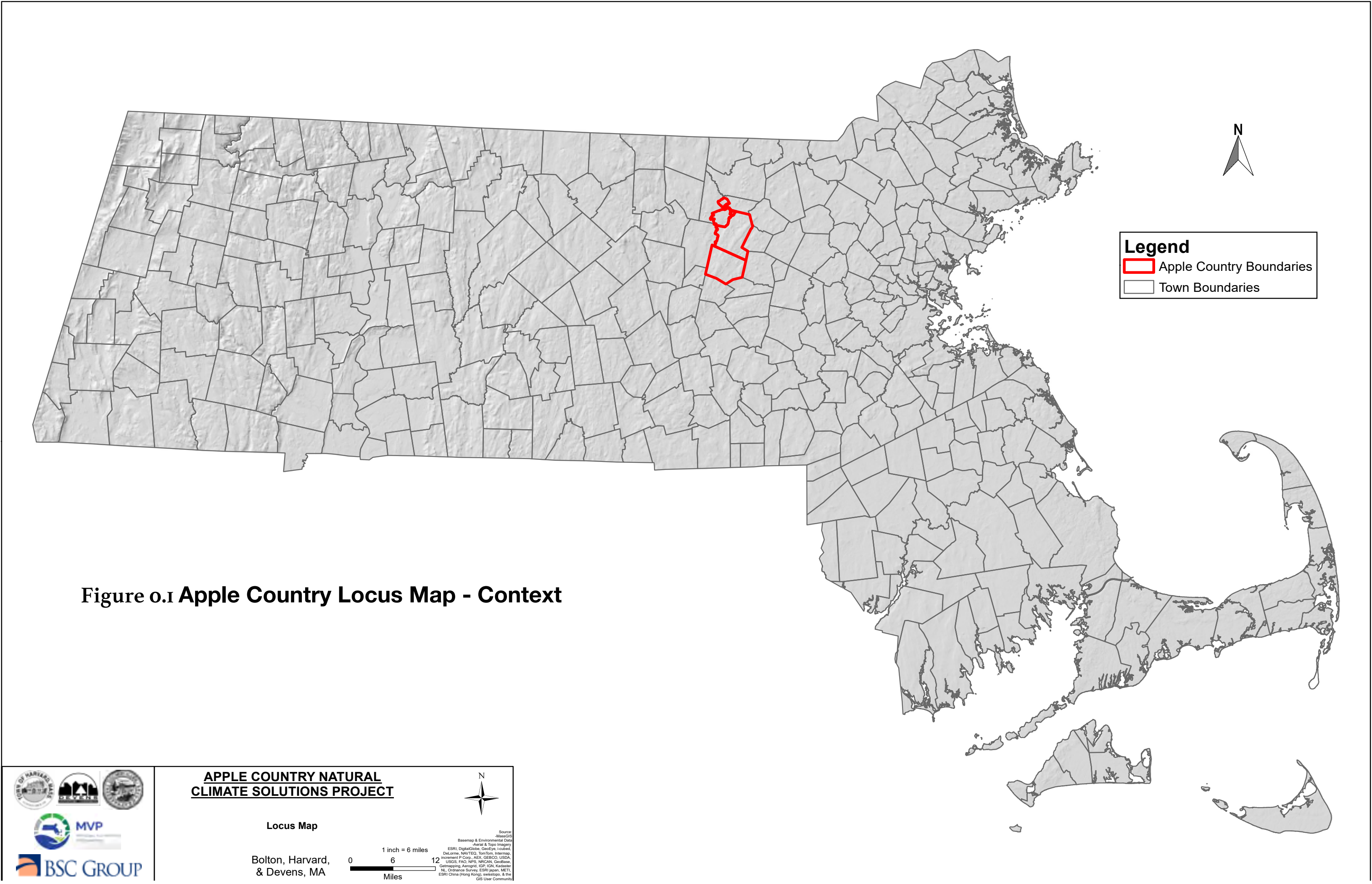


Figure 0.1 **Apple Country Locus Map - Context**

The Apple Country communities contracted with BSC Group, Inc (BSC), Linnean Solutions (Linnean), Regenerative Design Group (RDG), and Woodwell Climate Research Center (WCRC) to provide the necessary consulting services to implement the Apple Country Project with community leaders, stakeholders, and citizens. This report is intended to provide a planning-level assessment of opportunities to develop specific NbS/NCS and associated long-term management strategies for addressing the challenge of climate change. The report results from a coarse-scale screening of natural resource assets within the project area.

Regional Setting: Apple Country

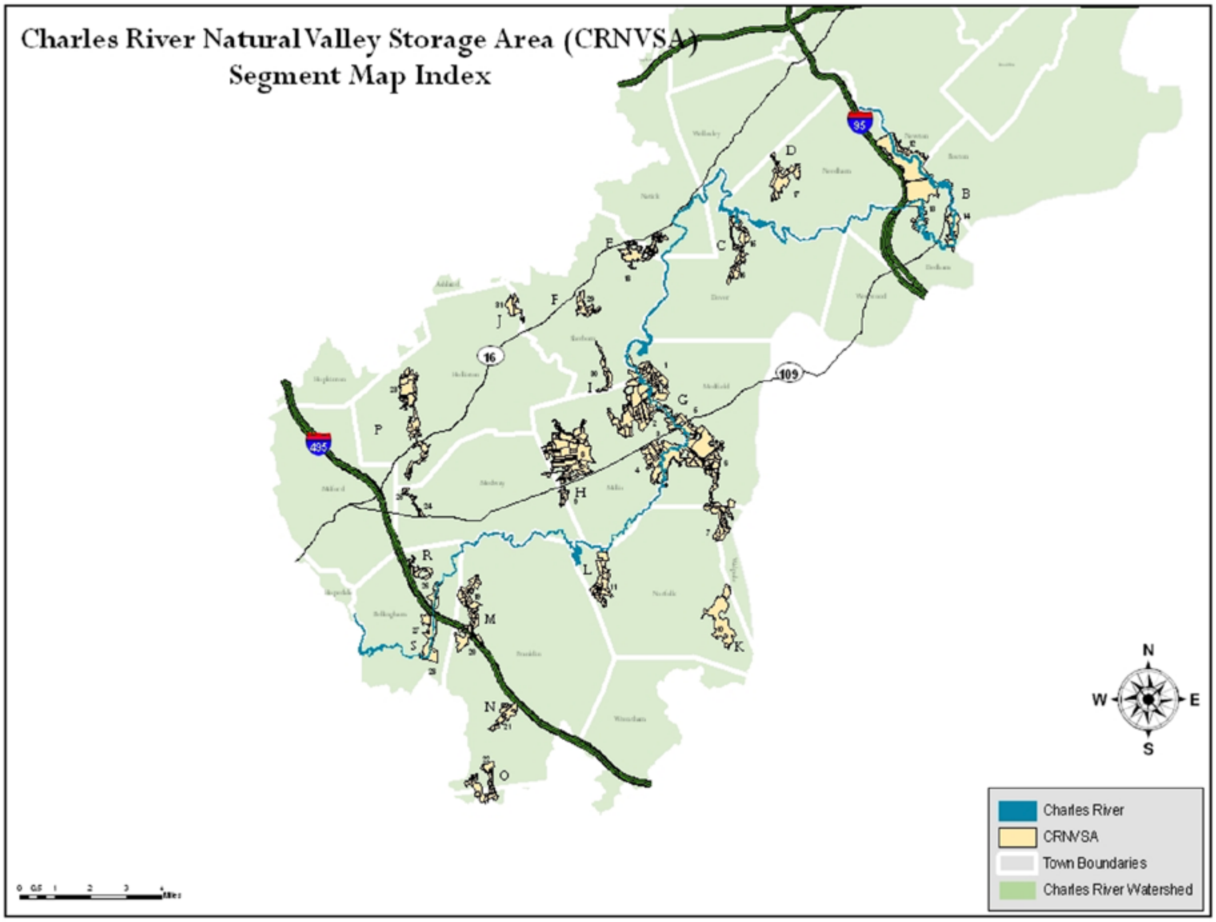
The project study area, "Apple Country", comprising the Towns of Bolton and Harvard and the Devens Regional Enterprise Zone, is situated 15 miles northeast of Worcester and 30 miles northwest of Boston placing it in the suburbs of Massachusetts' two largest cities. Relatively more affordable housing, compared to Boston's inner suburbs, and convenient access to the Boston-metro area via Route I-495, Route 2, and the Fitchburg commuter rail line place Apple Country squarely in the Massachusetts region experiencing some of the most intense pressures from development. Its apple orchards, farm stands, country stores and fairs, and outdoor recreation attract visitors from within the Nashoba Valley and across eastern and central Massachusetts. Finally, as headwater towns for the Nashua, Concord and Merrimack Rivers, the ecological functioning and environmental stewardship decisions made in the region have implications for downstream communities in these watersheds.

Within the region, Bolton and Harvard are characterized by extensive forests and wetlands, productive farmland, and active floodplains laced by roads and low-to-medium density development. Devens, a former army base, includes important natural resources, but also sustains the largest areas of degraded lands within the Apple Country project area. These degraded areas are being redeveloped strategically, using smart-growth principles and other innovative planning approaches that foster restoration and conservation of natural spaces while supporting economic development. The forests, wetlands, meadows, farms, and turf/ornamental lands in these communities play an essential role in the ecological functioning, carbon functioning, and provision of, and need for, community and ecological climate resilience in the wider region. Despite the valuable natural resources of these three communities, Apple County's location in the region of Massachusetts experiencing some of the most significant development pressure exacerbates the effects of climate change on these communities and highlights the urgency of protecting the natural resources that provide substantial climate-related ecosystem services.

Why Nature-Based Solutions?

As recognized by the Massachusetts Municipal Vulnerability Preparedness Program, which prioritizes NbS, NbS are cost-effective approaches to addressing the dual challenges of climate change and decline/loss of biodiversity, while supporting human well-being and sustainable development. NbS practices and strategies work with nature to sequester and store atmospheric carbon in biomass and soil, and provide a wide range of ecosystem services that enhance ecosystem and community resilience to the hazards associated with our changing climate, such as increased flooding, drought, high heat, incidence of pests, invasive species and diseases, and more severe storms. In addition to providing the desired climate mitigation and resilience ecosystem services, NbS deliver a variety of co-benefits, such as improving public health, improving water quality, supporting biodiversity, providing recreational, educational and spiritual opportunities, improving wildlife habitat, supporting social needs, and aesthetics.

Natural Climate Solutions (NCS) refer to NbS that specifically address reduction of carbon in the atmosphere (climate mitigation) by supporting the removal of atmospheric carbon and storage in ecosystems through natural processes. Green Infrastructure (GI) and Low Impact Development (LID) are NbS terms that are often associated with management of water, particularly stormwater. All four terms include practices and strategies that are encompassed by more than one definition. See page 4 for more specific definitions of these terms.



Source: U.S. Army Corps of Engineers

Figure 0.2. Charles River Natural Valley Storage Area Project

A highly successful example of a NbS in Massachusetts has been the Charles River Natural Valley Storage Project, in which 17 wetlands located in the middle and upper part of the Charles River watershed were purchased to provide flood storage. This project is estimated to have prevented $6 million in flood damages, with the purchase of 17 wetlands saving millions of dollars when compared to the cost of constructing a flood control structure.

The excerpt below describes the radical land alterations that European colonizers made to the lands that are now known as Apple Country. It does not discuss the Native Peoples who were forcibly displaced by the colonizers or the significant ecological degradation caused by these changes.

Worcester County Soil Survey, 1985 (excerpt)

"The first [European colonizers] established their farms and towns on the uplands. They cut and burned the forests and removed the stones to clear the land for farming. In the mid-1800's about 80 percent of the land in the survey area was cleared for crops, hay, or pasture. The developing industrial enterprises utilized the abundant streams as sources of power, and the workers built houses near the mills and factories.

The early agriculture was almost entirely self-sufficient. Farmers grew wheat, corn, potatoes, buckwheat, flax, vegetables, and fruit for family use. They produced meat, butter and cheese, eggs, and wool. In time, small surpluses were produced for market in the larger towns.

Still later, markets developed in Boston, Providence, and Springfield. The peak of agriculture came during the Civil War. Later, the opening of land in the West and the advent of railroads and canal systems aided the development of the Nashoba apple belt. The Nashoba apple belt includes the towns of Berlin, Bolton, Harvard, Lancaster, Leominster, and Sterling and towns just north of the survey area. This area still leads the northeast in the production of apples (in 1985).

Timber apparently was never produced on a sustained yield basis in the survey area, even during the height of the lumbering industry. At present, about 43 percent of the land in the survey area is wooded. Most of the woodland is in poor condition and is harvested mainly for firewood and fence posts. A small portion ofthe woodland is actively managed for timber production and Christmas trees." (page 2)

Terms and Definitions

Brief definitions of NbS terms are listed below, along with links to websites that provide additional information.

Nature-based Solutions (NbS) refers to actions that work with nature to meet the challenges of climate change (both mitigation and resilience) and decline/loss of biodiversity, while providing benefits to humans that support sustainable development and human well-being (Seddon et al 2020). NbS is a comprehensive term that includes Natural Climate Solutions, Green Infrastructure, and Low Impact Development. Seddon et al (2021) recommend the following four principles to ensure that outcomes provide the anticipated benefits, and do not inadvertently undermine intended goals:

1. NbS do not replace or slow down the rapid phase-out of fossil fuels.

2. NbS encompass many natural ecosystems on both land and in the ocean.

3. Implementation of NbS occurs through engagement and consent of Indigenous Peoples and local communities in a manner respecting cultural and ecological rights.

4. Benefits for biodiversity must be explicitly designed into NbS.

To learn more about Nature-based Solutions, visit: Nature-based Solutions Initiative (University of Oxford).

Natural Climate Solutions (NCS) refers to conservation, ecological restoration and land management practices that protect, restore or enhance ecosystem carbon banks and carbon sequestration capacity in ecosystems such as forests, wetlands, grasslands and agricultural lands (Griscom et al 2017). Fargione et al (2018) estimate that if implemented, 21 specific NCS interventions have the potential to sequester and store the equivalent of 21% of the 2018 net annual emissions in the United States. To learn more about Natural Climate Solutions visit: US Nature 4Climate website: https://usnature4climate.org/?%2F.

NbS/NCS include many Green Infrastructure (GI), and Low Impact Development (LID) Best Management Practices (BMPs), which are described below.

Green Infrastructure (GI) is a cost-effective, efficient approach to managing water, particularly stormwater, that protects, restores, or mimics the natural water cycle and uses elements of nature to absorb and treat stormwater in proximity to where rain falls, rather than utilizing traditional "grey" built infrastructure to convey stormwater away as quickly as possible. Examples include bioswales, rain gardens, riparian buffers, pervious pavement, green walls and roofs, tree plantings, and wetland and floodplain restoration, among others. To learn more about Green Infrastructure, visit: https://www.epa.gov/green-infrastructure/what-green-infrastructure and https://www.americanrivers.org/threats-solutions/clean-water/green-infrastructure/what-is-green-infrastructure/.

Low Impact Development (LID), similar to GI, refers to cost-effective, efficient development practices that mimic or utilize nature to maximize the stormwater infiltration, evapotranspiration, air quality, wildlife habitat and ecological resilience potential of a developed site. LID minimizes paved surfaces while protecting, restoring, and/or creating green spaces. Examples include rain gardens, green walls and roofs, rain barrels and other water conservation/efficiency methods, implementation of healthy soils practices, and wetland, floodplain and forest conservation and restoration. To learn more about LID, visit https://www.epa.gov/nps/urban-runoff-low-impact-development.

Massachusetts Climate Policy Landscape

Massachusetts has long been a leader in U.S. progressive climate policy, particularly through investment in sectors with high greenhouse gas emissions like energy, transportation, and buildings (US Climate Alliance, 2020). Massachusetts has recently enacted legislation to reduce net GHG emissions (link here), which commits the state to achieve Net Zero emissions in 2050 and authorizes the Secretary of Energy and Environmental Affairs (EEA) to establish an emissions limit of no less than 50% reduction from 1990 levels for 2030, and no less than 75% reduction from 1990 levels for 2040. The bill also includes strong provisions for environmental justice in deploying climate-related programs.

The approaches endorsed in the legislation include significant roles and targets for sectors that emit GHGs, but little involving the land base or natural climate solutions. However, three new plans -- the Massachusetts 2050 Decarbonization Roadmap, the Resilient Lands Initiative, and the Healthy Soils Action Plan -- build on earlier Massachusetts leadership with recommendations and policies to protect and restore the carbon sequestration and storage potential of all of the lands in the Commonwealth.

The Massachusetts 2050 Decarbonization Roadmap's Land Sector Report focuses on impacts to terrestrial carbon from three principal drivers: forest growth, conversion of forests to development, and commercial forestry. The Roadmap's analysis, as it relates to Apple Country, predicts losses to above-ground carbon stocks due to conversion of forest cover to buildings, lawns, and other ornamental landscapes. While the Roadmap's land use and land cover scenarios suggest that Massachusetts forests will continue to be a net carbon sink by 2050, its authors recommend further inquiry to build out existing data to inform better policy. Two key recommendations are to explore additional change scenarios that diverge from current and historical trends, and to expand beyond carbon accounting to consider the many community resilience co-benefits of forests in decision-making.

Co-benefits of forests and other land covers are acknowledged in the ***Resilient Lands Initiative (RLI)*** and ***Massachusetts Healthy Soils Action Plan (MA HSAP)*** reports, whose policy recommendations nest carbon sequestration and storage within a larger framework of resilient and restorative land management. Protecting resilient ecosystems mitigates negative impacts from land conversion, land management, and climate change. This framing is especially relevant in the context of Apple Country, a region likely to see significant development in the coming decades. Several key strategies from RLI explicitly link the need for Nature-based Solutions that address ecological and community health, especially in Environmental Justice areas and other regions that are disproportionately impacted by climate change.

The findings and recommendations of the MA HSAP align with RLI's insights, albeit through the lens of land cover change and land management impacts on soil health. Like RLI, the MA HSAP prioritizes the protection and expansion of the Commonwealth's significant carbon sinks, namely forests and wetlands. Similarly, MA HSAP notes the inevitability of land conversion, with two of its six priority actions calling for healthy soils programs and standards for developed lands.

Each of these plans establishes targets that are at once aspirational and achievable. The communities of Apple Country have the opportunity to lead the way in the implementation of some of the Commonwealth's climate-smart land-based goals, including:

- No Net Forest Loss (RLI, MA HSAP)
- No Net Wetland Loss (RLI, MA HSAP)
- No Net Soil Organic Carbon Loss (MA HSAP)

To achieve these goals, Apple Country communities will need to minimize conversion of forests and wetlands to other land cover types and uses; restore degraded lands by rewetting drained wetlands, removing fill from filled wetlands, and reforesting unused open lands, and create local incentives and bylaws to support this work. For more details, please see the recommendations sections.

Global Context for Local Action

The climate adaptation, resilience and carbon mitigation actions and recommendations in this report are supported by global frameworks and international agreements that attempt to limit global warming, preserve and enhance biodiversity and wetlands, reverse habitat loss, and develop sustainable communities and societies in the process. The United Nations Intergovernmental Panel on Climate Change (UN IPCC) has warned of the catastrophic consequences of exceeding a 1.5-2°C increase in average global temperatures, and set forth a vision for a Decade of Action to dramatically reduce greenhouse gas emissions and begin to reverse the effects of climate change. Local actions, such as the NbS recommended in this report, are critically important for meeting these global targets. Climate change and biodiversity loss are global problems with local solutions. Please see Appendix 5 and the Apple Country website Global Context page for further discussion of this global context for local action.

Public Involvement, Community Engagement, and Outreach

Broad public involvement was integral to the success of the Apple Country Natural Climate Solutions project. Community members contributed key technical expertise, historical and institutional knowledge about the communities, as well as diverse perspectives that generated and prioritized potential solutions for restoring and enhancing the region's ecological and community resilience. All meetings other than site tours and walks were conducted virtually to maintain safety and comply with public health guidelines during the COVID-19 pandemic.

Community involvement and engagement began with the establishment of a Core Team. The Core Team was composed of municipal staff from the three communities, residents, volunteer members of local organizations, regional and state content experts, and the consulting team. Over the course of four meetings, the Core Team provided guidance regarding stakeholder outreach, identification of locations for site visits, and feedback on proposed NCS/NbS.

Two stakeholder groups were also convened. The first centered on farmers and open space managers (land managers who intensively manage their lands). The discussion focused on land management practices and opportunities to protect, regenerate, and enhance soil health. The second was centered on forests and wetlands (land that is typically not as heavily managed). This group discussed goals for these types of lands and threats from potential land conversion. Information shared in both Core Team meetings and stakeholder meetings was used to inform areas of focus for subsequent agricultural, turf, forest, and wetland site tours to observe land management practices and outcomes at a variety of locations across the region.

In late 2020, three site walks occurred (one in each of the three project communities) with the goal of identifying specific NbS/NCS actions and strategies to protect and enhance ecological resilience. Each Apple Country community's Core Team selected the specific site walk locations that were assessed, based on their local knowledge of climate vulnerabilities and strengths and their priorities for NbS/NCS. These site walks involved a total of over 30 locations. Results are presented in Appendices 10-12 and shared on the project data viewer and NbS webpage. For example, the team looked at locations with a known history of flooding and assessed opportunities for specific NbS that could be implemented at each particular site. Due to the COVID-19 pandemic, a limited number of Town staff, property owners and managers, and the consulting team attended these walks. However, both the site tours and site walks were recorded, and in some cases live-streamed, to allow virtual participation by additional interested individuals.

Following the site walks, a third Core Team meeting was held to share results and gain further feedback from Core Team members. A fourth Core Team meeting was held to present key findings of this report, answer questions, and obtain feedback on the draft report.

Specific stakeholders, especially those representing community members who will be most vulnerable to the impacts of climate change, were contacted individually for their feedback on the project. Representatives from Indigenous groups connected to the United Native American Cultural Center (UNACC) in Devens also participated in the project, sharing historical knowledge of the land, traditional knowledge, and insights on ways to heal and restore the region's ecosystems. Members and affiliates of the UNACC were consistent participants in the Apple Country and continue to engage with ongoing Apple Country projects.

Broader community engagement and outreach occurred through multiple means. A project website (https://climateresilient.wixsite.com/applecountry) was launched early on which includes project background and information, educational materials, and an interactive regional data viewer. In the late winter of 2021, a community survey was administered to collect broad input as the consulting team developed its recommendations. Over 130 people participated in the survey. Results are compiled in Appendix 9. Educational

(below) Apple Country Team assesses Still River floodplain soils in red maple (*Acer rubrum*) floodplain swamp, while observing COVID-19 pandemic protocols. December 8, 2020, MassWildlife Bolton Flats Wildlife Management Area, Bolton, MA

materials and information pertaining to the role of wetlands in providing carbon storage and climate resilience have also been developed, to bring the work of the project to town residents. A StoryMap about the Apple Country project and one about wetlands and climate change have been developed and added to the project website, to provide further educational material for the community. Finally, a community meeting was held on May 20, 2021 to invite community discussion on the draft project findings and recommendations. More information on the public involvement and community engagement effort can be found in Appendix 1.

Screenshot of some of the Apple Country Team members during the Apple Country Community Meeting webinar held via Zoom during COVID-19 pandemic. May 20, 2021.

1

APPLE COUNTRY REGIONAL ANALYSIS AND OPPORTUNITIES

This section documents existing conditions and NbS opportunities within Apple Country's three communities. The maps, tools, and data presented enable the Apple Country communities to identify and prioritize: 1) the most ecologically valuable, carbon-rich and climate resilient ecosystems (including agricultural ecosystems) for protection/ conservation; 2) opportunities for ecological restoration and enhancement of community and ecological climate resilience and carbon storage/ sequestration functions through NbS and to identify; 3) policies and regulatory responses that support NbS and their many co-benefits; and 4) Best Management Practices relevant to supporting climate resilient, carbon-protective and healthy soils, agriculture, forests and wetlands/floodplains; and 5) lands that are at greatest risk from future development.

The assessments and analyses presented are built upon the best available climate change and ecological data, including prior and ongoing climate change data and reporting conducted by the communities, information gathered using various mapping, and online tools described throughout the report and in the Appendices, and site visits in each of the three communities. The findings based on analysis of these data and information were enriched and guided by a robust set of community engagements and field investigations described in the **Public Involvement, Community Engagement, and Outreach** section of the Introduction to this report.

Natural resource assets, including soils, farmland, forests, wetlands and other ecosystems, were evaluated based on their climate vulnerability/resilience, carbon storage/sequestration, and their capacity to support the community and ecological climate resilience, and carbon conservation goals of Apple Country. The project's collaborative approach and regional scope offer unique opportunities to implement NbS on a scale that can positively impact shared and significant natural areas that define the character, culture, and ecology of these Apple Country communities and the greater surrounding region.

Each Town-specific section of this report provides assessments, analysis, and recommendations specific to each of the Apple Country communities, whereas this regional report section provides assessments, analysis and recommendations that are regional in nature or that can be applied in any of the three communities.

Land Cover Scenarios and Projections

All land covers, whether highly modified such as impervious parking lots or relatively wild such as forested wetlands, shape the ecological performance and climate resilience of a region. By understanding the current composition of Apple Country's land cover, vulnerabilities to climate change and other disturbances as well as opportunities for conservation and restoration can be discovered. These insights can help identify the type, number, and location of Nature-based Solutions to address these vulnerabilities and increase resistance and resilience to climate disturbances.

What is the difference between land cover and land use? **Land cover** indicates the **physical land type** such as forest or open water, whereas **land use** documents how people are **using the land.**

Land cover data documents how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types. Water types include wetlands or open water. Land use shows how people use the landscape – whether for development, conservation, or mixed uses. The different types of land cover can be managed or used quite differently.

Land cover can be determined by analyzing satellite and aerial imagery. Land use cannot be determined from satellite imagery. Land cover maps provide information to help managers best understand the current landscape. To see change over time, land cover maps for several different years are needed. With this information, managers can evaluate past management decisions as well as gain insight into the possible effects of their current decisions before they are implemented.

Apple Country Land Cover

About two-thirds of Apple Country is currently classified as forest according to the Mass-GIS data for 2016 (Figure 1.1, Table 1.1). Bolton and Harvard each have about 70% of the area classified as forest (including forested wetlands), with Devens having a significantly smaller area of forest at 48%. The area of developed lands (land cover determined by human actions) is also highly variable, with Devens showing 38% developed, Bolton 14%, and Harvard 13%. Grassland is the third most common cover class followed by non-forested wetland. There are small areas of cropland in Bolton and Harvard.

The total area of wetlands, including both forested and non-forested wetlands, is 2000 acres or 15.5 percent of the total land area in Apple Country (Table 1.1). The percentage of wetland area in Devens is significantly less than Bolton or Harvard.

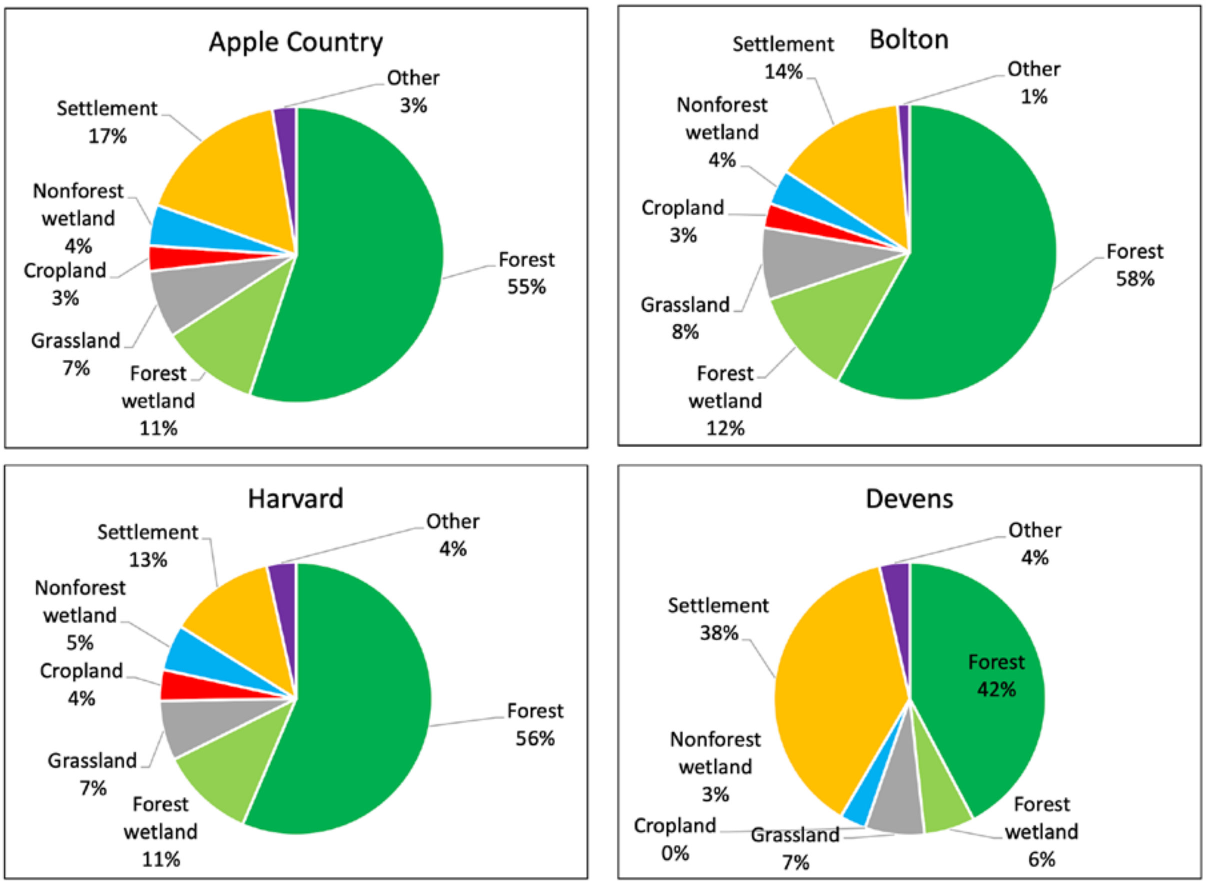


Figure 1.1. ***Percent area by land cover class from Mass-GIS data, 2016. The category labelled "forest" includes areas covered with trees that are classified as "non-forest", to be compatible with the broad land cover classifications as defined by the USGS National Land Cover Data. Areas for the detailed Mass-GIS classifications are shown in Table 1.1.***

Table 1.1 ***Area data by detailed land class based on Mass-GIS data. Detailed classifications were aggregated to the broad land cover classes typically used in national and international reporting of land-based GHG emissions and removals. Areas for Harvard do not include areas within the Devens jurisdiction. Based on the detailed classifications, the total areas and percentages of wetland in Apple Country are shown in the footnote[1].***

Land classes	Bolton	Harvard	Devens	Apple Country
Forest				
Deciduous Trees- non forest (9)	582	667	199	1,449
Evergreen Trees- non forest (10)	198	208	52	458
Forest (11)	6,689	7,417	1,620	15,727
Palustrine Forested Wetland (13)	1,503	1,653	267	3,424
Total forest	**8,973**	**9,946**	**2,138**	**21,057**
Grassland				
Pasture or Hay (7)	533	560	4	1,096
Grassland or Herbaceous (8)	356	359	261	975
Scrub/Shrub (12)	122	124	47	294
Total grassland	1,011	1,042	312	2,365
Total cropland (6)	345	543	0	887
Non-forest wetland				
Palustrine Scrub/Shrub Wetland (14)	117	146	22	286
Palustrine Emergent Wetland (15)	377	655	117	1,149
Total wetland	495	801	139	1,435
Settlement				
Impervious (2)	714	747	750	2,211
Developed or Open Space (5)	1,144	1,109	932	3,185
Total settlement	1,858	1,857	1,682	5,396
Other				
Unconsolidated Shore (19)	0	0	0	0
Barren Land (20)	65	32	59	156
Open Water (21)	98	389	94	581
Palustrine Aquatic Bed (22)	7	89	7	102
Total other	169	511	159	839
Total land and inland water	12,850	14,700	4,430	31,980
[1]Combined areas of wetlands:				
Wetlands total	1,998	2,454	406	4,859
(percent)	15.5	16.7	9.2	15.2

Mass Audubon's 6th edition of Losing Ground shows that the communities of Apple Country are located in the I-495 corridor outside of Boston, a region of rapid development in Massachusetts (Audubon 2020). This area, characterized by low-density suburban development, is nested within the Northeast Megaregion, a swath of increasingly urbanized lands from Boston to Washington, D.C. (Atlas for a Green New Deal). Land use pressures within this megaregion - and the disastrous effects to biodiversity from continued conversion to urban cover - are also recognized by global initiatives like the Half-Earth Project (see Global Context Appendix 5 and project webpage), which aims to reverse the ongoing extinction of the natural world. Many factors contribute to how any one site will be used in the future and accurately predicting this change is very difficult at the site level. However, examining historical trends in land use and land cover can provide a mechanism for estimating likely changes at the community and regional scale.

To understand likely land cover change, this study primarily looked at the data from The New England Land Futures Project (NELF) to determine the amount and location of new development with,the USDA Cropland Data Layer (CDL), the National Land Cover Dataset (NLCD), and the MassGIS 2016 Land Cover/ Land Use data to determine land cover change. Together these data suggest that a minimum of 2,000 acres of land are likely to be developed between 2016 and 2050 in Apple Country, the majority of which will replace lands such as forests and farms with low-density residential housing.

The 'Likely Developed Acres' used in the calculations and discussion of land consumption on carbon fluxes and stormwater dynamics found in this report are based on the NELF 'Recent Trends Scenario'. For more on

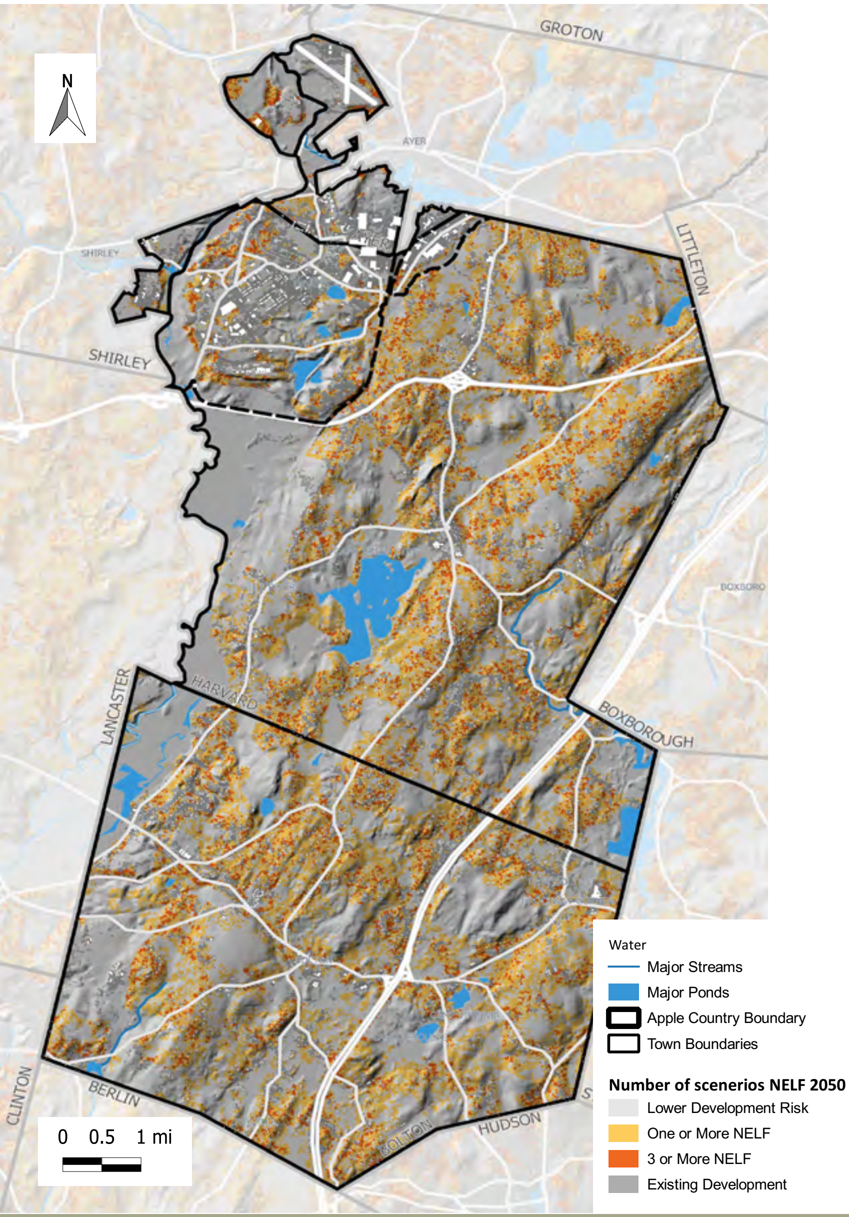
Table 1.2 ***Acres Impacted by New Development by 2050, "Majority Developed" Composite Analysis of New England Land Futures Data in Apple Country***

Receiving Land Cover (2016 data)	Acres	% of Land Change
Upland Forests	1,427	68.2%
Turf, Lawn, and Landscaped	161	7.7%
Wetlands, including forested wetlands	154	7.4%
Isolated Trees	153	7.3%
Impervious/ Paved	138	6.6%
Grassland	41	2.0%
Pasture and Hay	9	0.4%
Annual and Perennial Cropland	9	0.4%
Total Developed Acres	**2,092**	

the methods used here and a description of NELF mapping, see Appendix 3.

Population growth, changing housing preferences, and internal migration are some of the factors driving this development (EOEEA, 2020). The UMass Donahue Institute projects the population of Harvard and Bolton to increase by roughly 23% by 2040 (Donahue Institute Online Mapping Tool), requiring the development or redevelopment of many acres in Apple Country. Applying thoughtful planning practices like smart-growth principles and natural resource conservation zoning (NRCZ)

Figure 1.2: ***Likelihood of Development by 2050, New England Land Futures Scenarios***



can shape the form of development and its attendant ecological, aesthetic, and economic impacts. NRCZ, for example, is the act of restricting development in an area to protect an important or vulnerable natural resource. According to the Pioneer Valley Planning Commision, floodplain bylaws restricting all development are the most common form of NRCZ ordinances. High carbon or erodible soils, environmentally sensitive water tables, and upland catchment areas of wetlands are a few types of natural resources that could be protected with local action. The planned redevelopment of the former Fort Devens Army base offers many other examples of innovating planning.

Watershed-Scale Projections for Climate Change

Climate change has already had observable effects on the environment. Consistent with other parts of the Northeastern US, changes in Apple Country include continued rising temperatures, changes in precipitation patterns, more frequent droughts and heatwaves, and extreme storm events. The following section includes downscaled climate projections for heat and precipitation from the Northeast Climate Adaptation Science Center (2018) for the Nashua watershed basin, which includes all three Apple Country communities as shown on the Resilientma.org website. Portions of Apple Country also lie within the Merrimack basin and Sudbury-Assabet-Concord (SuAsCo) basin. Detailed climate projections for all three can be found in Appendix 6 and on the project website. Projections are reported for a high (RCP 8.5) greenhouse gas emissions scenario which assumes “business as usual” emissions. Although greenhouse gas reduction pledges have been made at local, state, national, and global levels, this more conservative emissions scenario has been chosen because we have not yet begun to slow the progress of global temperature change. The most recent global climate modeling (Climate Model Intercomparison Project 6) and real-world observations indicate global temperatures are rising faster than previously expected. The UN Environment Programme (UNEP) has confirmed that GHG emissions have continued to increase despite scientific warnings, increased policies and societal attention, and governmental pledges. The organization estimates that the 2019 level of climate action sets Earth on a course to increase the global average temperature by 3.0°C-3.2°C (twice the preferable target of 1.5°C) by the end of the century (UNEP 2019).

Heat

The region is expected to experience increased average temperatures throughout the 21st century. In the Nashua watershed basin, summer and fall are expected to see the greatest increases in maximum temperatures. While the average summer temperature in the region was 68.8°F between 1971-2000, it may be as high as 78°F (a 9% increase) by 2050 and 82°F (a 16% increase) by 2090. Due to these increases in maximum temperatures, the region is projected to experience more extreme heat days (days >90°F) increasing from 4 days at baseline (1971-2000) to almost 75 days by end of century, including potentially 16 days over 100°F (Northeast Climate Adaptation Science Center, 2018). Projections from the University of Maryland Center for Environmental Science estimate that by 2080, the current (2020) climate in Massachusetts will feel similar to the current climate in Maryland which is 7.7°F warmer and almost 16% drier (Fitzpatrick & Dunn, 2019).

Extreme heat days are notable for several reasons. They increase the risk of heat stress for people, in general, and especially for outdoor workers, and they can exacerbate respiratory illnesses. Extreme heat can result in power outages due to increased demand on the electric grid for air conditioning, damage roads due to thermal expansion, and potentially lead to tree mortality and other ecological impacts. The greatest increases in minimum temperatures are anticipated during the winter and fall. While historically, between 1971-2000, 4 out of every 10 days of the year had a minimum temperature below freezing, that could shrink by almost half by the end of the century. By 2050, winter temperatures could average above freezing (32.2°F), up from the baseline 25.2°F (Northeast Climate Adaptation

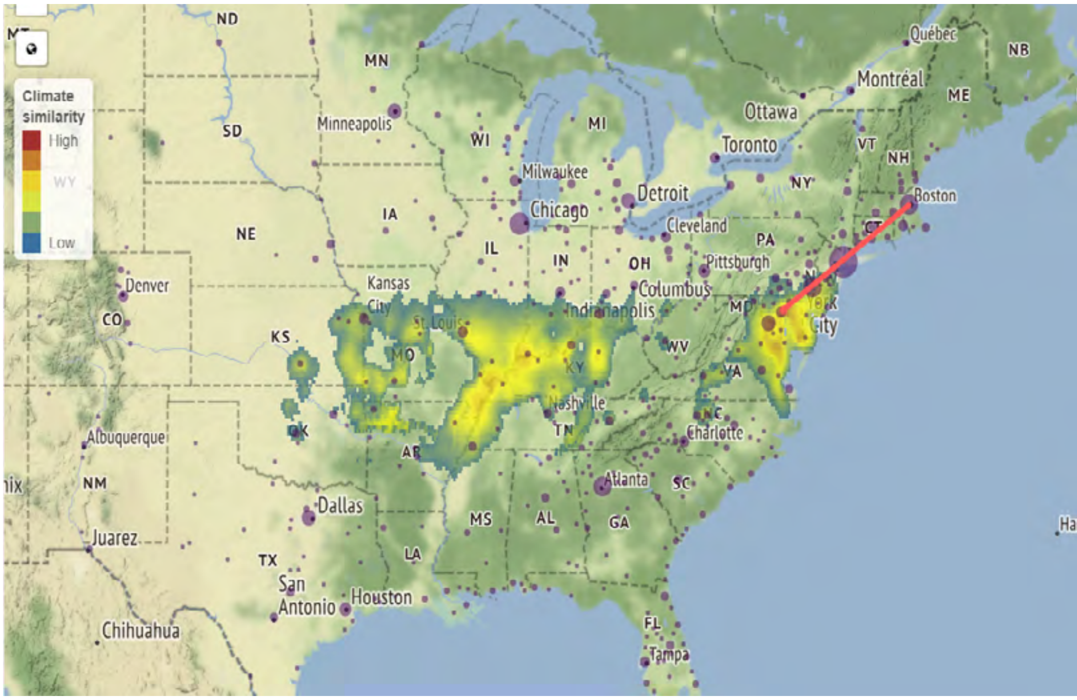


Figure 1.3: ***Map showing climate shift from 2020 to 2080. Worcester, MA's climate in 2080 will feel similar to today's climate in Baltimore, MD. Source: University of Maryland Center for Environmental Science***

Science Center, 2018). Marked changes of this nature are expected to have significant ecological effects, not least of which is the northward migration of cold-intolerant pests and diseases that will no longer be excluded by regular deep freezing. Economic impacts in agriculture (fruit production) and forest products, such as New England's maple syrup and cranberry production, as well as foliage and snow-centric tourism, are expected. Growing degree days are a measure of accumulated heat units over the growing season. Crops and pests typically have a temperature range in which growth and development occurs; below or above this range, there is little growth. Due to changing temperatures, Apple Country can expect an increase in growing degree days, however, this increase will primarily occur through warmer spring and fall seasons which could increase growing degree days in these seasons by up to 178% and 195%, respectively, by the end of the century (Northeast Climate Adaptation Science Center, 2018).

While many sources acknowledge that longer growing seasons and increased atmospheric carbon dioxide may stimulate plant growth, these same conditions also support the growth of pests, crop diseases, and invasive species. Regarding pests specifically, rising temperatures are expected to increase the rate at which insects digest food, causing them to demolish crops faster, and warmer temperatures are more suitable to cold-blooded insects allowing them to become more active and more able to reproduce (Deutsch *et al.* 2018). Soil respiration is also anticipated to increase, changing soil conditions.

In 2019, the Town of Harvard studied the impact of climate change on agriculture as part of its MVP Planning Grant efforts and identified the following key impacts related to warmer average temperatures and extreme heat events:

- Warmer weather for longer periods will increase the growing season for many crops and the development of tree fruit will begin earlier. It will also allow insect pests to complete more life cycles per year allowing populations to grow and may require additional insecticide sprays.
- Warmer than usual temperatures in the winter may allow pests to survive that would normally die off due to cold winter temperatures.
- Warmer than usual fall days can affect the hardiness of fruit tree buds making

***Table 1.3:* Select temperature projections for the Nashua Watershed Basin**

Nashua Watershed Basin		Observed Baseline 1971-2000 (Days)	Mid-Century Projected Change in 2050 (Days)*	End of Century Projected Change in 2090 (Days)*
Days with Maximum Temperature Over 90°F	Annual	4	+9 to +30	+13 to +70
	Summer	4	+8 to +26	+ 11 to +56
	Fall	<1	+<1 to +3	+1 to +10
Days with Minimum Temperature Below 32°F	Annual	156	-19 to -38	-23 to -64
	Summer	85	-2 to -8	-4 to -20
	Fall	31	-9 to -15	-9 to -22

Source: Northeast Climate Adaptation Science Center 2018
***Higher end of ranges apply to a high-emissions (i.e., "business as usual") emissions scenario assuming significant reductions in greenhouse gas emissions do not occur.**

them less resilient to extreme cold snaps. Temperature fluctuations in the spring expose tree flowers to freezing damage.
- The number of chilling hours per year will decrease which may mean some apple varieties which require more than 1,200 chilling hours cannot be grown in the region (Harriman & Cooley, 2019).

Precipitation
The Northeast United States has already experienced a larger increase in the intensity of rainfall events than any other region in the United States in the last fifty years, a trend that is expected to continue. The region may receive more than 52” total annual precipitation by 2050 compared to a 1971-2000 baseline of 45.9”, an almost 14% increase. The greatest increase in precipitation is expected during the winter season, with the region potentially experiencing an increase of up to 22% by 2050 and up to 39% by 2090 (Northeast Climate Adaptation Science Center, 2018). Earlier in the century, this additional winter precipitation may fall as snow but the majority will fall as rain as temperatures continue to increase later in the century.

As described in the Harvard, MA report on agriculture and climate change, these changes in precipitation can have multiple impacts such as:
- Extreme precipitation events cause soil erosion and runoff of fertilizer, manures, and pesticides into surface water;
- Increased wet weather will increase plant diseases, because fungi and bacteria grow best under wet conditions and can be more easily spread in rainy weather;
- Wet weather makes pest management more difficult by washing pesticides from plants and making it difficult to apply pesticides; and
- Prolonged rain in the late summer and fall can severely damage crops and make harvest difficult (Harriman & Cooley, 2019).

Precipitation in the summer and fall seasons is more variable and may either increase or decrease throughout the 21^{st} century. Consecutive dry days are also variable; however, due to combined effects of higher temperatures, reduced groundwater recharge from extreme precipitation events, and earlier snowmelt, summer and fall droughts may become more frequent (Northeast Climate Adaptation Science Center, 2018).

Erratic weather, extreme heat, and more frequent droughts pose challenges to wetlands, forests, agriculture and healthy soils. Drier than normal conditions and drought can cause drying of wetlands (Moomaw *et al.* 2018) and stress plants, whether wetland, forest, agricultural or other land cover types. In agricultural settings, extreme heat can reduce plant growth if air and soil temperatures exceed a crop’s optimal levels. As available water levels in the soil are reduced through extended droughts, this effect becomes more pronounced (Irmak, 2016).

Organic matter, made up of 58% carbon, serves as a battery for both water and nutrients (Natural Resource Conservation Service, 2021). Reductions in growth can also reduce the amount of carbohydrates, the building block of soil organic matter (SOM), that crops and other plants can deposit into the soil. Without new SOM, the ongoing metabolic activity of soil organisms and natural oxidation can result in net losses of organic matter from farm soils, making them even more vulnerable to many forms of extreme weather (Craggs, 2016).

Ecological Climate Resilience

Ecological climate resilience refers to the persistence of healthy functioning ecosystems and biodiversity as the climate changes and the ability of these natural systems to recover from climate-related disturbances while adapting to longer term changes. The Nature Conservancy (TNC) suggests the metaphor of a stage (geophysical and ecological setting) where the actors (species) may change, but the stage remains and continues to support a changing cast of characters (species), healthy ecological functions and ecosystem services (see: Conserving Nature's Stage). Resilient landscapes are anticipated to be more effective at sustaining exemplary habitats and rare species. Often, they will be both more biodiverse, and more effective at sustaining biodiversity at all levels (genetic, population, species) over time (Anderson *et al* 2016b).

The climate resilience of human communities tends to be greater when communities are integrated into a landscape that includes healthy ecosystems (MA EOEEA Adaptation Advisory Committee 2011), and thus human well-being as the climate changes is integrally tied to the well-being and resilience of the ecological systems and biodiversity that supports life. For instance, communities that are proximate to healthy and functioning floodplains, salt marshes, forests and freshwater wetlands generally experience fewer problems with flooding than similar communities with highly impacted aquatic and wetland ecosystems.

Resilient landscapes and ecosystems tend to be those with the following characteristics (Anderson *et al* 2016b):

- A wide range of landscape, landform, and microclimatic diversity, which tend to be created by diversity in topography, elevation and hydrology;
- Low levels of human disturbance, pollution and modification;
- Connectivity at both the local and the landscape scale, which supports movement of abiotic materials, individuals, populations and species in response to climatic changes; and
- Minimal barriers to species movement.

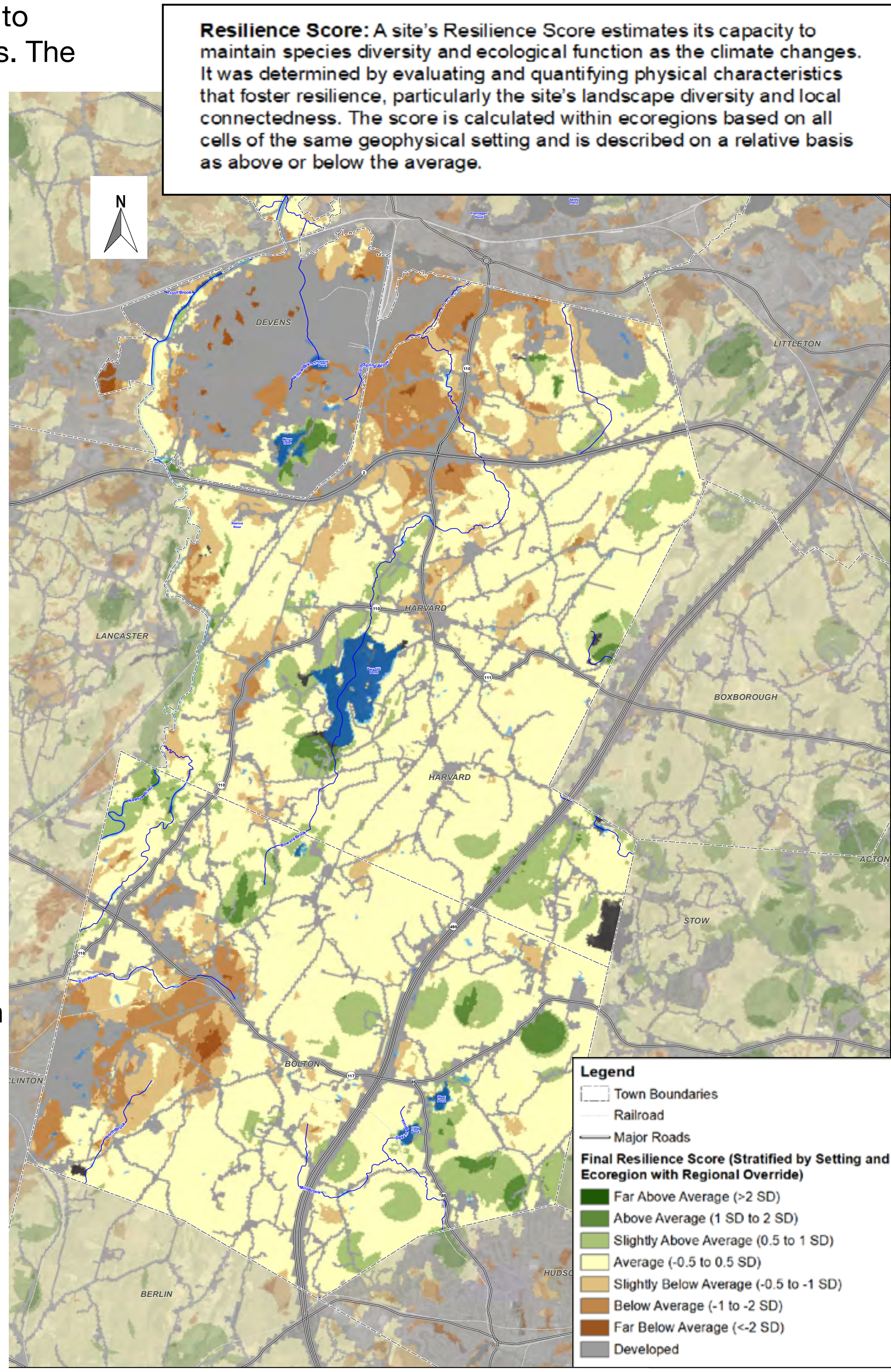
The Value of Nature

The project website Educational Resources page includes five Mass Audubon "Value of Nature" Ecosystem Services Fact Sheets that provide valuations of, and discussion about, the many ecosystem services provided by forests, coastal areas, wetlands and waterways, grasslands and farmlands, and urban green spaces. Mass Audubon reviewed over 100 technical papers as the basis for the fact sheets. Apple Country leaders and community members may use these fact sheets to support implementation of nature-based solutions as a means of increasing ecological climate resilience that supports the climate resilience of the community.

Climate Resilience Assessment: Mapping

The ecological climate resilience and biological condition of land within Apple Country was evaluated using The Nature Conservancy's (TNC) "Resilient and Connected Landscapes for Terrestrial Conservation" (RCL) GIS datasets, the University of Massachusetts CAPS MA Index of Ecological Integrity dataset, the Massachusetts Natural Heritage and Endangered Species Program BioMap2 Tool, MassAudubon's MAPPR Tool 2.0, Massachusetts Bureau of Geographic Information (MassGIS) floodplain, wetland and open space data layers, and other natural resource mapping. Appendix 4 provides the resulting maps, which indicate areas within the Apple Country communities that provide the greatest level of ecological climate resilience, local connectedness, and ecological and habitat integrity, and are most likely to continue to do so in the coming decades. The project website includes an [interactive data viewer]() that allows users to explore the above-mentioned mapped data layers in an active way. Appendix 4 also provides a detailed discussion and analysis of these maps with regard to the climate resilience of Apple Country. As is generally the case with large-scale mapping tools, on-the ground analysis of mapped areas is a best practice to confirm mapped information at the local scale.

Citizens and leaders in Apple Country can utilize these maps and data layers to better understand the ecological climate resilience or vulnerability of specific locations when developing and comparing potential project locations. Considering and comparing the ecological climate resilience and potential vulnerability to future development of each site allows decision makers to prioritize ecological climate resilience benefits among other factors. These maps can also be used to identify opportunities for conservation and ecological restoration or enhancement, and to identify adjacent communities with high value ecological resources in close proximity to similarly high value ecological resources in the Apple Country communities. By identifying larger areas of ecological strength, or areas that provide corridors between large areas, collaboration with neighboring communities can protect and conserve regionally significant ecological resources and the ecological and climate resilience ecosystem services that they provide.



<u>Figure 1.4</u>: ***Apple Country Ecological Climate Resilience Map (TNC)***

Review of these maps shows a patchy distribution of areas with high ecological integrity and climate resilience. Taken as a whole, there is some general alignment of areas exhibiting good resilience, high ecological integrity, and important core and supporting habitat for state-listed wildlife species. Devens is identified as nearly entirely developed in the TNC resilience mapping, suggesting little value from an ecological services perspective, but it is interesting to note that BioMap2 Core and Critical Natural Landscape reach well into the southern portion of Devens, and continue to the south of Route 2A aligned with the FEMA floodplain mapping.

Climate Resilience and Soils

"The body of a soil is a sky where seeds and worms and ions fly. Just as the sky links outer space to Earth's surface by means of increasingly dense atmospheric layers, so the soil links the surface to planetary bedrock by means of increasingly dense layers called, appropriately, horizons. Where the bottom layer of the sky rubs up against the top horizon of the soil, all terrestrial life is found."

– William Bryant Logan, in Dirt: The Ecstatic Skin of the Earth (1995)

The soils of Apple Country, like the ecosystems they support, are diverse. Each of these soils has a unique mix of sand, silt, clay and organic material layered into horizons shaped by geological, glacial, and land use history. As with most soils in the northeast, the forces of the last glacial period deposited, sorted, and sifted a base of mineral materials across the landscape, with which living organisms, plant and animal, have co-mingled. In the 10 millennia since glacial retreat, weathering, erosion, deposition, and the powerful forces of life, including humans, have shaped this material into the living soil that blankets the region.

Soils' innate characteristics, as well as how they are managed by people, influence their capacity to provide services like stormwater infiltration and nutrient availability. This variation depends both on inherent and dynamic properties.

Inherent properties—such as the slope and how much sand is present in that soil—typically develop over centuries. Rapid change can occur, but only when large disturbances, like landslides or construction projects, remove or add large quantities of material in a short time.
Dynamic properties—such as the level of compaction or concentration of soil organic matter—can and do change more rapidly with changes to land cover and land management.

Since 1933, the soil scientists with the Natural Resources Conservation Service (NRCS) have sought to describe, classify, and map the soils of the United States through the Soil Survey. The classifications, descriptions, and use assessments for these many soils can be found at the Web Soil Survey and in the Soil Survey Geographic Database (SSURGO). The work of this report is largely based on these sources.

In Massachusetts, the Soil Survey recognizes approximately 200 distinct soil series. Forty-one of these soil series are present in Apple Country; a list of these soils and their relative abundance can be found in Appendix 8. As illustrated in Figure 1.5 from the 1985 print edition of the Worcester County Soil Survey, the glacial forces and other soil forming factors have resulted in a clear patterning of soil types in the landscape. For example, the ridge tops tend to be covered with either the Paxton series or the Chatfield-Hollis-Rocky Outcrop complex.

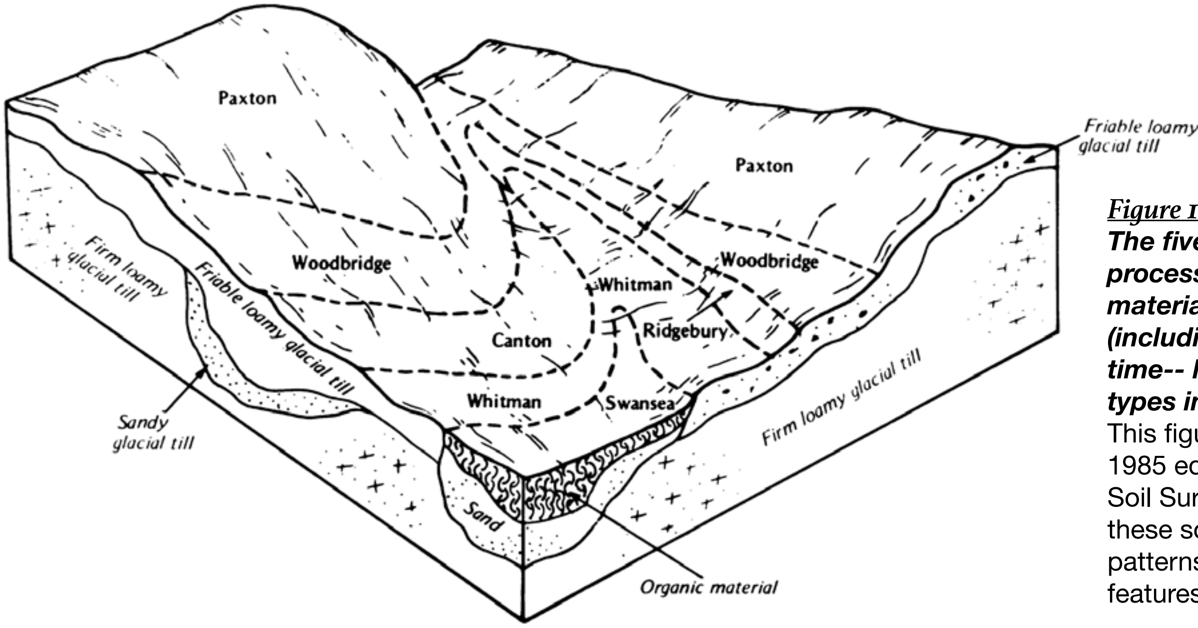


Figure 1.5:
The five physical and ecological processes of soil genesis-- parent material, topography, organisms (including humans), climate, and time-- have formed 41 distinct soil types in Apple Country.
This figure, originally published in the 1985 edition of the Worcester County Soil Survey as Figure 3, shows that these soils often occur in predictable patterns relative to topography, water features, and other soil types.

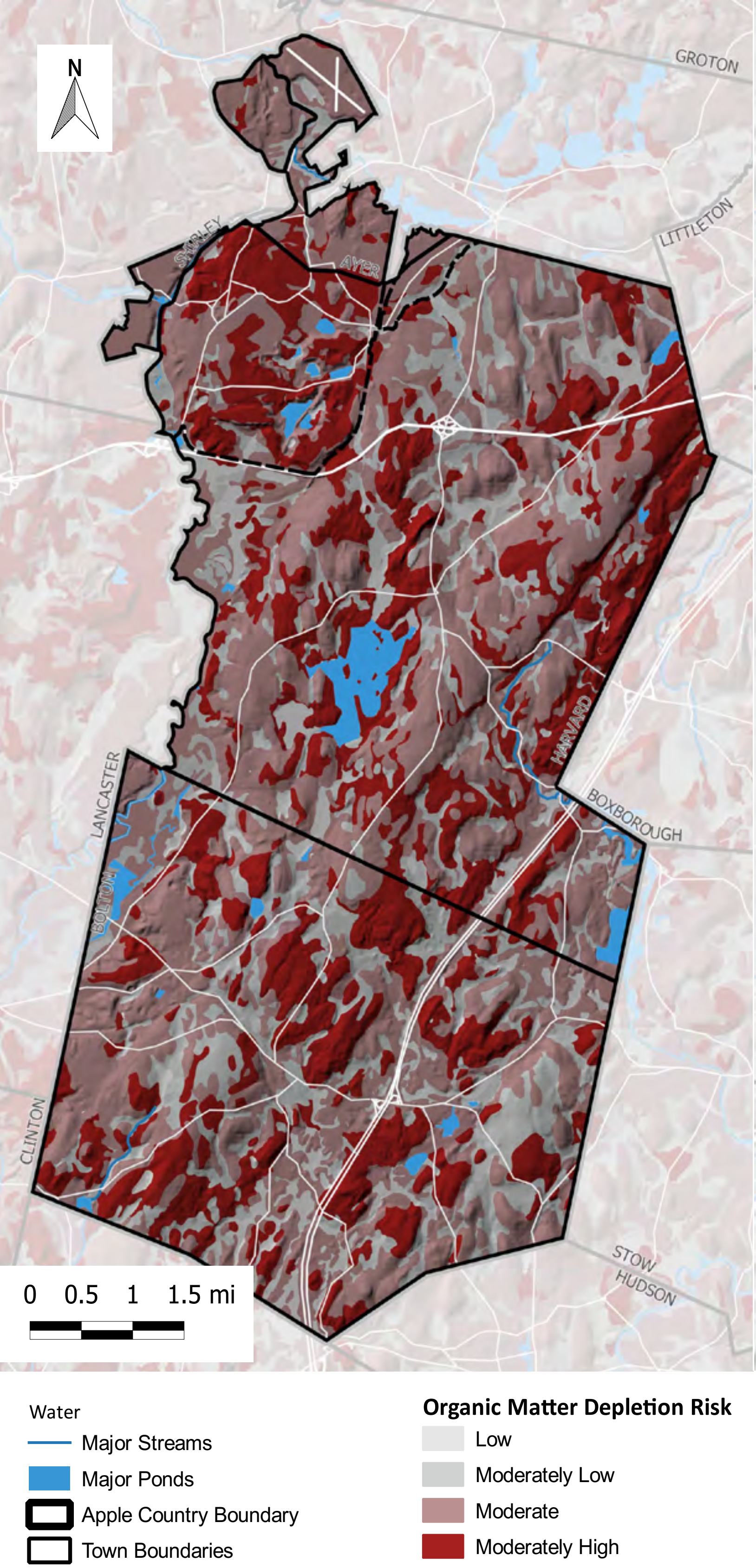
Ten soils series (Table 1.4) cover almost 80% of the area of Apple Country. The vast majority of these soils are well drained sandy loams. Freetown Muck, a wetland soil, occupies 1,458 acres or 4.7% of the land surface. Udorthents - excavated or highly disturbed soils - are found under 1,005 acres or 3.2% of Apple Country.

In Figure 1.8, the major soils of Apple Country's uplands are highlighted. Because many of these soils are sandy in nature, they are at risk of erosion and loss of organic matter from both management and development. Organic matter, composed of approximately 58% soil organic carbon, changes over time and as land cover, land use, and hydrology shift. Figure 1.6 shows the relative vulnerability of Apple Country's soils to loss of soil organic matter. This rating is largely due to the physical and chemical properties of soil texture and can be linked closely to its drainage classification as shown in Figure 1.7 (Soil Survey 2020).

The soil organic carbon content of all soils in Apple Country is illustrated in Figure 1.9. This dynamic constituent of a soil's composition largely determines its relative water holding capacity, fertility, and overall resilience to drought, flood, and other disturbances (Bronick and Lal, 2005).

Table 1.4: ***Soil Types of Apple Country***

Major Soil Map Unit	Total Acres	Percent of Total Area
Canton fine sandy loam	1,215.8	3.89%
Chatfield-Hollis-Rock out-crop complex	7,760.0	24.80%
Freetown muck	1,457.8	4.66%
Hinckley loamy sand	2,053.0	6.56%
Merrimac fine sandy loam	1,188.1	3.80%
Other	2,745.7	8.77%
Paxton fine sandy loam	5,535.8	17.69%
Pits	376.7	1.20%
Poquonock loamy sand	697.9	2.23%
Quonset loamy sand	1,028.4	3.29%
Ridgebury fine sandy loam	800.8	2.56%
Swansea muck	557.5	1.78%
Udorthents	1,004.5	3.21%
Walpole sandy loam	450.2	1.44%
Whitman fine sandy loam	352.2	1.13%
Windsor loamy sand	1,081.8	3.46%
Winooski very fine sandy loam	487.9	1.56%
Woodbridge fine sandy loam	2,499.7	7.99%
Grand Total	**31,293.6**	**100.00%**



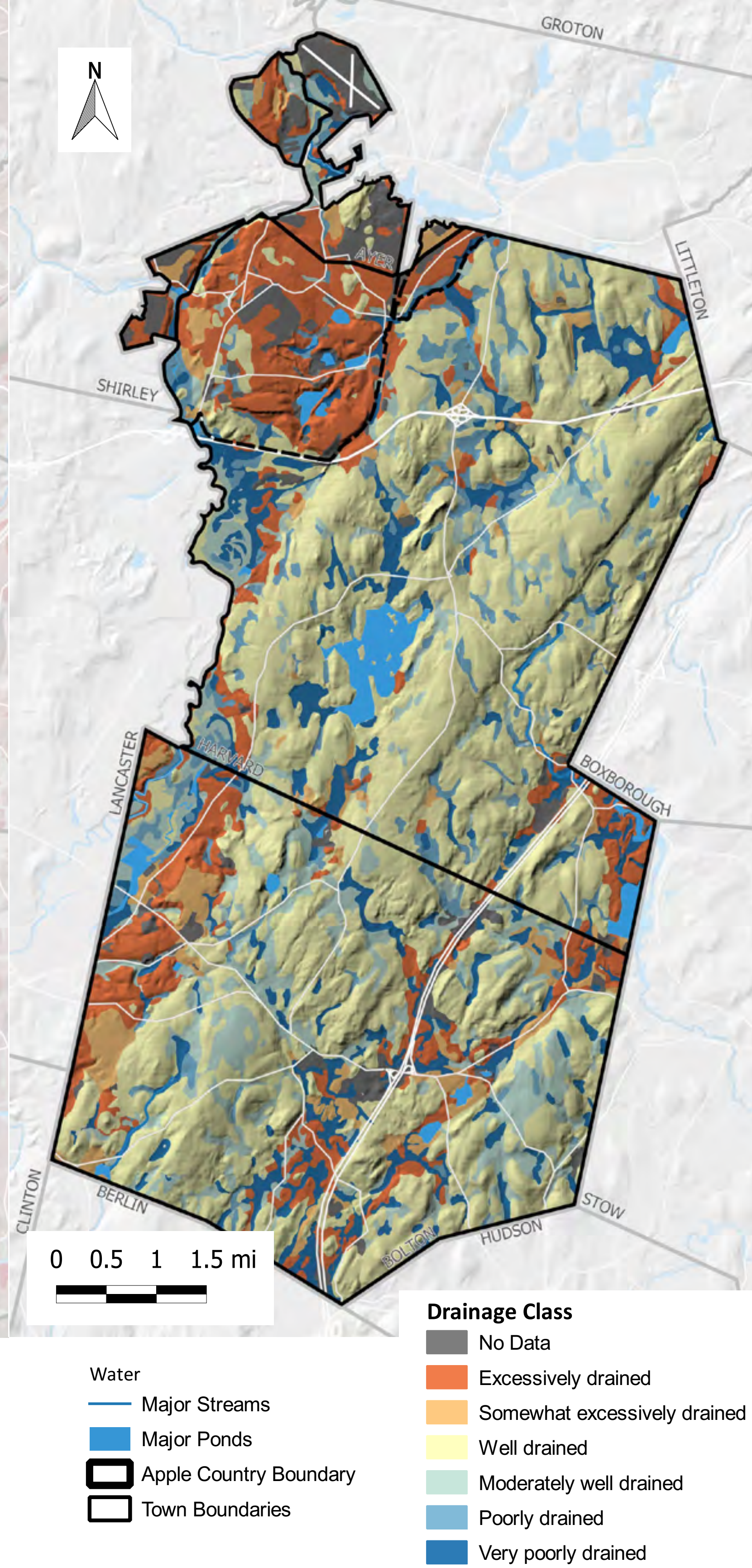


__Figure 1.6:__ (left)
Organic matter depletion risk, soils of Apple Country

__Figure 1.7:__ (right)
Soil drainage classifications of Apple Country

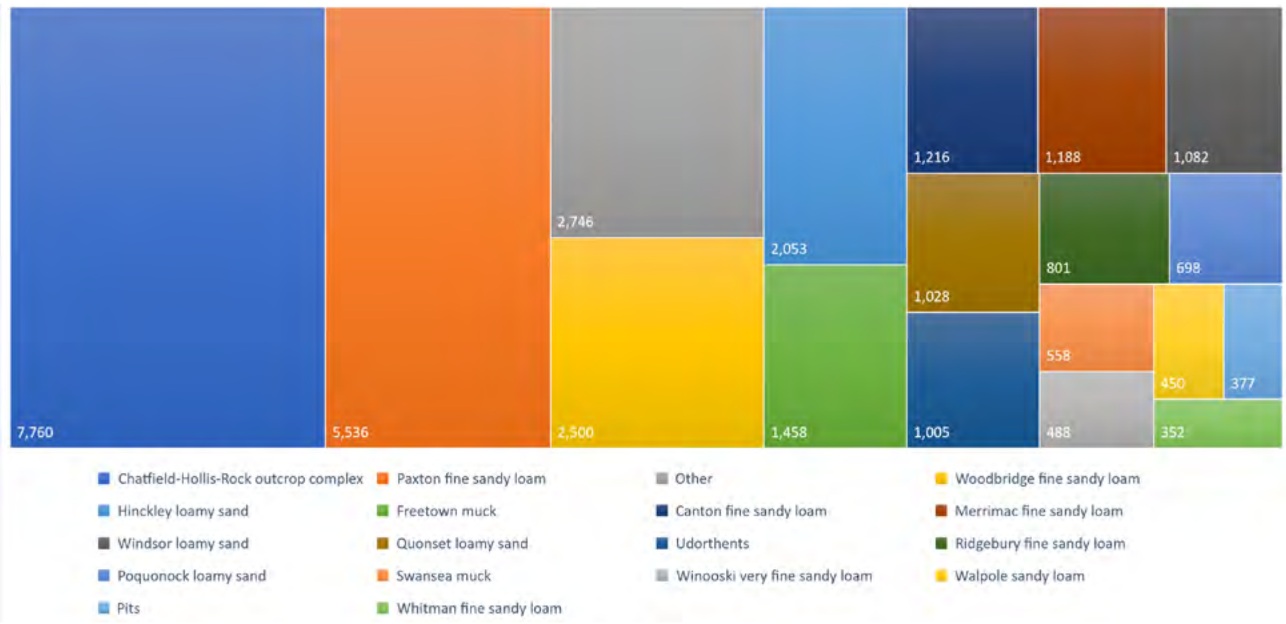
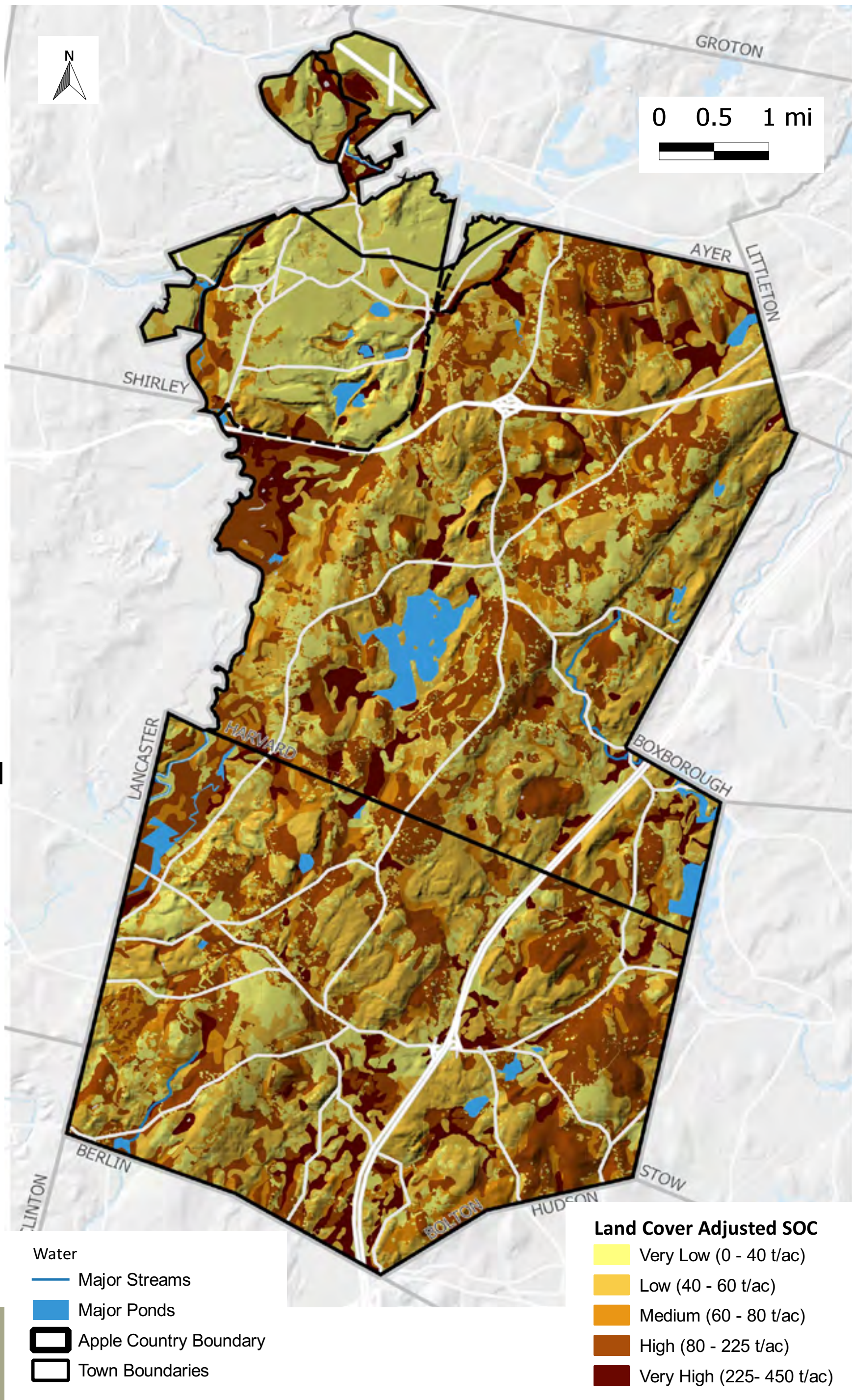


__Figure 1.8.__ ***(left) Major Upland Soils of Apple Country***

__Figure 1.9__ ***(right) Apple Country High Value Soil Resources***

Healthy Soils and Climate Change

Soil health is a measure of a soil's dynamic function within the bounds defined by its inherent properties. Broadly speaking, the less frequently and intensely soils and the ecosystems they support are disturbed, the more fully they can achieve their dynamic function potential. This relative measure is influenced by a combination of physical, chemical, and biological properties; impacts of land cover; historical use; and historical and present-day management. As a result, forests and other living perennial land covers have a higher concentration of SOC, and better overall health. For example, well-drained Paxton soils under forest cover typically hold 74 metric tons of soil organic carbon per acre. The same soil under conventional annual cultivation contains only 24 metric tons per acre. Assuming no other significant alterations to the soil have occurred, this SOC concentration gap represents the potential below ground carbon-drawdown benefits from reforestation, equal to 50t/ac or approximately 183.5 tons of CO_2e.



On Fungus

Threaded into nearly every square inch of the ground are tiny, biological wires called mycelia. They're the raw, exposed nervous system of the mushrooms that hold the planet together. When your feet press against the ground, or when it rains, or when a tree falls over, the fungal network responds, streaming chemical data in all directions and altering its growth and behavior accordingly. Crusading mycologist Paul Stamets calls mycelia the "neurological network of nature," and a "biomolecular superhighway." He likens this fungal network to the human nervous system and the structure of the Universe itself. Link here.

***Table 1.5* (below) describes some of the ways the many types of soil function can be measured. There is no single measure of soil health, but the research conducted for the Massachusetts Healthy Soils Action Plan (HSAP) shows that many soil functions are improved as the amount of soil organic carbon increases. Appendix 7 provides additional information about the HSAP.**

Indicator Category	Related Soil Function	Some Measures
CHEMICAL	Nutrient Cycling, Water Relations, Buffering	Electrical Conductivity, Soil Reaction (pH)
PHYSICAL	Stability, Water Relations, Habitat	Aggregate Stability, Available Water Capacity, Bulk Density, Macropores, Micropores
BIOLOGICAL	Biodiversity, Nutrient Cycling, Filtering	Microbes, Fungi, Respiration, Soil Enzymes, Total Organic Carbon

Climate Resilience

Healthy soils are beneficial for ecosystems and human communities. Soil underpins everything—all landscapes and all land uses. Organic matter, that part of soil composed of decaying life, is a driver of many positive soil functions and thus a key indicator of healthy soils. Most people understand that soil supports the growth of plants and landscapes that define our daily lives—a grassy lawn, a field of sweet corn, a riverbank, a city shade tree, a protected forest. Of course, soils also support habitat, feed, and forage for the non-human world. Healthy soil makes biodiversity happen. In turn, biodiversity (all its component parts, from microbes and fungal threads, to pollinator plants and mast producing trees, to top predators) is nature's engine that keeps soils healthy and drives carbon, water, nutrient, and energy cycling.

The changing climate has brought into sharp focus the carbon sequestering and storage functions of soil. As noted by Ontl and Schulte (2012), "the amount of C [carbon] in soil represents a substantial portion of the carbon found in terrestrial ecosystems of the planet. Total C in terrestrial ecosystems is approximately 3170 gigatons (GT; 1 GT = 1 petagram = 1 billion metric tons). Of this amount, nearly 80% (2500 GT) is found in soil (Lal 2008). Soil carbon can be either organic (1550 GT) or inorganic carbon (950 GT).

Soil organic carbon (SOC) is constantly in flux. Disturbance of soil through poor land management and unchecked development patterns and practices all release carbon into the atmosphere and disrupt a landscape's ability to sequester carbon through photosynthesis. Healthy soils are central to retaining, filtering, infiltrating, and storing water. By these functions, soils prevent flooding, erosion, and spreading of contaminants, and they provide local climate cooling. When the characteristic structure, biology and chemistry of soils is intact, they work like a sponge to slow stormwater, recharge groundwater, and clean polluted surface flows. As climate change brings more and heavier storms to our region, these vital soil functions become even more essential (Ontl and Schulte, 2012).

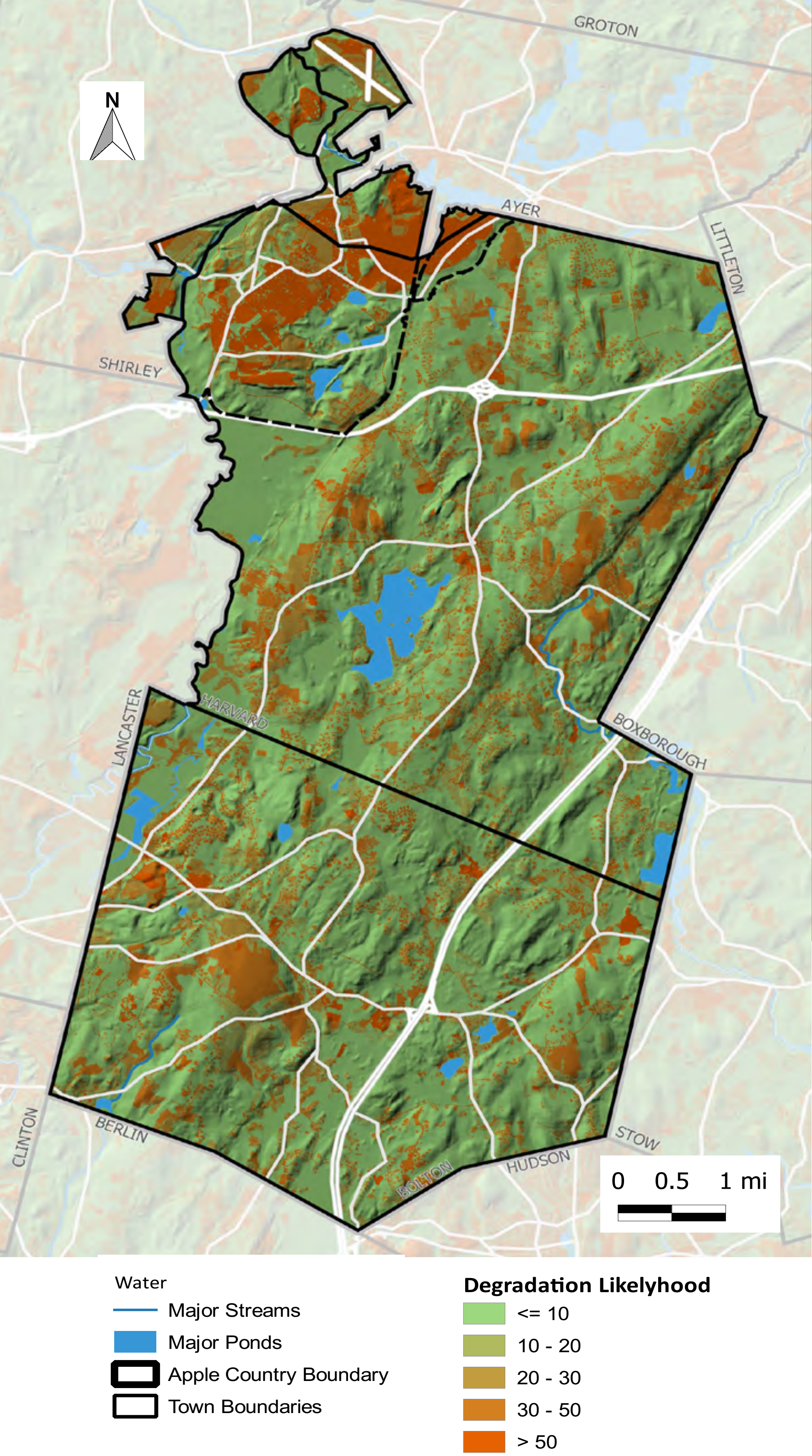


__Figure 1.10.__ ***Estimated Soil Degradation Based on Land Use History, Apple Country***

Memory - Soil - Hope - Resilience

"Looking at soil as memory, a repository of recorded changes and renewals, may yield what some say is most urgently needed in biospheric research today: a forward-looking outlook - a sense of hope. That quaint, distinctly non-scientific term is cropping up now, more and more, even in the august academic literature...It is the interface between memory and yearnings, the tension between what is remembered and what can yet be. The soil, by virtue of its memory, is a conveyor of hope, foreshadowing tomorrow's fruitfulness in sights sprouting today. Seen across long durations, soil is innately resilient, often able to renew itself, to resurrect its life-sustaining functions, even after damaging upheavals and disturbances."

\- H. Henry Janzen (2016)

Figure 1.10 can be understood as a snapshot of today's soil health. The most degraded lands, including the Devens Air Base, roadways, and former mines, are shown in tones of deep orange and red. These areas represent sites where restoration or redevelopment could have a beneficial impact on regional soil health. Small subdivisions and agricultural sites are shown in mid-tones of orange. The soils of these sites should be responsive to better management practices. Green areas represent the healthiest soils and are logical priorities for conservation.

Carbon Mitigation: Avoided Emissions and Potential Sequestration

Calculating the contribution Nature-based Solutions can generally contribute to carbon mitigation requires many assumptions about the scale, timing, and intensity of adoption, implementation, and management practices. Because carbon stored in the soil is largely a dynamic pool that is constantly being fixed through photosynthesis and released by oxidation and digestion at different rates, the calculus becomes even more complex. With these considerations in mind, we estimate the carbon content of Apple Country soils at approximately 2.9 million metric tons (equal to 10.8 million tons of CO_2). Each year, through natural processes, the living landscapes of these communities both release and capture carbon. At present, this results in an estimated net gain of 4,300 tons of CO_2 equivalent. Protecting both the existing stocks of SOC and future sequestration is best achieved through the conservation of the soils with highest carbon concentrations and land covers with greatest drawdown capacity. In Apple Country, soils classified as highest and moderate conservation value total 12,121 acres and 4,794 acres, respectively.

Table 1.6: ***Though improving the health of the soils of any real place requires careful analysis and site specific planning, these four principles, developed by the NRCS and expanded on by the HSAP, offer a simple framework for tending soils under the five major land types of Apple Country. For the purposes of this soils section of this report and the figures and tables within this section, "wetlands" includes forested wetlands, and "forests" refers to upland forests.***

Principles	Forests	Wetlands	Agriculture	Recreational + Ornamental	Impervious
Minimize Disturbance	+ Keep as forests + Minimize fragmentation + Employ BMPs + Restore degraded forests	+ Keep as wetlands + Minimize fragmentation + Restore former/ degraded wetlands	+ Reduce tillage + Establish vegetative buffers + Restore degraded farmlands	+ Protect natural resources during development + Employ BMPs + Restore degraded soils	+ Protect natural resources during development + Restore degraded soils
Maximize Soil Cover	+ Leave deadwood and slash in place	+ Vary soil topography in replications and restorations	+ Plant cover crops + Incorporate field residues/mulch	+ Incorporate mulches, compost, and perennials	+ Incorporate green stormwater infrastructure like rain gardens + Reclaim unused pavement
Encourage Biodiversity	+ Protect old-growth forests + Manage against invasives	+ Manage against invasives + Encourage endemic plant communities in replications/restorations	+ Plant cover crops + Incorporate perennials + Incorporate animals	+ Plant mixed species grasses + Plant pollinator habitat + Plant shrub + tree layers	+ Plant trees, shrubs, grasslands and pollinator habitat
Maximize Living Roots	+ Leave stumps	+ Encourage endemic plant communities + soil function in replications/ restorations	+ Avoid fallow + Cover crops + Strip cropping + Dedicated grasslands	+ BMPs for mowing + Emphasize perennials	+ Plant trees, shrubs, and grasslands and pollinator habitat

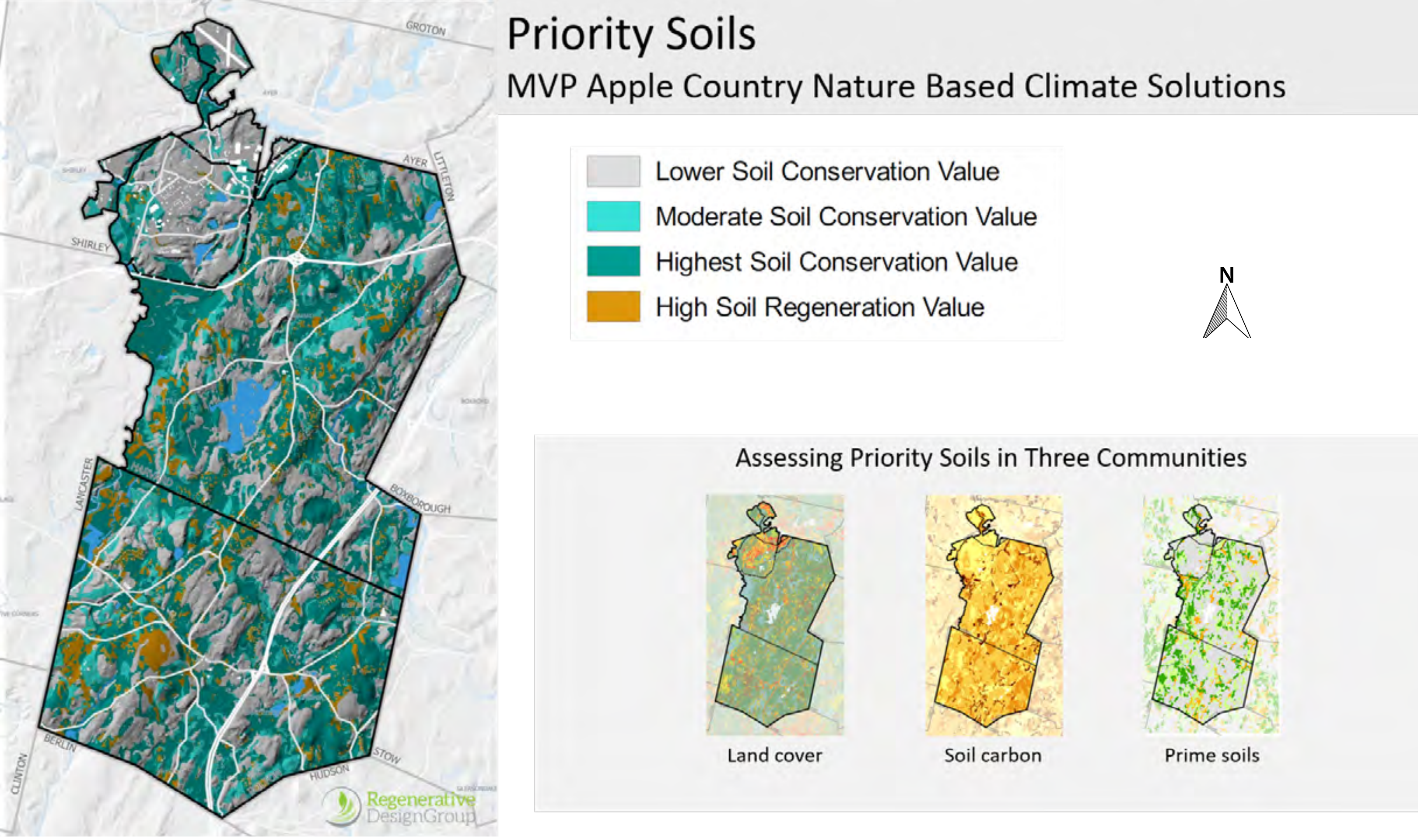


Figure 1.11 ***Overview of Priority Soils Assessment Approach***

However, as previously discussed, land cover, land management, and climate changes all affect the fate of soil carbon and its rate of flux. Increasing perennial cover through reforestation or lower till agriculture and rewetting drained wetlands are a few of the effective ways of regenerating soil health and ecosystem resilience by increasing sequestration capacity. Over 2,600 acres were identified as having high soil regeneration value in Apple Country. If all of these lands were reforested, the same methodology used for estimating SOC stocks predicts that the pool of soil organic carbon could grow by approximately 165,749 metric tons, or the equivalent of 609,459 tons of CO_2. Since the average Massachusetts resident emits 11 tons of CO_2 per year, this increase could offset the annual emissions of 55,405 people living in Massachusetts.

A few notes on soil carbon in general: The carbon numbers reported here are looking at soil organic carbon (SOC). This represents non-living, decomposed organic material, held in soils. It does not include the living roots of trees, and also excludes carbon held in leaf litter and aboveground biomass. Each ton of SOC is equivalent to 3.677 tons of CO_2.

SOC is not permanently stored - it can be released through disturbance of the soil, as in development or via flooding or fire. In most ecosystems there is a limit to how much carbon can be stored in the soil. In agriculture, turf, and landscaping, it will accumulate for several decades and then slow to almost no additional accumulation. In Massachusetts forests, it can accumulate for several centuries, but often reaches equilibrium at about 200 years. Wetlands are unique in that they can continue to sequester carbon for millennia. This accounts for their high carbon stocks and the great importance of protecting and restoring them.

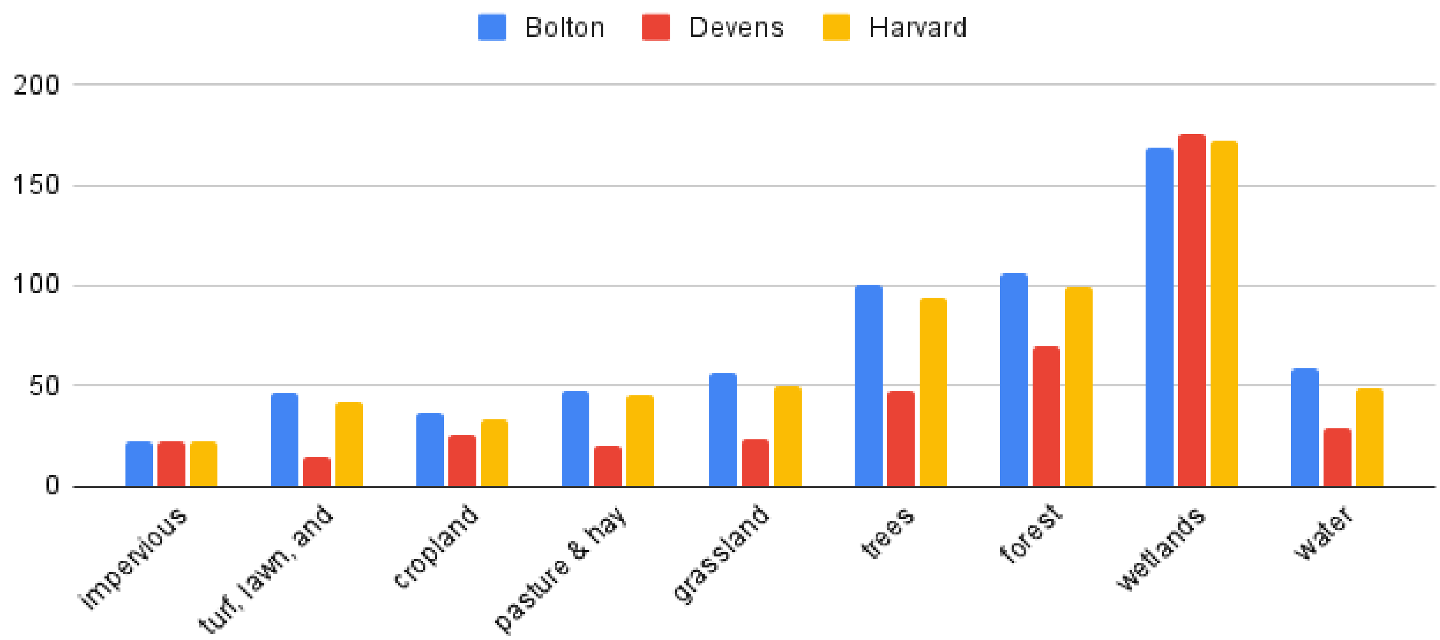


Figure 1.12 ***Average SOC/acre by town and land cover type CO_2e. "Wetlands" includes wetland forests and "Forests" refers to upland forests.***

Spotlight on SOC

The current soil organic carbon stock for Apple Country overall is an estimated 2.9 million tons, equivalent to 10.8 million tons of CO_2. That's equal to about 15% of the total emissions for Massachusetts in 2017. The majority is held in forests and wetlands.

Soil organic carbon, or SOC, is presented here in metric tons per acre. Each ton is equivalent to 3.677 tons of carbon dioxide. As most state-level carbon figures are presented in carbon dioxide equivalent (CO_2e), this convention is used here as well.

As noted above, SOC varies by soil type and land cover. The Consultant team has prepared town-by-town averages for each land cover type. Broadly speaking, wetlands have by far the highest SOC levels, followed by forests, as shown in Figure 1.12. Farmland, turf, and landscaped areas are lower, and impervious areas like pavement and buildings have the lowest levels. SOC levels in Devens are lower than the other towns in most cases. This is due to the abundance of sandy soils in Devens, which tend to show a lower soil carbon storage capacity.

Wetlands occupy 16% of Apply Country but contain 29% of the SOC. Forests occupy 49% and contain 53% of the SOC. Other land cover types contain disproportionately small levels of SOC. The distribution of carbon stocks by land cover type is shown in Figure 1.13.

Because of the extremely high levels of SOC found in wetlands, their protection is paramount. "Wetlands" includes wetland forests and "Forests" refers to upland forests.

Table 1.7: ***These total estimated stocks of soil organic carbon by major land cover type in Apple Country were derived by adjusting the SSURGO SOC values based on the methodology described in Appendix 8.***

Land Cover	Bolton	Harvard Not Devens	Devens	Apple Country
Impervious	17,512	17,525	18,129	53,173
Turf, Lawn, and Landscaped	53,400	47,335	13,994	114,729
Annual and Perennial Cropland	11,070	18,079	0	29,149
Pasture and Hay	25,226	25,685	73	50,984
Grassland	20,280	17,855	6,106	44,241
Isolated Trees	78,486	83,126	11,091	172,702
Upland Forests	714,254	744,200	114,877	1,573,332
Wetland, Including Forested Wet-lands	307,616	390,214	60,398	758,228
Water	4,297	5,532	1,747	11,575
Total	**1,232,139**	**1,349,553**	**226,415**	**2,808,114**

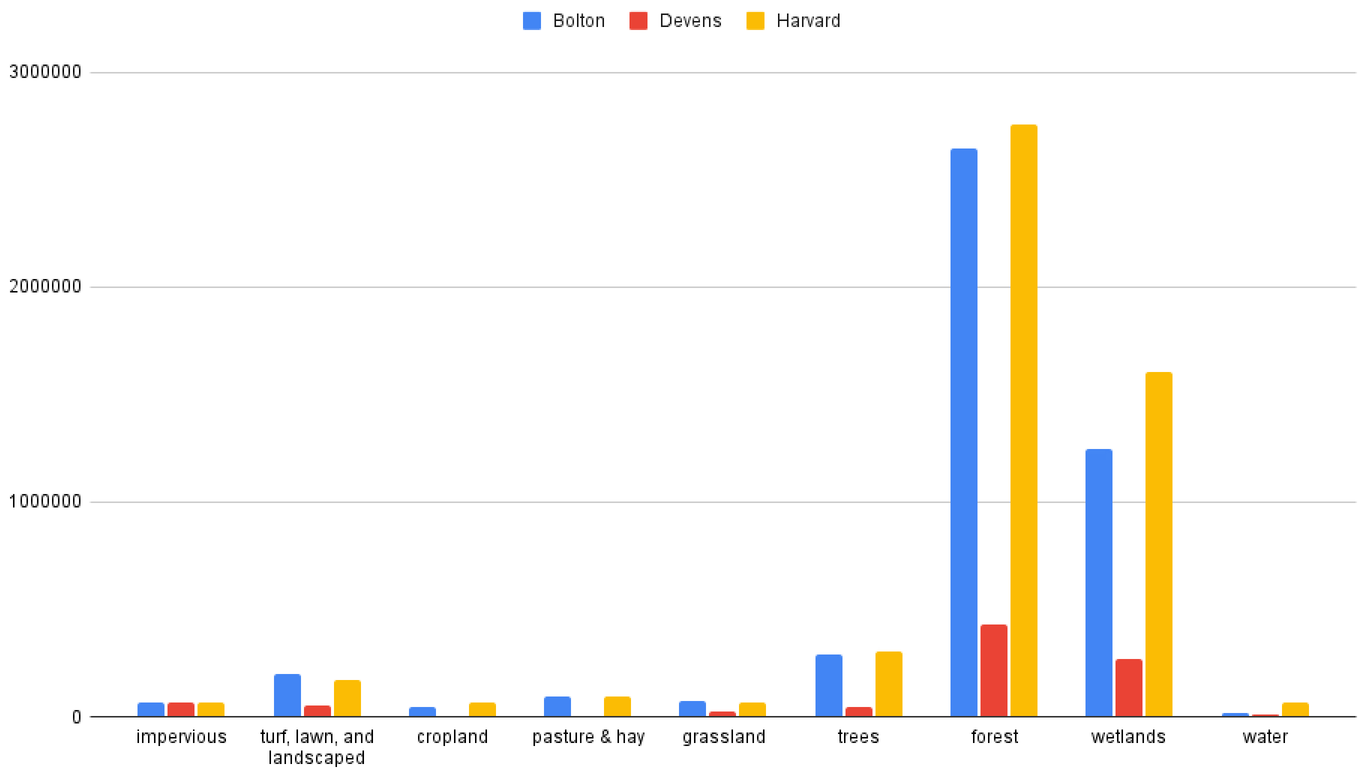


Figure 1.13. ***Soil carbon stocks by town and land cover. "Wetlands" includes wetland forests and "Forests" refers to upland forests.***

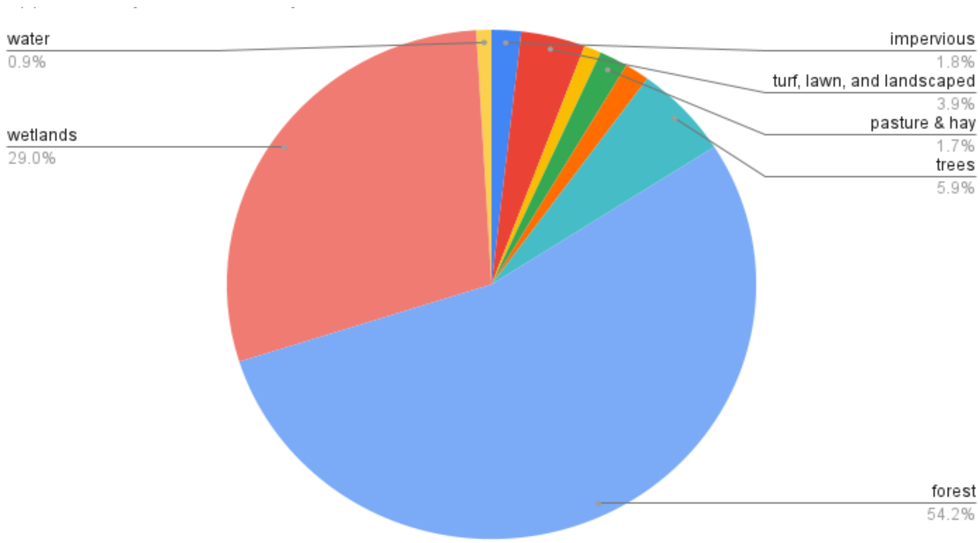


***Figure 1.14*. Apple Country soil carbon stocks by land cover.**

Four factors influence SOC levels in Apple Country. By far the most important is losses due to clearing of land for development. As noted earlier, 'land conversion' was based on a composite analysis of five land cover change scenarios developed for the New England Landscape Futures Project (NELF 2018). Next is the natural sequestration that occurs in forests and wetlands. Next is the use of BMPs that increase carbon sequestration. Finally comes the SOC losses from forest harvests, which are quite small in Apple Country. Three scenarios were prepared for this report, based on those used in the Massachusetts Healthy Soils Action Plan (HSAP), through which potential changes in SOC over time were analyzed.

***Table 1.8:* The three scenarios here examine the impact changes to land cover conversion to development, rates of natural carbon sequestration, adoption of soil-smart best management practices, and forest management have on soil organic carbon stocks and flux in Apple Country in 2050. For more on the New England Landscape Futures project, see Appendix 3.**

	Scenario 1	Scenario 2	Scenario 3
Land use change from development as identified by the New England Landscape Futures projections for 2050 (NELF 2018)	All development identified in NELF occurs	25% of development identified in NELF is **avoided**	50% of development identified in NELF is **avoided**
Natural sequestration	Natural sequestration rates applied to all acres remaining undeveloped in 2050	Natural sequestration rates applied to all acres remaining undeveloped in 2050	Natural sequestration rates applied to all acres remaining undeveloped in 2050
Best Management Practices (BMPs)	**No increase** from current levels. Current levels based on state figures from HSAP.	**Modest growth in adoption** based on state figures from HSAP.	**Ambitious growth in adoption** based on state figures from HSAP.
Forest harvest	Based on state-level figures, assumed that 0.75% of forest is harvested annually	Based on state-level figures, assumed that 0.75% of forest is harvested annually	Based on state-level figures, assumed that 0.75% of forest is harvested annually

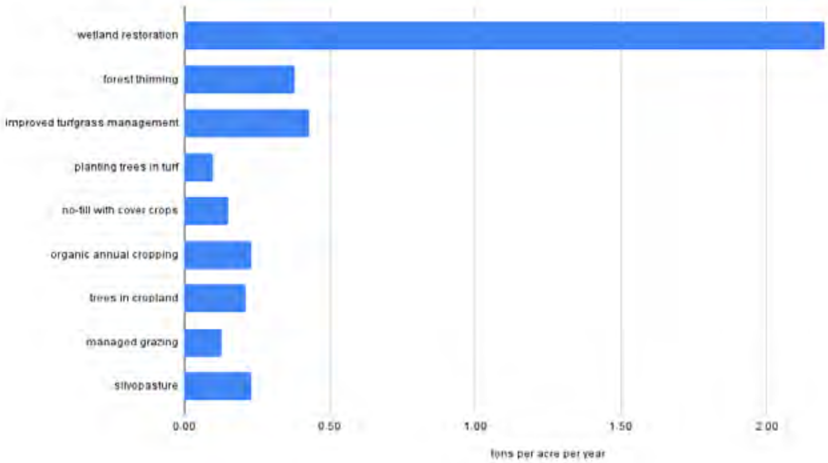


Figure 1.15. ***Per-acre impacts of BMPs on soil organic carbon sequestration rates***.

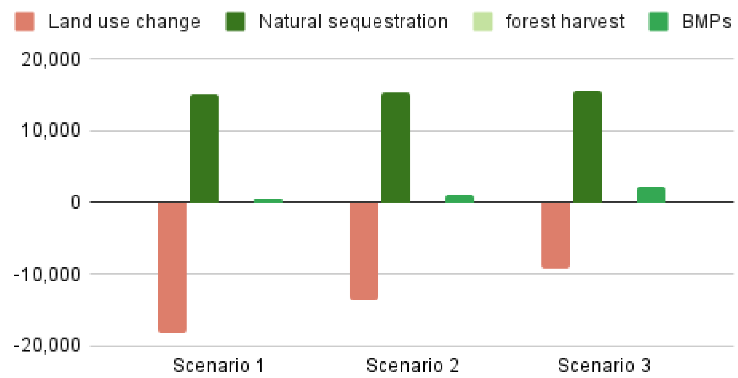


Figure 1.16. ***Apple Country carbon fluxes in 2050 in tons CO_2e/yr***

Note that carbon emissions are shown as negative numbers and carbon sequestration is shown as positive numbers.

Wetland restoration is a promising BMP that provides a sizable carbon sequestration benefit. To identify how many acres of restorable wetlands are to be found in Apple Country, additional analysis will be required. For the purposes of this report, state figures for inland, non-peat wetlands identified as restoration priorities were used as a proxy. This approach generated a figure of 10 restorable acres for all of Apple Country. However, the restorable area is likely substantially higher.

Not all BMPs are equal in their SOC impacts. Some BMPs also sequester carbon in aboveground biomass and tree roots, though this is not shown here. These practices include wetland restoration, silvopasture, and tree intercropping. Figure 1.15. shows the per-acre impacts of BMPs suited to Apple Country.

The SOC flux was calculated for the year 2050 for Apple Country as a whole and on a town-by-town basis. The town figures were very similar and are not shown here. Figure 1.16. shows the fluxes at the Apple Country level for land use change, natural sequestration, forest harvest, and BMPs. It can be readily seen that reducing land use change is by far the biggest lever available.

The net flux of SOC in 2050 varies considerably from scenario to scenario. In Scenario 1, net flux is a loss of 3,429 tons of CO_2 equivalent. Since the average Massachusetts resident emits 11 tons of CO_2 each year, Scenario 1 is the same as adding an additional 322 people's emissions (this is only by way of comparison, as sequestration is not a replacement for reducing emissions). In Scenario 2, the results show a gain of 1,365 tons of CO_2, the same as removing the emissions of 128 average Massachusetts residents. Scenario 3 yields a net gain of 6,159 tons of CO_2 equivalent, which by way of comparison is the emissions from 579 average Massachusetts residents. These results show that reducing development by 25% could make Apple Country soils a net source of carbon sequestration by 2050. See Figure 1.17.

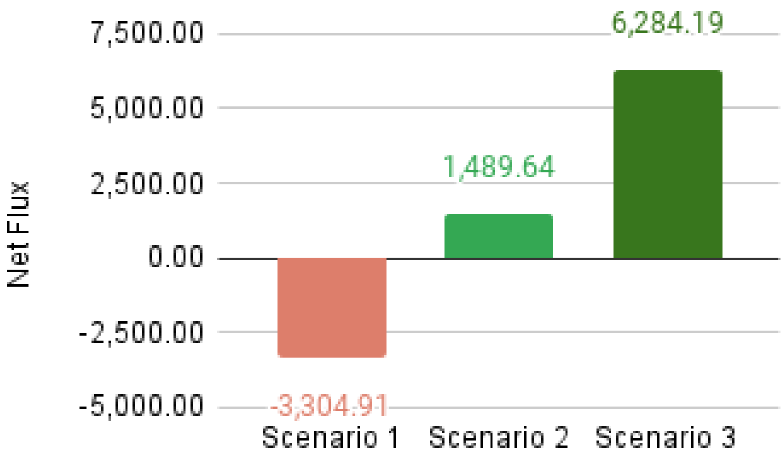


Figure 1.17. **Apple Country net flux 2050 tons CO_2e/yr**
Note that carbon emissions are shown as negative numbers and carbon sequestration is shown as positive numbers.

Note that soils and land management are also a source of emissions. The average acre of agricultural land in Massachusetts emits about 1 ton of CO_2 equivalent per year, from synthetic fertilizers, enteric methane of cattle, and other sources. Fertilizer use on lawns and landscapes is also an important source of emissions of the greenhouse gas nitrous oxide. On the other hand, soils are not the only source of carbon sequestration. The living aboveground biomass of trees and other woody plants is a carbon sink, as are roots and leaf litter - none of which are included in SOC calculations. These carbon sinks are, however, discussed below in the Forests section.

Apple Country's abundant forests and wetlands are powerful engines of natural carbon sequestration. Land use change (loss of forests, wetlands, and farmland to development) is by far the biggest factor impacting the net flux of soil carbon in all three scenarios, with 154 acres of wetlands and 1,427 acres of upland forests likely converted by 2050 (NELF Likely Developed Acres) in Scenario 1. If converted to lawn or other ornamental land cover, these developed wetland soils would lose the equivalent of 166,384 tons of carbon dioxide to the atmosphere. This fact makes avoided development the most powerful tool in Apple Country's toolbox for reducing emissions and supporting the Commonwealth's goal of Not Net Loss of soil organic carbon.

Together with greater adoption of BMPs on all land cover types, actions to limit development can also increase the net soil carbon sequestration rate for Apple Country.

Agriculture

Agriculture and Soils in Apple Country

Hayfields, orchards, and fields of vegetables are common sights along the roadsides of Apple Country. The commercial and non-commercial farms that make up these elements of the landscape are vestiges of a more expansive agricultural industry that shaped the economy and ecology of this region from the period of European colonization through the mid-20th century. The Soil Survey of Worcester County penned a brief history of the expansion and contraction of agriculture in the region in its 1985 edition of the Survey. This is included in the Regional Setting section of this report.

Today, according to the latest land cover data from MassGIS and the NRCS, farms and homesteads occupy around 2,197 acres*, or roughly 6% of Apple Country's total land area (ACNCS Acreages Sheet). Figure 1.18 shows that the vast majority of this farmland is (80%) used for hay, pasture and perennial forage. Orchards of apples, once a major land use for the hillsides of this area, are currently grown on only 278.4 acres. Data from the 2016 CropScapes Mapper from the USDA showed annual crops were grown on 125.7 acres (USDA CropScape Data Layer, MassGIS 2016 Land Cover).

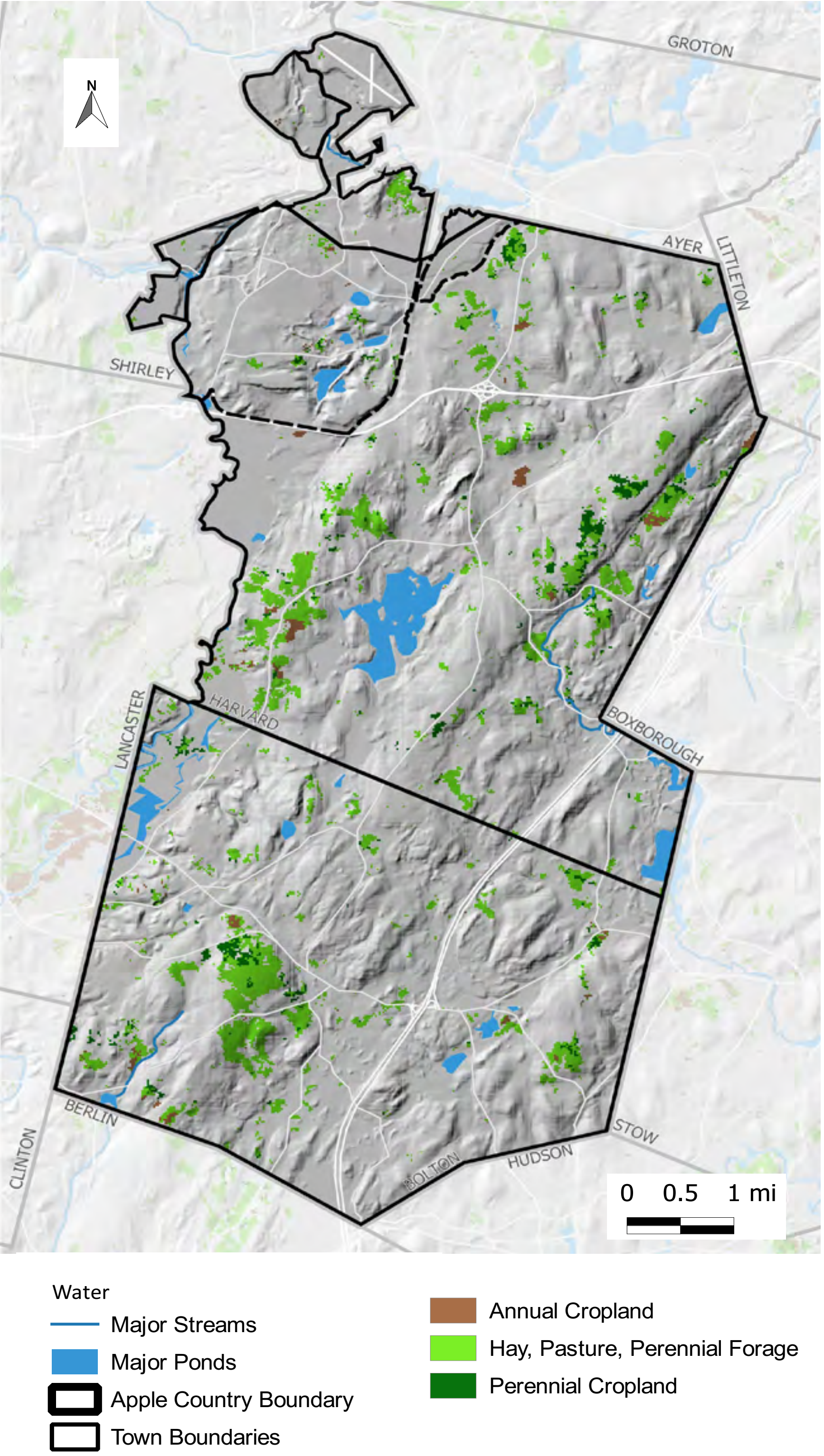


Figure 1.18. ***Active agricultural land in Apple Country.***

The polygons identified on this map represent those lands identified as being actively managed for agricultural production in 2016 by the CropScapes Mapper from the USDA. It is worth noting that this represents only a portion of the lands owned by farmers and often reported as "farm land".

Most agriculture, with the exception of hydroponics and other indoor growing, depends on soil to supply the crops with water and nutrients. While many soils can be modified to support some crop growth, the NRCS has identified a certain subset of farm-friendly soils as "Prime Farmland", "Farmland of Statewide Importance", or "Farmland of Unique Importance". These agricultural soils exhibit combinations of physical, chemical, and biological characteristics that make them well suited for growing food, fiber, feed, and forage.

Within Apple Country there are a combined 13,286 acres of soils in these classes. Only about ten percent, or 1,383 acres, of these more productive soils are actively farmed. Forests, including some maple sugarbushes, grow on 5,002 acres, or 38%, of these soils. Other significant land cover types of prime and other important farmland include 1,497 acres turf and ornamental landscape, 929 acres impervious surfaces, and 2,762 acres wetland (MassGIS 2016 Land Cover, NRCS SSURGO-Certified Soils).
In recent years, some forested prime farmland in Massachusetts has been re-cleared for crop production as interest in local food production has grown.

***Table 1.9:* Land Cover of Prime Farmland Soils in Apple Country**

Land Cover Class MassGIS 2016	Farmland*	Percent of Farmland Soils by Landcover
Impervious (2)	929	7.0%
Developed or Open Space (5)	1,497	11.3%
Cultivated Crops (6)	640	4.8%
Pasture or Hay (7)	743	5.6%
Grassland or Herbaceous (8)	433	3.3%
Deciduous Trees- non forest (9)	745	5.6%
Evergreen Trees- non forest (10)	235	1.8%
Forest (11)	5,002	37.6%
Scrub/Shrub (12)	182	1.4%
Palustrine Forested Wetland (13)	1,706	12.8%
Palustrine Scrub/ Shrub Wetland (14)	200	1.5%
Palustrine Emergent Wetland (Persistent) (15)	856	6.4%
Unconsolidated Shore (19)	0	0.0%
Barren Land (20)	43	0.3%
Open Water (21)	46	0.3%
Palustrine Aquatic Bed (22)	29	0.2%
Total Acres	**13,286**	**100.0%**
Percent of Grand Total	**42.46%**	
*sum of prime, state, unique		

**It should be noted that this number is based on land cover data, and not the higher acreages of the USDA agricultural census data. The majority of this difference can be attributed to the forested acres of land owned by farmers being counted as farmland (farmers as a group are the single largest forest holders in the State). A small portion of the acreage gap can also be attributed to other agricultural lands in fallow or other uses not easily identified from satellite imagery, such as grasslands and shrublands. In this table, wetland forests are included as Palustrine Forested Wetlands.*

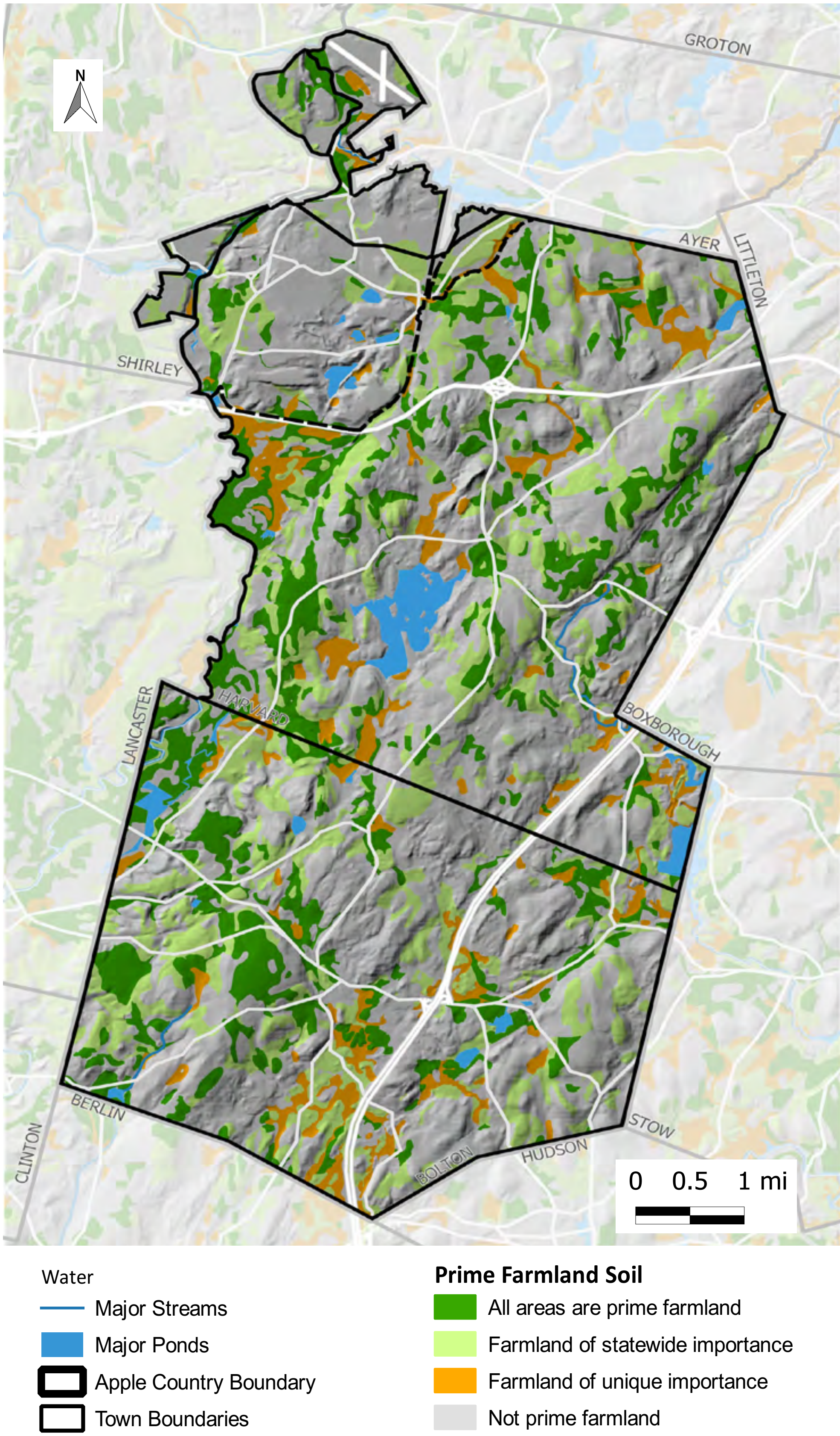


***Figure 1.19.* Prime Farmland Soils of Apple Country**

Carbon in Agricultural Soils

Apple Country's agricultural land holds an estimated average of approximately 41 tons of soil organic carbon per acre. From a strict carbon accounting perspective, this soil carbon density is low compared to other land cover. In aggregate, Apple Country's 2,197 acres of active farmland (CropScapes 2016) hold approximately 80,133 metric tons of SOC, with 50,984 t found in Pasture/Hay and 29,149 t in Cultivated soil. Because typical agricultural practices including tree clearance, the harvest of biomass, and tillage are shown to reduce soil organic carbon over time, intensified cultivation or the conversion of pasture to annual crops could reduce these stocks.

Conversely, a number of agricultural practices and cropping systems can rapidly increase SOC concentrations while providing other benefits. These practices embody the four principles for healthy soils described by the NRCS: 1. Use plant diversity to increase diversity in the soil; 2. Manage soils more by disturbing them less; 3. Keep plants growing throughout the year to feed the soil; 4. Keep the soil covered as much as possible.

Because agriculture occupies only a small portion of Apple Country's area, even ambitious adoption of agricultural practices that protect and enhance SOC have limited effect on the total carbon stocks and fluxes. However, practices that build soil organic carbon also have a cascade of other benefits both to the farm ecosystem-- like better water and nutrient holding capacity-- and places downstream-- including less, cleaner runoff, greater erosion resistance, higher biodiversity, and improved wildlife habitat. This is where the necessity of looking beyond strict carbon accounting comes into play.

On Regenerative Agriculture

Regenerative Agriculture is a system of farming principles and practices that increases biodiversity, enriches soils, improves watersheds, and enhances ecosystem services. Regenerative Agriculture aims to capture carbon in soil and aboveground biomass, reversing current global trends of atmospheric accumulation. At the same time, it offers increased yields, resilience to climate instability, and higher health and vitality for farming and ranching communities. The system draws from decades of scientific and applied research by the global communities of organic farming, agroecology, Holistic Management, and agroforestry.

\- Terra Genesis International

(left) Adding trees to existing pasture typically increases the rate and retention of soil organic carbon while providing protection to both animals and grass from extreme heat. Image Eric Toensmeier.

Recent national and global supply chain disruptions leading to short-term shortages of various food products during the early stages of the coronavirus pandemic demonstrate the importance of local and regional food production as climate change, biodiversity loss, and potential future pandemics or other social disruptions pose increasing threats to long-distance supply chains. Although Apple Country is not currently a major food-growing region of the state, protecting, restoring, and stewarding its agricultural lands through protection and better management can help ensure future farm and food system resilience in the region.

In 2020, a series of round-table discussions among 192 farmers from six Northeastern states were convened by the Northeast Organic Farming Association (NOFA) to discuss soil health and some of the ways farmers are navigating these issues. They found that regionally, barriers to adoption of better soil management practices echo those found nationally, with an additional emphasis on the need for more education and technical support. Interviews with several Apple Country farmers and technical service providers suggest many of the initial findings from these NOFA events are relevant. In general, farmers need more access to education and technical support and prefer learning from other farmers. Specific support areas mentioned were:

- Increasing efficiencies within healthy soils practices.
- Scaling Up Healthy Soil Practices.
- Long-term soil and water quality testing and monitoring.

The need for incentives was also widely discussed, but opinions varied on methods, with some farmers specifically expressing support for payment for practice models, while others felt payments should be outcome-based. Farmers also discussed the need for more investment in local/regional food systems and smaller-scale farms more typical of the region—and showed interest in grants/ funding that help pay for equipment, provide a buffer while transitioning to new practices, purchase cover crops, and implement perennial buffer strips and windbreaks.

Protection of agricultural lands and better management of their soils can't be the end goal, however. Farmers need long-term support that increases the viability of farming as a livelihood and incentivizes and rewards practices that contribute to carbon drawdown. Support with transition planning, as farmers prepare to retire, is also necessary to maintain the ecological and agricultural gains that have been realized through years of hard work. With coordinated financial and other support, farm transition could be an opportunity to address racial inequities in land access.

Forests

Forest Resilience

Forest and Tree Resilience
As with other ecosystems, there are two elements to forest and tree resilience: the climate resilience provided by forests and trees to the surrounding landscape and communities, both human and ecological, and the capacity of forests and trees to respond to our changing climate with resilience.

Climate Resilience Provided by Forests and Trees
As anyone who walks into a forest or passes beneath a tree on a hot summer day knows, forests and trees cool the air and provide shade, creating a welcome respite for humans and wildlife alike. The shady interiors of forests support biodiversity resilience by

contributing to a natural variety of habitat types because of their vertical and horizontal structure, and the different tree species that occur. More specifically, large and linear intact forests, such as forested riparian floodplains, create refugia and travel corridors for biotic and abiotic elements to migrate across the landscape, thereby increasing opportunities for biodiversity to respond to climate change with resilience (Anderson *et al* 2016b).

Photo credit G. Davies

Forests and trees also play a critical role in the global water cycle and in buffering extreme hydrologic events. Forests and trees absorb rainwater and slow runoff, reducing flooding that results from severe storms both locally and downstream. Forests and trees buffer the effects of severe storms by serving as windbreaks and by preventing erosion of the soil surface. Additionally, researchers have found that large, forested areas impede the formation of hurricanes and tornadoes as a result of forest canopy transpiration and associated local turbulence and the manner in which large forests act as water vapor pumps (see discussion below) (Makarieva *et al* 2008 as cited in Nobre 2014). The cooling effect of forests helps conserve water in waterways and water bodies within and adjacent to forests, and also helps to maintain lower water temperatures in addition to lower air temperatures. Lower water temperatures maintain higher dissolved oxygen levels which then help to support cold water fisheries and reduce the risk of eutrophication. They lag temperature change from season to season and from day to night. This explains why winter snows are deeper in fields and may be minimal in forests, thus allowing for greater infiltration, which leads to aquifer recharge and minimization of floods during peak precipitation seasons.

Large forested areas act as regional and even continental water vapor pumps (Newell and Newell 1992 as cited in Nobre 2014), transferring humid coastal air inland hundreds of miles or more. In the case of extremely large forests such as the Amazon, “flying rivers” of windblown water vapor travel as far south as Northern Argentina (United Nations Food and Agriculture Organization 2019). The Amazon forest has been estimated to pump approximately 20 billion tons of water into the atmosphere per day, which is greater than the amount of water discharged from the Amazon river into the ocean each day (Expedição Rios Voadores 2021). Without the transfer of water vapor from humid coastal areas, inland landscapes and interior continental lands would suffer from more water shortages and droughts. Forested coastal states like Massachusetts help move water vapor further inland, thereby reducing the risk of drought for regions and states that are further inland.

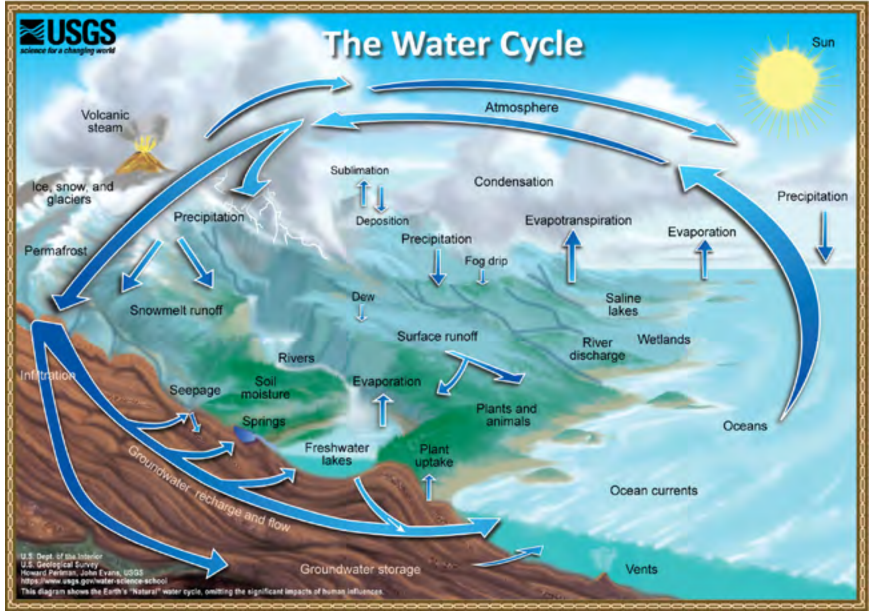


Figure 1.20: ***The Water Cycle***
Source: Howard Perlman, USGS and John Evans, USGS

Trees and the Water Cycle

Trees are involved with several key processes in the water cycle. Evapotranspiration is a term describing the combined processes of 1) transpiration: plants, through physiologic and metabolic processes, absorbing water through their roots and moving the water up through stems, into their leaves, and then releasing water vapor through leaf stomata (similar to pores) into the atmosphere and 2) evaporation: liquid water on the surfaces of plants and land converting to gaseous form and moving into the atmosphere.

Principles of Managing Forests for Climate Resilience and Carbon Sequestration
Land managers and policy makers are faced with both assisting forests to adapt to a changing climate, and reducing climate-related losses of carbon or increasing carbon dioxide removal from the atmosphere. These twin climate-related goals are also linked with the need to sustainably produce many different forest services including water management, provision of fiber for wood products, recreation opportunities, and so on. A changing climate poses risks to all of these functions. Ontl *et al.* (2019) conclude that it is important to include an assessment of climate vulnerability that considers the effects of management actions over extended timescales, and clearly identifies other management goals that affect co-benefits. They suggest that consideration of extended timescales can reveal synergies between adaptation and mitigation, that assessing climate vulnerability can increase desirable management outcomes, and that managing for multiple co-benefits is an effective way to engage landowners and helps ensure that the desired climate-related outcomes are achieved.

Resilience of Forests and Trees as Our Climate Changes

Land Use Change – Loss of Forest
The most permanent of the stressors compounded by climate change, and the one that poses the most significant near-term and long-term threat to Massachusetts forests, is land use change. New England's forests are largely owned by families and individuals, many of whom are over sixty (Catanzaro *et al* 2016). As ownership changes hands within families, decisions relating to continuing forest stewardship versus subdivision and development are made. Loss of forests and farmland to residential, solar energy and commercial development is a growing threat in New England (Foster 2017), and the decisions that individual and family forest owners make in the near future could have a significant impact on forest conversion rates. Once cleared and covered/paved/developed, there is little chance for land to recover ecological function until long after the area is abandoned by humans. Conversion of forest to lawn significantly impairs the ecological function of the landscape, with return to forest highly unlikely; however, lawn does allow infiltration of precipitation and provides some cooling, particularly in comparison to paved or other impervious surfaces.

Pests, Diseases, Invasive Species

The second most disruptive stressor is invasive species. As the climate changes, pests, diseases and invasive species become more numerous and are more effective at damaging native species in part because native species may be stressed by altered climatic conditions. Some of the pests that currently pose a threat to Massachusetts forests include the emerald ash borer (*Agrilus planipennis fairmaire*), the hemlock wooly adelgid (*Adelges tsugae*), Asian longhorn beetle (*Anoplophora glabripennis*), white pine weevil (*Pissodes strobi*), eastern spruce budworm (*Choristoneura fumiferana*) and beech bark disease, with more novel pests and diseases likely to emerge over the coming decades. Common invasive species include oriental bittersweet (*Celastrus orbiculatus*), multiflora rose (*Rosa multiflora*), Norway maple (*Acer platanoides*), common reed (*Phragmites australis*), and garlic mustard (*Alliaria petiolata*).

Photo credit G. Davies

Natural Disturbances
There is a strong potential for natural disturbances to have significant effects on Massachusetts' forests (Swanston *et al.* 2018). Of particular concern in the Northeast U.S. are drought, fire, and weather events such as ice storms and hurricanes. Some of these natural disturbances are of small scale in Apple Country but nonetheless may be severe when they occur. In the Northeast, excess rainfall is likely to be the most impactful of the natural disturbances, causing flooding, crop failure, and soil erosion (Dupigney-Giroux 2018).

Southern Species
Native New England species are likely to become increasingly stressed and outcompeted by southern species that are adapted to warmer temperatures and are expected to become increasingly dominant over time. Northward shifts in species ranges caused by the warming climate have already led to an upslope shift in the boundary between northern hardwood forests and boreal forests in Vermont's Green Mountains (Horton *et al* 2014 as cited in Tobin *et al* 2015).

Forest Health
A forest is more than a collection of trees standing next to each other. It is more than a crop plantation of woody tree species. A forest is a connected web, rooted in soil formed over millennia, and supported by synergistic (and competitive) relationships between individuals and between species (Simard *et al* 1997, Song *et al* 2015). The journal *Nature* has coined the term "wood wide web" for this belowground web of interconnected roots, fungi and soil (Wohlleben 2016). Research has demonstrated below-ground connections between trees, even those of differing species, via mycorrhizae, the filamentous fungi that serve as connections through the soil between tree roots (Song *et al* 2015). Trees transfer nutrients across these below-ground networks

in mutualistic relationships that strengthen the resilience and health of the community of trees in the face of stressors such as drought and pest infestations, both of which are increasing as the climate warms (Simard *et al* 1997, Song *et al* 2015).

Wohlleben (2016) observes that managed conifer plantations suffer far more storm damage and tree fall than old growth forests where trees grow closer together and through natural processes live as an integrated community. In old growth forests, young trees grow much more slowly than in forests where wood-harvesting is occurring. The wood harvesting often creates canopy spaces that allow more sunlight to reach the younger trees, generating faster but weaker growth. The slower growth of young trees in mature and old growth forests with closed canopies results in tree trunk cells that are much smaller and less prone to breakage than those found in faster growing saplings. Thus old growth/closed canopy forest conditions enhance the storm damage resilience of the forest.

Other researchers (Mildrexler *et al.* 2020, Moomaw *et al.* 2020, Leverett *et al.* 2021), also have found that large, old trees and old growth forests tend to be the most climate resilient, and additionally store and continue to accumulate the most carbon, and support the greatest biodiversity and deliver a wide range of other ecosystem services. Large trees (as defined by Mildrexler *et al.* (2020) as greater than 21 inches diameter at breast height (dbh) and high carbon forests are more resilient to drought and fire, support greater water availability, soil health, microclimate buffering and more biodiversity. Large diameter trees act as focal centers for mycorrhizal communication and inter-tree resource sharing, leading to the fullest development of below-ground connections in the "wood wide web" (Mildrexler *et al.* 2020).

Intact, undisturbed forests tend to have fewer invasive species than disturbed forests (Leverett *et al.* 2021). Forests, like soil (Janzen 2016) and wetlands (Moomaw *et al* 2018), require time to develop and to function to their fullest capacity.

In cases where a forest has been degraded, forest health may be improved by assessing forest diversity, composition, structure, regeneration capability, and site-specific stressors (Ferrare *et al* 2019) as well as status of invasive species, forest pests and pathogens, deer browse impacts and the condition of soils (Catanzaro *et al* 2016). Specific forest restoration measures such as removing unhealthy trees or invasive plants may help improve forest resilience and health if forest condition and stressors warrant.

Assessment of Carbon Stock Changes in Forests and Trees Outside Forests

With regard to maximizing carbon storage in forests and trees, Mildrexler *et al.* (2020) found that large diameter trees (i.e. 21-inch dbh or greater) store disproportionate amounts of carbon, compared to smaller diameter trees. In the temperate forests studied, the large diameter trees stored 42% of the above-ground carbon, yet represented only 3% of the 636,520 trees that were inventoried. Likewise, larger diameter trees sequester more carbon per year than smaller diameter trees, although the smaller, younger trees may be growing at a faster rate. These researchers note, "...forests cannot accumulate above ground carbon (AGC) to their ecological potential without large trees (Lutz et al., 2018)." Leverett *et al.* (2021) came to a similar conclusion studying eastern white pines (*Pinus strobus*) in Massachusetts and found that large diameter trees and older forests accumulate more carbon faster than younger, smaller trees. These researchers found that the above-ground live carbon can double during the trees' 80 to 160 year age range.

In addition to storing more carbon, older and structurally diverse forests are highly likely to be more resilient to climate change (Thom *et al.* 2019). These findings point out the critical importance of conserving and protecting existing large diameter trees and intact forests where large trees are abundant, as well as letting middle-aged forests grow into the older age classes that have higher proportions of large trees.

"...forests cannot accumulate above ground carbon (AGC) to their ecological potential without large trees."
(Lutz *et al.*, 2018)

Carbon Rock Stars: Large, Older Trees and Forests

"A large northern red oak measures 14 feet in circumference. Its height is 100 feet. Approximately 50% of this dry weight is carbon, or 7.7 tons. This amount of carbon has a CO2 equivalency of 28.2 tons. Let's say we have a 12-inch [diameter at breast height] DBH, 50-foot tall young northern red oak. It would take 35 young trees to match the carbon of the one large oak. Using a 6-inch DBH, 40-feet tall oak, the number of young trees needed to match the one big tree soars to 151! Finally, let's drop to a 4-inch DBH and 25-foot height. The number of oaks required skyrockets to 465! It takes 10 or more years to get a young red oak up to this [4-inch DBH] size...Let's take a young, newly planted tree from nursery stock...its diameter is 1 inch and it is 4.5 feet tall...it would take 61,364 newly planted trees to match the carbon in our one large oak, and they would be three years old!... Assuming each 1-inch diameter seedling controls only 5 ft² of ground space, then the total area needed to hold the seedlings becomes...7.0 acres... The lesson is clear: Save big trees where possible."

- Robert Leverett, American Forests National Tree Champion Program, Native Tree Society, and Friends of Mohawk Trail State Forest

<u>Figure 1.21:</u> ***Infographic: Tree carbon storage equivalencies.***

Land Emissions: Greenhouse Gas Inventory for Forests and Trees

To help deploy natural climate solutions across the U.S., the Woodwell Climate Research Center collaborated with the World Resources Institute and Local Governments for Sustainability (ICLEI-USA) to enable communities, including the Apple Country communities, to assess their greenhouse gas inventory for forests and trees outside forests (e.g., trees in urban and suburban areas, agricultural lands, golf courses, and other areas not classified as "forest"). This information is critical for identifying how communities could reduce emissions from land use or increase carbon dioxide removal from the atmosphere by planting trees and forests. The inventory protocol can be applied to counties or other jurisdictions via a fully functional online tool called the Land Emissions and Removals Navigator (LEARN).

In 2020, the three Apple Country communities were enrolled in a training cohort of more than 20 participating communities (most often counties) around the U.S. to learn about the methodology through a series of 8 webinars, and used the LEARN tool to develop GHG inventories for forests and trees outside forests for all of Apple Country. The results of these GHG inventories support this MVP project, but funding for Apple Country participation came from another source besides the MVP program. Results are used throughout this document to support recommendations for actions that each community can consider as they develop climate action plans.

The assessment aimed to quantify how carbon stocks are changing in forests and trees outside forests in Apple Country. Below, and using National Land Cover Data (NLCD), estimates are presented for several main categories of land use and land cover: forest remaining forest, forest converted to non-forest, non-forest converted to forest, and trees outside forests. For the purposes of this forest and tree carbon assessment, forested wetlands are included in the forest category. These estimates form the basis for identifying opportunities to take actions that can increase the stock of carbon in forests and trees or reduce the emissions of carbon from forests that are converted to non-forest and trees that are lost from non-forest areas.

Methods Overview

Methods are described briefly here, and with more detail in the Appendix 13. The basic approach is to estimate activity data (area and area-change) and regional removal (i.e. sequestration) and emission factors that enable counties and communities to include forests and trees outside forests in their greenhouse gas (GHG) inventories. By combining activity data with removal and emission factors, counties and communities can develop a baseline inventory of carbon stocks and stock changes in forests and trees outside forests.

Because other sections of this report make use of the 2016 Mass-GIS data for defining land use and land cover, estimates in this section have been adjusted to conform to the areas of forest and non-forest from that data set. Mass-GIS data are of higher resolution (about 3 meters) than NLCD data and therefore have greater accuracy for defining the areas by individual land classes.

Land Cover Change and Carbon Analysis: Apple Country

Land cover change between 2011 and 2016 was estimated from NLCD data (Figure 1.22). Detailed transitions are included in the Appendix. For all of Apple Country, the most significant losses of forest were to grassland, non-forested wetland, and developed land.

In this assessment, forested wetlands are included in the forest category, with other wetlands being included in the non-forested wetland category. The most significant gains of forest land were from grassland and non-forested wetland. The forest to and from non-forested wetland transitions were approximately in balance, suggesting that small changes in the area of tree cover caused the remote sensing classifications to shift between these two cover types. The Massachusetts Department of Environmental Protection (MassDEP) found that conversion of forested wetlands to shrub swamp or marsh during the 1990 to 2017 time period was largely driven by beaver activity and also found that losses of wetlands due to human activity were largest for forested wetlands (Rhodes *et al.* 2019). Other causes for shifts from forest to other land cover types could result from damaging wind or ice storms or other causes of tree damage or death. Forest increases The average canopy area of trees outside forests in Apple Country varies significantly by land cover class (Figure 1.23). Developed areas have the largest area of tree cover at about 2,500 acres. The percent cover by tree canopy is also greatest for settlement areas at about 40%. The other land classes have about 10% tree canopy cover, and the average tree cover for all non-forest land classes is 29%. These estimates represent the average area of tree canopy over the inventory period of 2011-2016, which includes trees that were established before 2011 and trees that were established during the inventory period. The area of tree canopy loss during the inventory period was relatively small, only 40 acres according to the NLCD data, of which most of the loss was in developed and grassland areas.

Because of the relatively coarse 30-m resolution of NLCD data, the area of tree canopy was also estimated using high-resolution aerial photography and the i-Tree CANOPY software. These estimates were applied to the 3-m resolution Mass-GIS areas of land cover rather than the NLCD estimates. Based on this analysis, the average tree canopy of non-forest land in Apple Country was 71%, significantly larger than the 29% estimate based on NLCD alone. The area of tree canopy loss over the inventory period based on the higher-resolution data was about 91 acres instead of 40 from the NLCD data. The tree canopy estimates based on the higher-resolution data sets are used in the next section for calculating the net CO_2 emissions associated with trees outside forests.

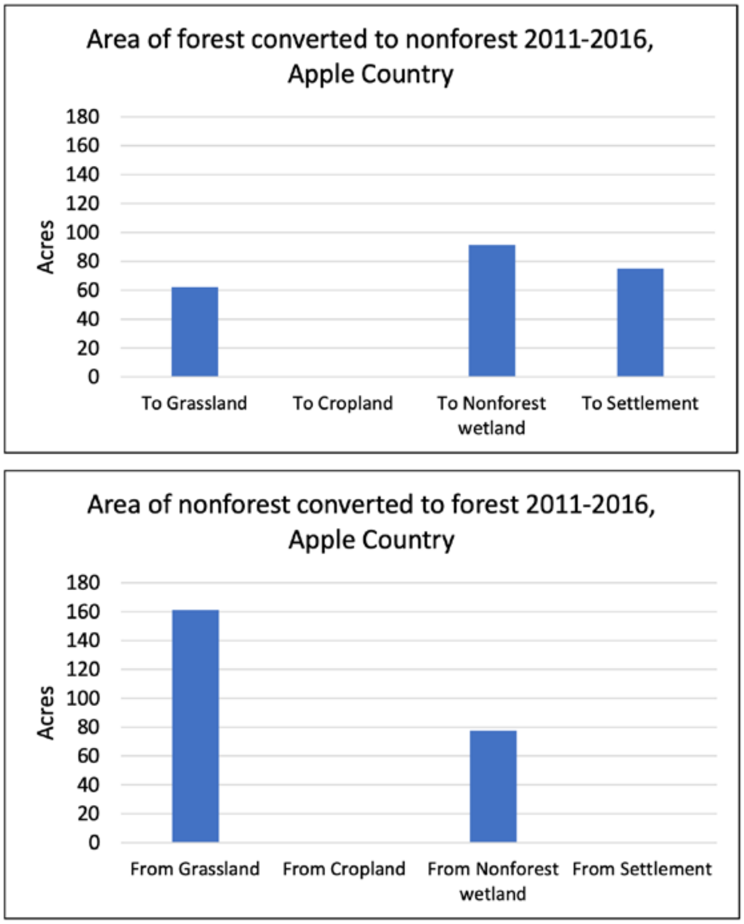


***Figure 1.22.* Area of forest converted to non-forest and non-forest converted to forest in Apple Country, from 2011-2016 based on NLCD data.**

Table 1.10. ***Net CO_2 balance of forests and trees outside forests of Apple Country, 2011-2016***

Source	Removals	Emissions
	(t CO_2e/year)	
Undisturbed Forest	-54,907	
Disturbance fire		0
Disturbance insect/ disease		0
Disturbance harvest/ other		2,086
Non-Forest to Forest	-690	
Forest to Cropland		2
Forest to Grassland		840
Forest to Non-forest Wetlands		1,440
Forest to Developed		2,337
Forest to Other Non-Forest		0
Trees outside of Forests	-31,165	3,207
Harvested wood products	0	
TOTAL	**-86,762**	**9,912**
Net GHG Balance	**-76,850**	

Forests and trees outside forests of Apple Country were a net sink of -76,850 metric tons CO_2/yr from 2011 – 2016 (Table 1.10). Removals of CO_2 from the air were much higher than emission of CO_2. Undisturbed forests and trees outside forests (primarily in settlement areas) represented the largest quantity of removals. The largest sources of emissions from forests and trees outside forests were loss of tree canopy of trees outside forests (3,207 metric tons CO_2/yr) followed by conversion of forests to settlement, forest harvesting, and conversion of forests to non-forest wetlands and grasslands.

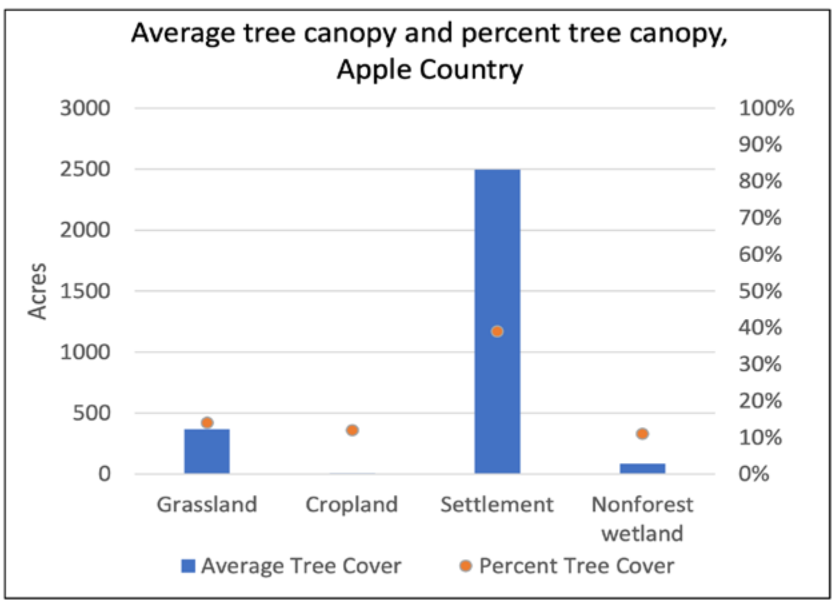


Figure 1.23. ***Average tree canopy area and percent tree cover of non-forest land based on NLCD data for Apple Country, 2011-2016.***

Wetlands

In addition to the information provided below, the Apple Country Natural Climate Solutions project website provides additional material about wetlands in the context of our changing climate, including fact sheets, videos, a StoryMap and Self-guided Field Tour, articles, an educational toolkit, and links to wetlands organizations. Citizens, Conservation Commissions and other community boards and organizations, teachers, librarians, and students will find this information helpful in learning more about wetlands and climate change.

Wetland Status and Trends

Global

Despite the many contributions to ecological and human well-being that wetlands provide for free, and their essential role in stabilizing the global climate and supporting biodiversity, as well as the growing recognition of their value, both monetary and otherwise, global wetland degradation and loss continue in a downward trajectory (Davidson 2014, Davidson and Finlayson 2018, Davidson and Finlayson 2019, Davidson *et al.* 2020). In a review of 189 reports of changes in the extent of wetlands from around the world, researchers found that over time, between 54% and 57% of natural wetlands have been lost, with possibly as much as 87% of wetlands having been lost since 1700 A.D. Losses have accelerated (3.7 times) during the 20th and 21st centuries, with 64% to 71% of losses occurring since 1900 A.D. (Davidson 2014). Researchers (Davidson *et al.* 2020) also found that deterioration of wetlands is widespread and became more so between 2011 and 2017. They concluded that the Ramsar Convention on Wetlands goal, "… to stem the degradation of wetlands has not yet been achieved". This international agreement, now half a century old, was agreed upon and signed in 1971 in Ramsar, Iran, and as of March 2020, 171 countries are signatories. This global loss of wetlands increases the importance of ongoing efforts in Massachusetts to conserve, protect and restore wetlands, and the significance of the successes that have been accomplished thus far.

National

At the national level in the U.S., the most recent assessment of the extent of wetlands is the U.S. Fish & Wildlife Service Status and Trends of Wetlands in the Conterminous United States 2004 – 2009 report (Dahl 2011). As shown in the figure below, wetland loss in the U.S. has diminished over time, but continues. Of note, approximately 633,100 acres of forested wetlands were lost between 2004 and 2009, representing the largest loss since the 1974 – 1985 time period.

In 2011, the EPA assessed the condition of wetlands in the U.S. for the first time and reported findings in the *National Wetland Condition Assessment 2011*, published in 2016 (USEPA 2016). The authors found that across the nation, "…48% of the wetland area is in good condition, 20% is in fair condition and the remaining 32% of the remaining area is in poor condition." In the Eastern Mountains and Upper Midwest ecoregion (which includes Massachusetts), only 52% of wetlands were estimated to be in good condition.

Massachusetts

The picture is brighter in Massachusetts itself. The Massachusetts Department of Environmental Protection (MassDEP) assessed the status and trends of wetlands in Massachusetts for the time period of 1990 to 2017 (Rhodes *et al.* 2019), with results as follows. In their report, MassDEP concludes that due to a variety of factors and in the context of local, state and federal wetland protection regulations, the total area of freshwater wetlands increased by 4,188 acres and coastal wetlands increased by 737 acres. Most of the freshwater wetland gains were for marshes (15,211 acres) and commercial cranberry bogs (1,837 acres), whereas wooded swamps lost 12,111 acres (4.21% of their land area), shrub swamps lost 635 acres. Bogs, the least common wetland type (only 5,364 acres) in Massachusetts, lost 114 acres. Much of the conversion of wooded swamp to shrub swamp or marsh resulted from beaver activity.

Human activity was deemed to have caused a loss of 1,548 acres and gain of 2,733 acres of Massachusetts wetlands. Wooded swamps were the wetland type most likely to be lost to human activity, and the human activity most likely to cause wetland loss during the years 1995 - 2005 was residential development, with cranberry farming being the second largest cause. During the years from 2006 – 2012, MassDEP enforcement actions greatly reduced wetland losses and led to restoration of 68.2 acres. During this time, commercial development became the primary cause of losses, followed by residential development and new road construction. Most of the coastal wetland gains were for beaches (625 acres) and tidal flats (421 acres), whereas salt marshes experienced a loss of 89 acres.

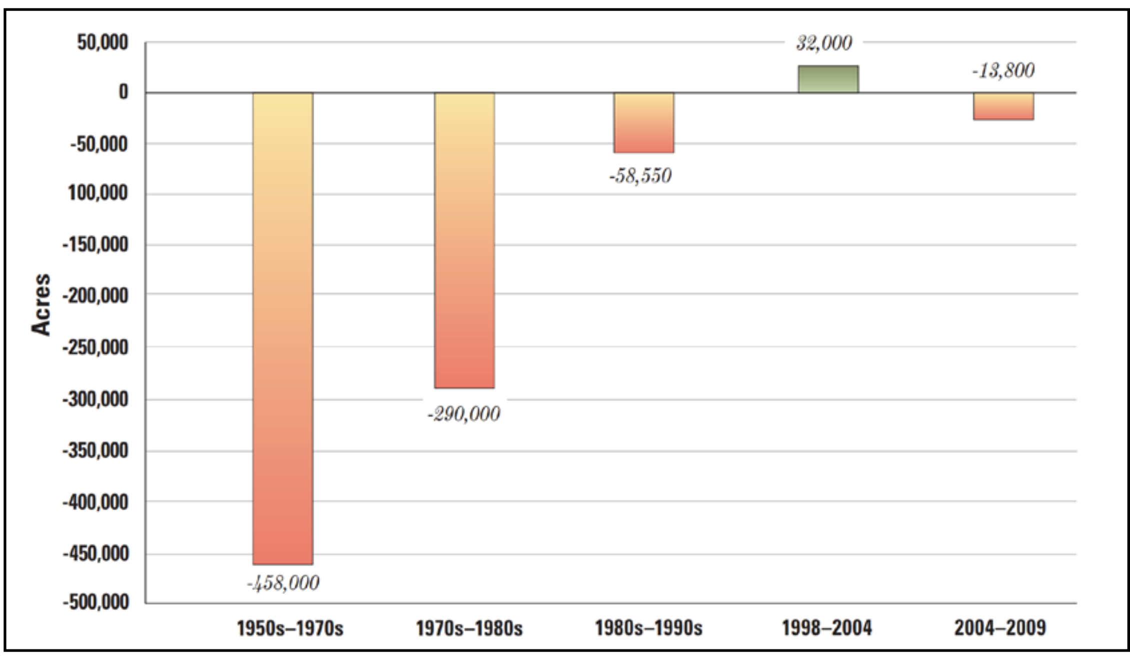


Figure 1.24. **Average annual wetland net loss and gain estimates for coterminous United States, 1954-2009.** Estimates of error are not graphically represented. Source: Dahl 2011.

Wetlands in the Global Carbon Cycle

Wetlands play a disproportionate role in sequestering and storing atmospheric carbon, and thereby in reducing global warming and stabilizing the earth's climate. Although wetlands occupy only 5% - 8% of the earth's land surface, they store approximately 20% - 30% of the world's soil carbon (Nahlik & Fennessy 2016), and store additional carbon in above-ground biomass (Moomaw *et al* 2018). Wetlands accumulate more carbon than uplands because decomposition of organic matter (high in carbon) occurs more slowly in anaerobic (i.e. lacking oxygen) wetland soils than in aerobic, oxygenated upland soils. The slower decomposition rates allow the accumulation of soil organic matter on an annual basis, whereas carbon oxidizes into the atmosphere more easily in upland soils, limiting accumulation (Vepraskas and Craft 2015, Nahlik and Fennessy 2016). Peatlands are a type of wetland that store particularly large volumes of organic, high carbon soil. Peatlands occur in cool, northern landscapes, including Massachusetts and Apple Country, as well as in tropical landscapes.

Apple Country Wetlands and Carbon

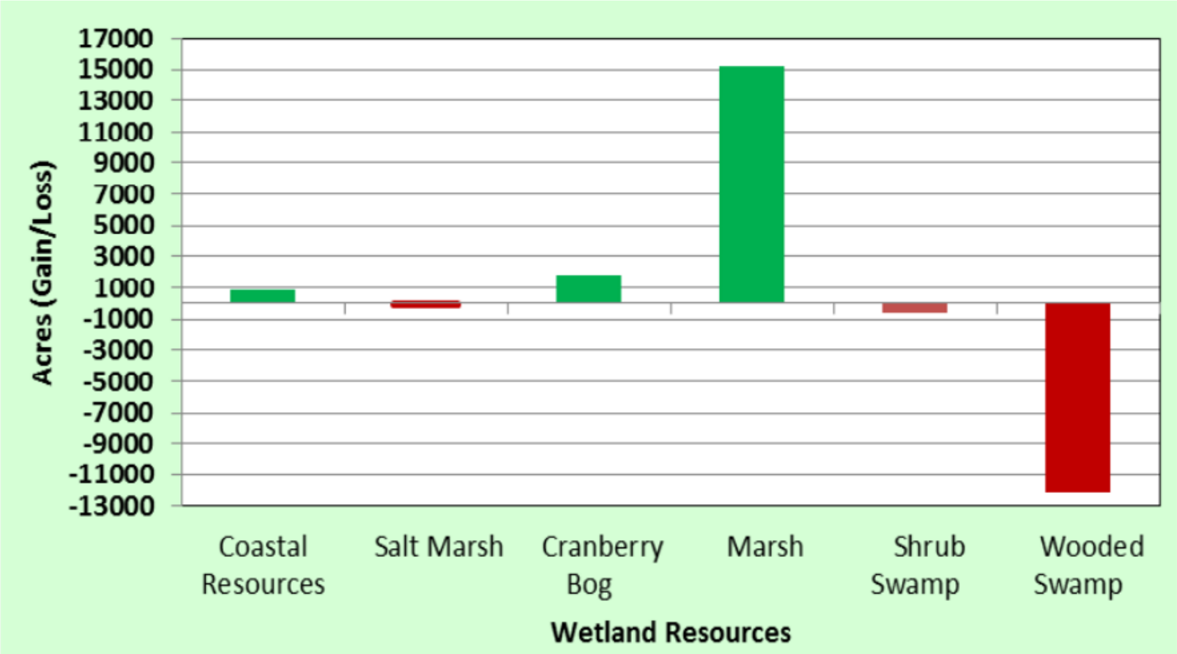
As noted above (see Figures 1.12 and 1.13), in Massachusetts Apple Country (Bolton, Devens and Harvard), as is the case globally, wetlands store a disproportionate amount of soil carbon. Apple Country wetlands occupy only 16% of the land, while storing approximately 27% of Apple Country SOC (see also Table 1.10, below). As mentioned in the above Soils section, this estimate of Apple Country SOC includes only non-living decomposing organic matter in soil, and excludes living roots, carbon in leaf litter and above ground biomass, so the ecosystem as a whole, including both living and non-living carbon, stores even more.

Impacts to Wetland Carbon Function

Changes in type of wetland often lead to changes in wetland function, so wetland-to-wetland conversions, in addition to wetland-to-development conversions (i.e. total wetland

Wooded swamps were the wetland type most likely to be lost to human activity, and the human activity most likely to cause wetland loss during the years 1995 - 2005 was residential development (Rhodes *et al.* 2019).

Figure 1.25.
Massachusetts Wetland Resources Losses and Gains 1990 - 2005
Source: ***MassDEP (Rhodes*** *et al.* ***2019)***



loss), are relevant with regard to ecosystem services provided by wetlands. Degradation of wetlands can also lead to reduced capacity to accumulate carbon or release of existing carbon stores. Additionally, although loss of wetlands to development requires wetland replication in Massachusetts, human-constructed wetlands often do not provide the full suite of ecosystem services provided by undisturbed natural wetlands.

Newly created freshwater wetlands, such as cranberry bogs or wetland replication areas, release more carbon (in the form of methane) than they sequester (in the form of carbon dioxide) for decades, centuries or thousands of years (Neubauer 2014, Neubauer & Megonigal 2015). On the other hand, newly created saltwater wetlands release very little methane due to their differing sulfur-based soil chemistry, and therefore become net carbon sequesterers relatively quickly after construction (Chmura *et al.* 2003, Moomaw *et al.* 2018). Restoration of degraded wetlands, such as those that are filled or drained, can lead relatively quickly to restoration of carbon sequestration and storage functions in both freshwater and saltwater environments (Moomaw *et al.* 2018).

Table 1.11: ***Wetland acreage and SOC stock for Apple Country by wetland type***

Wetland Land Cover	Acres	SOC Stock (Metric Tons)
Palustrine Forested Wetland (13)	3424	474,588
Palustrine Scrub/Shrub Wetland (14)	286	52,401
Palustrine Emergent Wetland (Persistent) (15)	1149	223,147
Palustrine Aquatic Bed (22)	102	8,093
Open Water (21)	581	11,575
Total wetland SOC stocks	**5,542**	**769,803**
Total Apple Country SOC stocks		**2,808,114**
Percent of Apple Country SOC held in wetlands		**27.41%**

Climate Resilience Provided by Wetlands

Wetlands also play a disproportionate role in providing climate resilience ecosystem services for human communities (McElfish *et al.* 2008) as well as ecosystems, such as flood control, storm damage prevention, cooling, improving water quality and water supply, fish, shellfish, and wildlife habitat, biodiversity, and both local and regional habitat/ecosystem connectivity (Erwin 2009, Association of State Wetland Managers 2015).

Protection from Flooding, Drought and Storm Damage

Wetlands absorb and store flood waters during storm and peak flow events, reducing flood and storm damage. Over time, they release these waters gradually, and during drought, high heat, and low flow times, these releases support base flow in streams and provide water supplies for humans and biodiversity. Functioning like a sponge, wetlands even out the troughs and peaks of the water cycle (Keddy 2010) and protect communities and ecosystems from the increasing frequency and severity of flooding, drought and storm damage.

Water Quality

Water quality tends to deteriorate during flooding events because water flows into upland areas, picking up pollutants and toxins that ordinarily are beyond the reach of flowing water. Unfortunately, water quality also tends to deteriorate during periods of low flow and drought, as the contaminants that are already in the water become more concentrated. Wetland soils and vegetation, acting as landscape-level kidneys, trap, filter, transform and bind nutrients (such as nitrogen), pollutants and sediment, such that water leaving a wetland is cleaner than water entering a wetland. Vegetation in wetlands shades streams and rivers, thus helping to maintain cooler water temperatures which then support higher oxygen levels in the water. The cooler temperatures and higher oxygen levels help support cold water fisheries and avoid algal blooms and other temperature-related water quality issues. Thus wetlands help protect water quality as we experience more hydrologic extremes and temperature increases that cause increases in flooding, low flow/drought and high heat days.

Carbon Sequestration

Carbon sequestration refers to the process whereby atmospheric carbon dioxide is converted into living plant material and then becomes soil organic matter after the plant material dies and begins to decompose, effectively sequestering the carbon out of the atmosphere and storing it in plant and soil material.

Localized Cooling, Maintaining Microclimate Conditions

Wetlands and waters provide localized cooling on the landscape, as do forested lands. This localized cooling benefits humans, fish and wildlife, allowing all species to respond to high heat and drought events with greater resilience. Landscapes that have a high density of wetlands (wetland mosaics) are more climate resilient than those that do not, because wetland mosaics create temperature and humidity gradients on the landscape, similar to how elevation changes create such gradients (Anderson *et al* 2016a). These gradients create opportunities for species to migrate locally in response to increases in temperature.

Cooler natural environments on publicly owned lands, such as conservation land and state and federal parks, particularly those that offer shade, provide local no cost recreational, educational and spiritual opportunities for citizens from all economic backgrounds. The COVID-19 pandemic has demonstrated the importance of locally available, publicly accessible outdoor spaces for supporting public mental and physical health. During high heat events, access to these cooler environments can be particularly important for residents who do not have home air conditioning, thus helping to address environmental justice issues.

Wildlife Habitat/Biodiversity – Landscape Connectivity

In addition to providing local temperature and humidity gradients and opportunities for local movements, wetlands, particularly riparian wetlands, can support landscape scale ecological connectivity that allows species to migrate regionally in response to climate changes. Landscape level ecosystem connectivity supports climate resilience by allowing biological and non-biological components of ecosystems to flow across habitats and ecosystems. This includes flow of water, food, materials, and of genetic material, individual organisms, and populations. Organisms may require different habitat types during different life stages, and greater ecological connectivity allows a wider range of species and populations to access the necessary habitats.

Impacts of Climate Change on Wetlands

Vegetated wetlands exist at the interface between fully aquatic and fully upland ecosystems, with relatively narrow elevation ranges, making them particularly vulnerable to the changes in the hydrologic cycle that our changing climate is producing (Erwin 2009, Moomaw *et al.* 2018). Wetlands often exist in low-lying areas, and thus receive both local climate-related impacts and those that accumulate from areas further up in the watershed (such as floodwaters) or on the landscape (Finlayson *et al.* 2017). In Massachusetts, we are experiencing both increases in heavy precipitation events with associated increases in flooding, and also increased incidence of drought and high heat.

Community Voices

The Apple Country Natural Climate Solutions MVP project is both welcome and timely – especially so in what is becoming a "metro-Boston sprawl zone" in our area. Open space preservation and floodplain protection are integral to the nature-based approach being taken in this project, and they are integral to the work of the Nashua River Watershed Association (NRWA). Indeed, a "greenway" approach has been at the center of the Association's mission for all of its 50+ years in existence. The NRWA acts as advocate and advisor for the establishment of the Nashua River Greenway. Conservation of the river's edge is a priority, as expressed in our founding vision of "sparkling blue water with a ribbon of green alongside it." We encourage a permanently protected corridor along the Nashua River and all its tributaries. In Bolton, Devens, and Harvard, this Greenway can be a natural buffer (ideally at least 300 feet wide) to filter pollutants, prevent soil erosion, provide flood storage, protect wildlife habitat, and offer outdoor recreation, like riverfront trails. Land protection equals water protection. A considerable public and private investment has made clean-up of the Nashua River a reality; climate change is going to require additional investment. Greenway creation will protect these investments while it enhances the use and enjoyment of our waterways. As water quality continues to improve and as more riverfront conservation lands are connected, Greenways will become an increasingly important asset to our communities. This Apple Country MVP project can assist in this most important endeavor.

- Al Futterman, Nashua River Watershed Association Land Programs Director

Increased flooding and heavy precipitation tends to occur in the late winter and spring, and drought/high heat tend to occur during the summer and early fall.

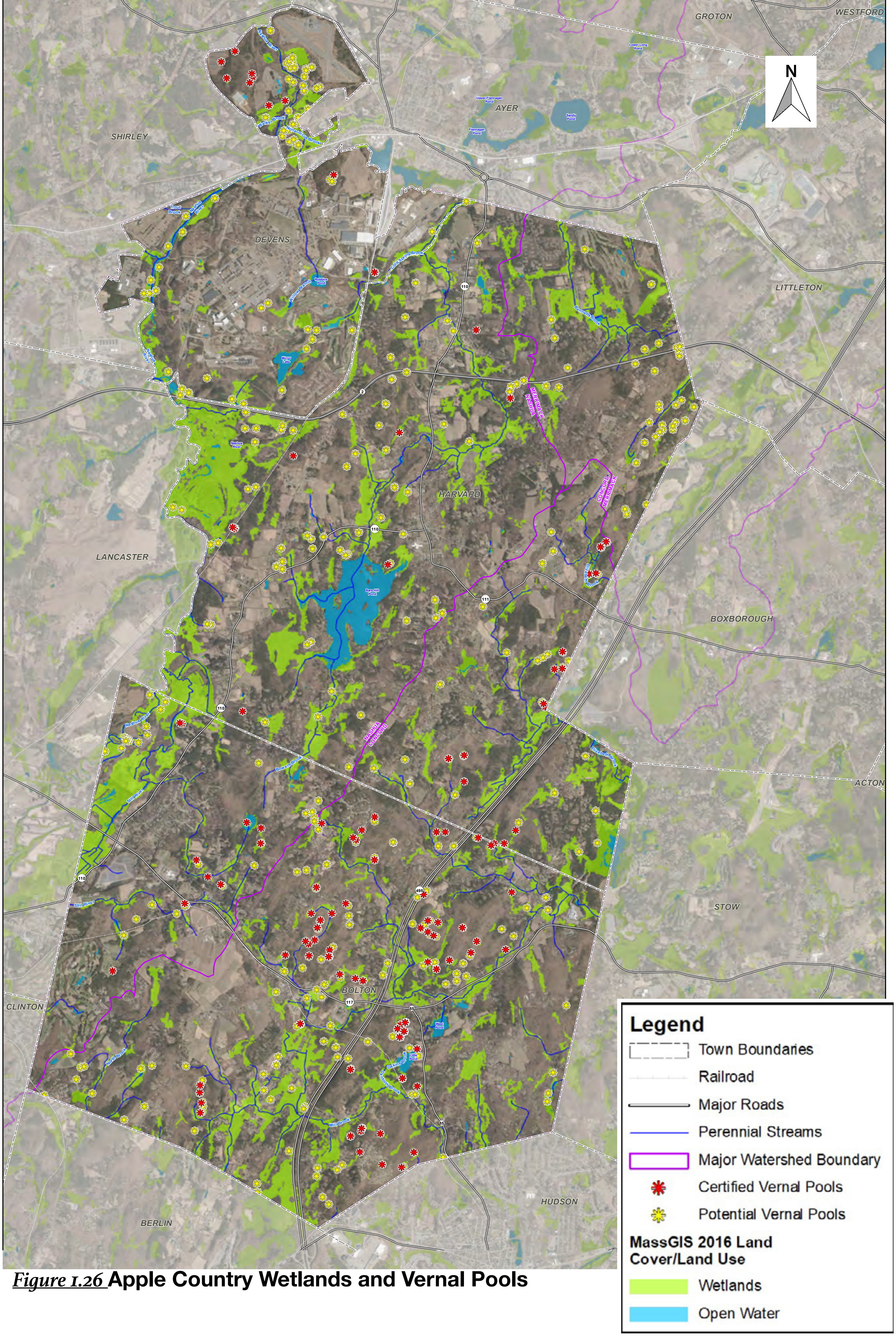
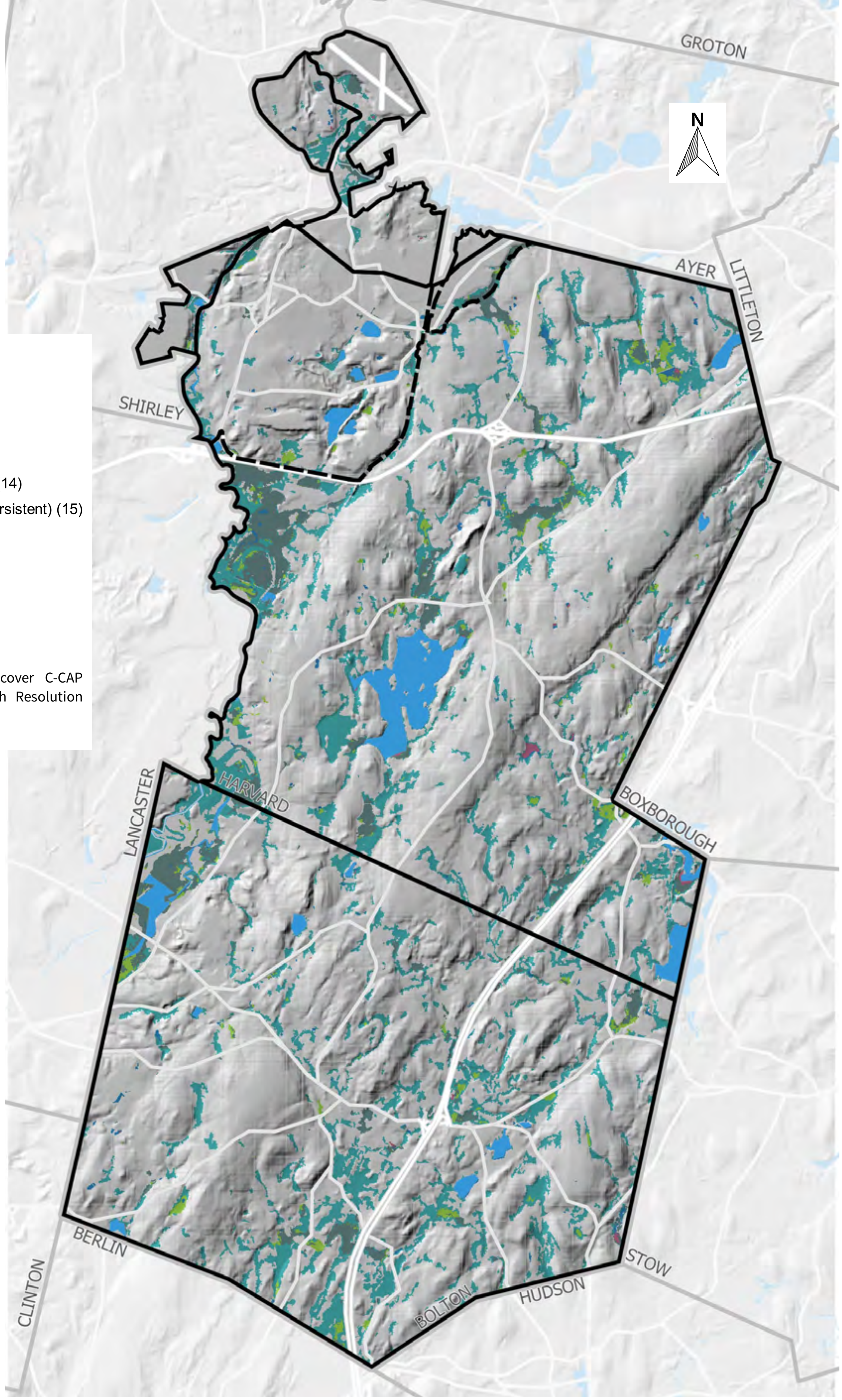


Figure 1.26 **Apple Country Wetlands and Vernal Pools**



Apple Country Boundary

Town Boundaries

Wetland Landcover

- Palustrine Forested Wetland (13)
- Palustrine Scrub/Shrub Wetland (14)
- Palustrine Emergent Wetland (Persistent) (15)
- Unconsolidated Shore (19)
- Open Water (21)
- Palustrine Aqautic Bed (22)

Map Descripton

This map shows the Wetland Landcover C-CAP classes from the Mass GIS 2016 High Resolution Landcover Dataset

Figure 1.27 **Apple Country Wetlands Land Cover**

When groundwater and surface water levels increase for sustained periods and/or recur with greater duration and/or frequency, soil biogeochemistry and vegetative species may shift, leading to the expansion of the area functioning as wetland (Erwin 2009), and demonstrating the importance of protecting buffer zones. Without naturally vegetated buffer zones, wetland expansion may be limited by development, and downstream flooding may be exacerbated under these changed hydrologic conditions.

During extended dry periods and drought, groundwater levels drop and surface water recedes, which can lead to die-off of wetland vegetation and replacement with upland species, particularly at the upland boundary of a wetland where elevation changes gradually. This may lead to loss of regulatory status as a wetland resource area if the wetland is delineated under such conditions. In some cases, particularly where wetland species predominance is at or just slightly greater than 50%, a shift of just one or two dominant species from wetland to upland can cause a regulated wetland area to lose regulated and protected status during dry periods, and then the area may shift back again during wetter times of year. Herbaceous species shifts are more likely to occur on these shorter time scales than shrub or tree species.

As the climate shifts, species and species assemblages are likely to shift (Lawler 2009). Southern species are moving northward, and opportunistic adaptable invasive species are increasingly prevalent. Warming temperatures allow pests and diseases to move northward as well. Severe storms may impact ecosystem structure, which may take a long time to recover, or may not recover, after the storm is over. Relationships between species may become disrupted, such as flowering being timed with warming temperatures during the spring, whereas pollinators time their arrival based on changes in daylight. Native Massachusetts species are increasingly stressed by these climate-related pressures in combination with other existing stressors such as pollution, loss of habitat and conversion of natural land cover to developed land, and hydrologic alterations. Combined, these pressures can lead to ecological shifts or ecosystem disassembly (Lawler 2009, Tate and Battaglia 2013). Highly visible examples of ecosystem disassembly where climate change is causal are occurring in coral reefs and in arctic ecosystems.

Vernal Pools and Climate Change

Vernal pools are small, temporary forest ponds that tend to dry out. Complex ecosystems composed of hundreds of species are often found in vernal pools, and they are essential habitat for at least some portion of the life cycle of many species. Vernal pools are common throughout the Northeast.

Since 1988, the MA Division of Fisheries & Wildlife (DFW) has maintained a program to officially certify field-verified vernal pools. These Certified Vernal Pools (CVPs) receive protection under federal, state, and local wetlands protection regulations under certain circumstances. 105 vernal pools have been officially certified in Apple Country, with many hundreds more potential vernal pools identified (Burne 2001).

Hydrology is a primary determinant of ecological function in vernal pool ecosystems (Brooks 2005). Vernal pools are fed by a complex interaction of groundwater, precipitation, and surface water flows, and respond to evapotranspiration (see page 4 for definition) dynamics and soil characteristics, all of which can have a significant effect on duration of flooding (Leibowitz and Brooks 2008).

Modeling presented by Cartwright (2020) shows that the percentage of time vernal pools are wet tends to decline under future climate projections. Premature drying resulting from a warmer, drier climate may cause the greatest vernal pool climate vulnerability and is a primary management concern (Cartwright *et al.* 2020). Vernal pools and the species that depend on them may also be affected negatively by other anticipated climate-related changes, including increased heating degree days, and changes in species composition (e.g. the arrival and expansion of invasive species and disease vectors).

Planning that focuses on protecting vernal pool ecosystem functions should consider pool size and current duration of flooding to prioritize the protection of climate resilient vernal pools. Opportunities to enhance vernal pool resilience could also focus on supporting the natural pool hydrology for example by protecting the vernal pool buffer zone and maintaining forest cover.

REGIONAL RECOMMENDATIONS

"Not only are the climate change and biodiversity crises two sides of the same coin, but ecological restoration can no longer be thought of as separate from the vital work needed to address these two issues in order to protect human health and wellbeing." – **Bethanie Walder, Executive Director of the Society for Ecological Restoration**

In addition to the key regional recommendations that are outlined below, community-specific recommendations are provided in each Town-specific section (Bolton, Devens, and Harvard). These community level recommendations include site-specific Nature-based Solutions (NbS) for each of the three Apple Country communities (see also -- project website's Nature-based Solutions page). The site-specific NbS information includes preliminary project scopes, costs, and photographic maps of the NbS locations, as well as general project planning and permitting considerations.

Protect

1. Accelerate conservation of areas with high climate value, prioritizing areas at highest risk of development.

   Where "climate value" can be understood as the overlap of:
   - Areas of high ecological climate resilience; and
   - Areas of high ecosystem services value (e.g. carbon sequestration and storage, stormwater management).

   See Figure 1.9 (page 46) for a map of key carbon banks and Figure 1.4 (page 42) for an overview of ecological climate resilience in Apple Country.

   a. Wetlands
      i. Given the outsized role that wetlands play in the global carbon cycle and in providing community and ecological climate resilience ecosystem services, and the heightened vulnerability of wetlands to the impacts of climate change, protection of the functions and ecosystem services that wetlands provide is critically important.

   b. Riparian Corridors/Floodplains
      i. River and stream corridors including their present and future floodplains and wetlands, such as those of the Nashua and Still Rivers and several streams in the project area, are exceptionally valuable for climate resilience, landscape scale connectivity, flood control and storm damage prevention, water quality and quantity, and for providing wildlife habitat, and should be a primary focus for actions intended to maintain and protect ecological integrity and to maintain the mosaic of features that will maintain climate resilience for the region.

"Protecting wetlands and riparian corridors has been suggested as one of the single best actions in promoting resilience and in sustaining biodiversity." (Naiman 1993 and Fremier 2015, as quoted in Anderson et al 2016a)

c. Forests
   i. Healthy, natural forests with large older trees and high biodiversity provide numerous benefits to both ecological climate resilience and ecosystem services, including as significant carbon banks.
   ii. Protection through conservation purchase or restriction is the most valuable way to minimize the threat of forest loss.
d. Farmlands
   i. Protect Prime Farmland and Farmland of Statewide Importance at risk of development. NELF shows the 957 acres of these soils at risk of development in Apple Country.

Restore

1. Prioritize restoration efforts that connect existing healthy ecosystems.

   a. Reforestation
      i. Incentivize strategic reforestation in riparian areas. There are currently 302 acres of unforested and undeveloped lands in the FEMA 100-yr floodplain found throughout Apple Country. Restoring these sites to forest can support the state goal of replanting 500-miles of unforested riparian buffers by 2030.
      ii. Reforest inactive impervious and/or degraded sites, such as airports, parking lots, mine lands, gravel quarries, and abandoned agricultural land. Regenerate forests in places where they provide greater resistance and resilience to climate change induced disturbance, such as on steep slopes.

Community Voices

"We at OARS couldn't be happier to learn about the Apple Country Natural Climate Solutions MVP project in Bolton and Harvard, two communities in the headwaters of the Sudbury-Assabet-Concord (SuAsCo) watershed, and neighboring Devens. Since the impacts of climate change are transboundary, OARS has been working to bring a watershed approach to building ecological, social and economic resilience. These headwater towns are the source of Elizabeth Brook, an important tributary to the Assabet River in Stow. Our small streams and wetlands are the nurseries for much of our wildlife, they recharge the precious groundwater resources upon which our communities and nature depend, and are a natural flood prevention system. Yet they are easily degraded by thermal pollution and other stormwater impacts. Making the right land use and infrastructure decisions now to protect natural functions of cleaning and recharging stormwater and reducing heat islands will protect our communities well into the future. This project is a much-needed model of municipal collaboration to bring durable resiliency to this region."

- Alison Field-Juma, Executive Director of OARS "Organization for the Assabet Sudbury & Concord Rivers" http://www.oars3rivers.org/

b. Pocket forests
    i. Plant pocket forests to increase tree cover in highly impervious and urbanized areas, reduce urban heat island, and improve carbon and water holding capacity of these heavily impacted soils.
c. Verge and ornamental plantings
    i. Use green infrastructure and verge plantings to connect and expand adjacent forest patches and corridors.
    ii. Add trees to lawns and at the edges of playing fields.
    iii. Contact EEA about becoming a pilot region for the 1-Million Tree Mass Savannas Program which aims to establish 25% canopy cover over ornamental lawns, gardens, and paved areas across the State.
d. Agroforestry
    i. Encourage the adoption of perennial, woody agriculture on agricultural lands throughout Apple Country including silvopasture and riparian agroforestry to increase agricultural resilience to climate change and accelerate carbon sequestration simultaneously.
    ii. Support farmers already practicing agroforestry, such as orchardists, by reviewing bylaws that impede BMP's and soil smart management.
    iii. Seek collaborations with Conservation Districts, the NRCS, MDAR, and the National Agroforestry Center to ensure local farmers have access to the technical, financial, and educational resources necessary to implement multi-benefit agroforestry practices as Nature Based Climate Solutions.
    iv. Discourage the conversion of forest to silvopasture while encouraging tree additions to existing pastures.
    v. Connect protective agroforestry in the buffer zones of water resources areas and on erosion-prone slopes with broader State-wide and regional reforestation, wetlands, and riparian zone restoration efforts.
e. Floodplain, hydrologic and wetland restoration
    i. Incentivize floodplain and wetland restoration in areas currently serving as floodplain and wetland as well as areas likely to become floodplain and wetland as the century proceeds.
    ii. Upgrade stream and river crossings to accommodate future storm flow volumes and to meet Massachusetts Stream Crossing Standards and avoid new stream and river flow constrictions and piping.
    iii. Accelerate retrofitting of suitable impervious surfaces with stormwater recharge features and street trees to regenerate lost soil-water function. Such restoration could be piloted on city and town-owned lands and be funded through resilience-oriented grants at the municipal level.
    iv. Continue to identify opportunities for wetland, floodplain, and stream/river restoration in Apple Country. Seek funding to support implementation of wetland, floodplain and stream/river restoration projects, including projects identified in this report.

2. Restore native species and resilient tree cover strategically where opportunities exist.

    a. Limit tree planting to native species and consideration of some slightly more southern species that will not become invasive, as a hedge against warming conditions.

        i. Avoid planting tree species that are anticipated to do poorly in Massachusetts during the coming centuries, specifically avoid planting where stress will make them a vector for pests and disease (e.g. parking lots and roadways).
    b. Plant climate-threatened trees where microclimate conditions create an advantage such as higher elevations, northeast exposures, or cooler, shaded ravines. By strategically including/ preserving these species, we may allow them to adapt to the region, and with them, their contingent ecosystems. At a minimum, this buys plants and their dependent wildlife time to migrate.
        i. Native species endangered by climate need access to a critical mass of mating partners to ensure their progeny are included in the genetic winners of the race. To support this transition, we must ensure mature seed-bearing mother trees prosper and are connected to others by their vector species (birds and rodents) (see e.g. Pocket Forests, above).

Manage Better

1. Evolve management practices for forests, wetlands, agricultural and ornamental lands.

    a. Species management
        i. Carefully manage against invasive species that disrupt healthy ecosystem functioning, and carefully consider planting future climate-adapted species rather than climate-vulnerable species.
            1. Roadway edges should be maintained with strategically differentiated groups of contrasting species selected for edge condition, salt and pollution tolerance, road safety and preferential selection of species that contrast with, rather than match, the composition of adjacent forests.
            2. Selected species should support a robust songbird and pollinator group to act as an immune system for the forest. There may also be opportunities to improve the health and stocking of existing forests through improved silviculture and addressing any problems of tree health from insects and diseases.
            3. To align with climate resilience and carbon sequestration goals, forest cutting can be limited to removal of invasive species and diseased individuals.
        ii. Support threatened native species and ecosystems (such as vernal pools).
            1. There may also be opportunities to improve the health and stocking of existing forests through improved silviculture and addressing any problems of tree health from insects and diseases.
        iii. In landscaped areas, mimic native ecosystems (such as by planting pocket forests; see Restore, above) and plant native and high value future-adapted species.
            1. Focus on reducing the loss of tree canopy by trees outside forests, particularly in developed areas (and especially in Devens).

    b. Climate-smart farming practices
        i. Support for good stewardship that protects and builds soils, maintains clean

waterways, supports biodiversity, and ensures a consistent food supply can help growers to both mitigate losses from existing production systems and proactively adapt to likely future conditions. This will continue to be the case as effects and interactions from climate change increase.

1. Given the characteristics of the soils, farms, and natural communities of Apple Country, the most promising of these multi-benefit practices include silvopasture, conservation agriculture, and managed grazing like intensive rotational grazing.
2. Protective agroforestry, the practice of planting and managing tree and shrub crops in the buffer zones of water resources areas and on erosion-prone slopes, can take many forms and can be used to produce any number of products including nuts, tree fruits, woody fodders and florals.

2. Expand management planning and explore new funding mechanisms.
    a. Watershed resilience planning
        i. Develop watershed resilience plans for sub-watersheds already significantly impacted by impervious cover or at high risk of future development to protect or regenerate soil function. Use land cover-related soil health and water quality factors to set sub-watershed (HUC12) forest land cover targets and priorities.
        ii. Coordinate floodplain restoration and planning for future floodplains within watersheds.
    b. Land cover management planning
        i. Develop management plans and guidance documents for the major land cover types (forests, wetlands, agriculture, turf/ornamentals) that prioritize conservation of ecosystem carbon, climate resilience ecosystem services, and biodiversity while also addressing landowner goals. Tailor plans and guidance documents to different landowner types.
    c. Apple Country Healthy Soils Program
        i. Establish a Healthy Soils Program for Apple Country or each jurisdiction to support private and institutional land owners. Create incentives to reward management practices that preserve forest and other perennial covers as well as practices that enhance soil and ecosystem health.
            1. For instance, given the unique character and dynamics of Apple Country, this region could develop a pilot soil carbon market where Devens' industrial tenants voluntarily purchase carbon credits from participating landowners in Harvard and Bolton, and from restoration efforts in Devens. This hyper-local strategy allows Devens to reduce its emissions, consistent with its 2020 CARP, by incentivizing good soil stewardship and improving economic viability for forest, farm and ornamental lands, and accelerating ecosystem restoration on degraded lands.
    d. Investments in regional agriculture and food system
        i. Increase direct investment in local/regional food systems and smaller-scale farms more typical of the region. Emphasize funding that helps farmers pay for equipment, provide a buffer while transitioning to new practices, purchase cover crops, and implement perennial buffer strips and windbreaks.
        ii. Increase or establish cost-sharing programs to assist farmers with training and equipment costs for transition to practices which increase soil health.

Table 1.12: ***Tree Species Viability as the Climate Changes.*** From Catanzaro et al 2016.

The following table provides tree species and predictions of how competitive they will be in the future. The values following each species name indicate whether species-suitable habitats will increase (+), decrease (–), or stay the same (●) under projected climate change.

Northern New England (Ecological subsections M211A, B, C, and D, and M211E and J)		
Tree Species	Low Emissions (PCM B1)	High Emissions (GFDL A1FI)
Balsam Fir	–	–
Black Spruce	–	–
Northern White Cedar	–	–
Paper Birch	–	–
Red Spruce	–	–
Tamarack	–	–
White Spruce	–	–
American Beech	●	–
Quaking Aspen	●	–
Sugar Maple	●	–
Yellow Birch	●	–
Bear/Scrub Oak	●	●
Bigtooth Aspen	●	●
Eastern White Pine	●	●
Red Maple	●	●
American Basswood	●	+
Bitternut Hickory	●	+
Black Cherry	●	+
Pitch Pine	+	●
Black Birch	+	+
Black Oak	+	+
Chestnut Oak	+	+
Northern Red Oak	+	+
Shagbark Hickory	+	+
White Oak	+	+
Threatened by Current Forest Health Issues (Do not target)		
Black Ash	–	–
Eastern Hemlock	●	●
White Ash	●	●

Southern New England (Ecological subsection M221A)		
Tree Species	Low Emissions (PCM B1)	High Emissions (GFDL A1FI)
Balsam Fir	–	–
Black Spruce	–	–
Eastern White Pine	–	–
Northern White Cedar	–	–
Paper Birch	–	–
Quaking Aspen	–	–
Red Spruce	–	–
White Spruce	–	–
Tamarack	–	●
American Beech	●	–
Northern Red Oak	●	–
Red Maple	●	–
Yellow Birch	●	–
Bear/Scrub Oak	●	●
Black Cherry	●	●
Sugar Maple	●	●
Bigtooth Aspen	+	●
Pitch Pine	+	●
American Basswood	●	+
Bitternut Hickory	+	+
Black Oak	+	+
Chestnut Oak	+	+
Shagbark Hickory	+	+
White Oak	+	+
Threatened by Current Forest Health Issues (Do not target)		
Black Ash	–	–
Eastern Hemlock	●	●
White Ash	●	●

Projected change in suitable habitat in the year 2100 based on Tree Atlas projections for a given ecological subsection. Prasad, A. M., L. R. Iverson, S. Matthews, M. Peters. 2007–ongoing. A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States [database]. www.nrs.fs.fed.us/atlas/tree, Northern Research Station, USDA Forest Service, Delaware, Ohio.

Community Voices

Bolton is pleased to work with regional partners that see the collective importance of planning, acting and creating policies that ensure a more sustainable future. Furthermore, for a group of communities that also see the importance of ecological values, services, and effects on the present and future related to climate change. Together the Apple Country team has ventured further toward becoming a more resilient community in a manner that may be replicable by other communities.

- Rebecca Longvall, Conservation Agent, Bolton, MA

Develop Better

1. Direct solar development toward previously developed sites and degraded soils (see "Soils of Lower Conservation Value").

    a. Develop local programs to incentivize solar development on already developed lands where co-benefits are high such as parking lots, flat roofs, roadsides, and brownfields.
    b. Create or Update Local Bylaws for siting ground mounted solar energy production facilities.
        i. Working Farms Provisions: Incentivize multi-use solar development on agricultural lands when it has clear benefits for farm viability and soil health.
        ii. Prime Farmland Soils + High Carbon Soils Provisions: Limit soil disturbance during full project lifecycle. Ensure disturbances are reversible on Prime and High Carbon Soils. Encourage or require living ground cover under and around arrays.
        iii. Forested Land Provisions: Require developers to provide carbon accounting that includes loss of biomass carbon from above and below ground, loss of SOC, and loss of future sequestration capacity. Limit soil disturbance during the full project lifecycle. Require alternatives analysis to avoid, minimize and mitigate impacts to ecosystem carbon. Establish performance standards for mitigation of lost SOC and biomass carbon and loss of future sequestration capacity.

2. Update wetlands regulations and performance standards.

    a. Wetlands bylaws and regulations: Update bylaws and regulations to explicitly recognize climate resilience and carbon accumulation (sequestration and storage) as one of the contributions of wetlands.
        i. Formalize protection of wetland carbon sequestration and storage, and other climate resilience functions, as Interests of the [Wetlands Protection] Act.
        ii. Maximize protection of the 100-foot buffer zone and consider expanding the width of the buffer zone beyond 100 feet.
        iii. Require invasive species management plans that avoid negative impacts on wetland resource area soil functions.

b. Wetlands performance standards: Develop climate resilience and ecosystem carbon performance standards for each type of wetland that is protected by state and local regulations. Update performance standards as follows:
    i. Require an "avoid, minimize and mitigate" alternatives analysis for proposed impacts to wetland carbon stocks and sequestration capacity.
    ii. Require net improvement/greater than 1:1 replication for impacts to carbon stocks and sequestration capacity and for impacts to climate resilience.
        1. Mitigation for carbon impacts should be calibrated based on quantification of the loss of stored wetland carbon and on the loss of future capacity to continue to pull carbon out of the atmosphere that the proposed impact will cause.
        2. Assign fee penalties for impacts to carbon and climate resilience Interests that are not replicated in accordance with the Order of Conditions.
    iii. Require avoidance of temporal loss or, for unavoidable temporal losses, require greater than 1:1 replication and mitigation based on quantification of the wetland carbon losses incurred during the temporal loss time period, and assign fee penalties for failure to avoid temporal losses and required replication.
    iv. Require stringent professional qualifications and experience for contractors performing wetland restoration and creation construction, as well as for those who design, monitor and supervise the contractors.
    v. Require documentation of hydrologic conditions that will support successful construction of replication wetlands at locations where wetland replications are proposed.
    vi. Avoid and minimize removal of, stockpiling, and drying of wetland soils during construction projects.
    vii. Where feasible, require translocation of impact area intact wetland soils and herbaceous and shrub/sapling vegetation into the wetland replication area.
c. Wetlands conversion fees: Establish conversion fees and penalties for damaged or converted wetlands that account for value of services provided for 'impact period' until full carbon stocks are restored. Value SOC at cost of mechanical removal between $200 and $600/t (Institute for Carbon Removal Law and Policy, 2020).

3. Expand general climate resilience performance standards and incentives.

    a. Soil Protection and Post-Construction Soil Performance Standard
        i. Create a comprehensive performance standard to protect and maximize soil health during and after site development. Require baseline soil health investigation prior to disturbance. Require minimization of development footprint including minimization of tree and topsoil removal from development site.
        ii. Establish stockpiling and soil movement requirements or guides to limit compaction, drying, erosion, loss of soil organic carbon stocks, soil removal from site, disruption of soil structure and function, and movement of harmful species or contaminants.
        iii. Include protection for existing trees, their root zones, and other existing vegetation to maintain and expand carbon sequestration capacity for developed soils. Limiting site clearance and stripping of topsoil could be an effective strategy.

Carbon Conservation for Wetland Replication

(above) *Intact wetland A-horizon soil, root mat, and living vegetation being translocated from impact area to restoration area.*

(above) *Translocated wetland vegetation and soil after translocation and during the 2016 drought.*

(below)
Area of traditional wetland replication (topsoil and nursery stock) during the 2016 drought.

RECOMMENDATION: To enhance carbon conservation and climate resilience when constructing wetland replication areas, where feasible, implement translocation of intact wetland impact area soils and herbaceous and shrub/sapling vegetation into the wetland replication area. A detailed explanation of this methodology is provided in Davies et al. (2019). The idea is to move as much of the full soil profile as possible (complete O and A horizons (topsoil) and as much of the B horizon as possible) with living vegetation intact, in blocks, and to carefully place the intact soil and vegetation into the wetland replication area, maintaining the root-soil contacts and the associated fungi/microbial communities throughout the translocation process, with minimal disturbance to the soil and vegetation.

This translocation process conserves Soil Organic Matter, soil carbon, and the soil-roots-fungi-microbes structure and biological community, as well as the plants from the wetland impact area. This method is most feasible where the impact area has few or no trees, few to no invasive species, and where the impact area and replication area are relatively close together. Cost savings include avoidance of costs for nursery stock, topsoil, mulch, transportation costs and carbon emissions from nursery, and monitoring of soil stockpiles. Because soil structure, organic content, and vegetative cover are preserved, this method may enhance drought resilience and soil water retention compared to wetlands constructed using standard methods. Invasive species are less likely to gain a foothold, as less soil surface is exposed, and there is little to no need for supplemental soil material that may have invasive seed sources.

Post-construction assessment: Translocated replication was more resilient to drought conditions, established higher levels of soil organic carbon, a denser vegetative cover, and higher percentage of dominant wetland plants than traditional wetland replcation.

    iv. For open space associated with development/ redevelopment projects, improve performance specifications for engineered soils that increase the stormwater infiltration and storage capacity in and around impervious surfaces.
  b. Require that green infrastructure and other Nature-based Solutions are integrated into development and redevelopment projects to mitigate or regenerate loss of ecosystem services due to the development process and increase in impervious surfaces.
  c. Control the sales and distribution of landscape materials and ornamentals. This can be achieved through local bylaws governing transfer and installation of species, as well as ongoing review by conservation and planning boards for new development.
  d. Incorporate the value of lost ecosystem services into fees for development or other land conversion such as a local 'green field' development fee, stormwater fee, and/or soil carbon loss fee.

4. Explore the potential for Regional Transfer of Development Rights.

  a. Explore the potential to institute an inter-municipal Transfer of Development Rights framework, emphasizing areas in Harvard and Bolton with high climate values (see above) as the sending regions and establishing the Devens Regional Enterprise Zone as the receiving area.
    i. There is sufficient infrastructure to support additional density and growth in Devens, provided it incorporates Nature-based Solutions and other sustainable development approaches.
    ii. In 2007, the four major counties of the Puget Sound came together to develop a regional TDR program in line with enabling legislation signed by the Governor. Each individual county had also previously adopted its own TDR program, establishing sending areas in the county and receiving areas in major cities. These efforts were mainly aimed at conservation and environmental protection, though some sending-receiving arrangements also promote watershed protection and affordable housing. The regional program builds upon these county-specific ones to integrate their functioning and maximize potential for smart growth and conservation. A Policy Advisory Committee and Technical Advisory Committee were both convened to provide expert guidance on program design and execution, including identifying and defining priority sending and receiving areas and appropriate and allowable inter-jurisdictional transfers. The Puget Sound Regional Council worked closely with the Washington State Department of Commerce and other partners to apply to the U.S. Environmental Protection Agency (EPA) for a West Coast Estuary Initiative grant in 2008. The partnership was successful and a $570,000, two-year grant (with $200,000 in local match) was secured to implement the regional TDR program.

Compact Development in Devens

Emerson Green is a compact development of 124 units in single family, duplex townhouses, and a small number of larger multifamily housing units, located in the Devens Regional Enterprise Zone. The development is in phase two of four planned phases. A key goal for the development is to create high quality housing that enhances the ecosystem in which it sits. The developer, Now Communities, led by Dan Gainsboro, was selected by MassDevelopment because they embrace these goals. The project has worked hard to squeeze down the developed footprint so as to maintain the forested areas nearby and create new shared open space. The developed area is approximately 15 acres, at over 8 units per acre density. Current zoning in many towns requires 80 square feet per house lot, meaning that 124 houses would require 248 acres.

Dan says “Prioritize plants and people ahead of cars.” One of the many innovative strategies employed at Emerson Green is to pave the alley roadways to a minimum width while expanding the drivable area with reinforced turf on either edge to support fire truck access. This strategy reduces impervious surfaces while maintaining emergency access.

The houses are built to high performance standards, achieving a Home Energy Rating System (HERS) ratings of 35 to 43, approximately a 60% savings of standard housing, and are solar-ready. This means that the energy load for the all-electric houses can be met by solar panels on the roof when owners make this choice.

Overall, this project shows how possible it is to build nice, compact, reasonably-priced housing that respects forests and connects with open space.

Planned development layout and aerial view of existing development phase showing compact arrangement and proximity of forest at Emerson Green, Devens.

Supporting Recommendations

Land-based climate resilience and mitigation actions and Nature-based Solutions are only implementable if there is people power behind them. Increasing public understanding of ecological climate resilience and ecosystem services, as well as awareness of the value of NbS and other Best Management Practices to protecting healthy ecosystem functioning, should be approached creatively and using all the tools and resources available through this and other projects addressing climate change in the Apple Country region. Applied research to document the beneficial effects of innovative practices can also position the region as a leader and partner in larger or interconnected climate resilience and mitigation efforts.

Outreach and Education

1. The Apple Country Natural Climate Solutions Project Website https://climateresilient.wixsite.com/applecountry provides the following educational information and materials. See Appendix 14 for a full list of resources available on the project website.
2. Wetlands
    a. Provide community education, including for teachers in schools, on the importance of protecting, restoring, enhancing, and creating wetlands, floodplains, streams and rivers and the climate resilience and carbon sequestration/storage ecosystem services they provide.
    b. Advocate for regulations and/or policies that prohibit the sale of peat moss. Although the peat is imported from other locales, addressing the loss of carbon from peatlands by reducing demand for peat products contributes to reduction of global carbon emissions. Provide education and access for alternatives.
3. Forests and Trees
    a. Advocate for increased funding for professional foresters and other consultants that assist landowners and communities in protecting and managing forests.
    b. Help landowners to understand and implement proactive climate adaptation measures such as those described in the Forest Adaptation Resources: climate change tools and approaches for land managers, 2nd edition from the U.S. Forest Service.
    c. Support private forest landowners to make formal plans and consider public-private partnerships to maintain forests as Apple Country forest landowners near retirement age through intentional estate planning.
    d. To minimize the threat of species loss to browsing herbivores (white tail deer), increase awareness about the value of hunting, and provide training to a new generation of hunters with incentives to encourage and facilitate deer hunting.
4. Soils and Agriculture
    a. Educate developers, contractors, and landscape professionals about preserving soil health during and after site development.
    b. Create and support continuing education and certification programs on healthy soils for all people engaged in site development including building inspectors, town planners, developers, general contractors, and equipment operators.

Research and Data Collection

1. Wetlands
    a. Using DEP Wetlands Change Maps, interviews with town conservation agents and others, develop an index of potentially restorable wetlands in Apple Country.
    b. Engage local and regional partners to increase monitoring and research around ongoing changes to wetlands and wetland soils from climate change, particularly along major river and stream corridors..
        i. Monitor for threats from invasive species and pests to facilitate early detection and treatment, including roadways (where risk is higher) and along stream and river corridors (where invasive species can easily be transported downstream.
        ii. Consider developing citizen science monitoring programs. Collaboration with schools and community organizations may be helpful.
2. Forests and Trees
    a. Engage local and regional partners to increase monitoring and research around ongoing changes to forests and forest soils from climate change.
        i. Monitor for threats from invasive species and pests to facilitate early detection and treatment, including roadways (where risk is higher).
        ii. Monitor to determine if management actions are successful or need revision.
        iii. Consider developing citizen science monitoring programs. Collaboration with schools and community organizations may be helpful.
3. Soils and Agriculture
    a. Require regular soil and water quality testing and data collection on municipal lands. Invite participation of institutional and private landowners. Testing guides management and produces data for ongoing research efforts on the effects of management on soil health and water quality.
        i. Monitor long-term effects of different management patterns and harvest intensities on soil organic carbon storage and sequestration.
        ii. Increase understanding of effects of land management practices on soil health, especially SOC concentrations, compaction/bulk density, and biological activity.

Community Voices

"Devens is proud to be partnering with Harvard and Bolton to take a closer look at our soil and forest resources and how they can and are contributing multiple co-benefits across the region, including reduced greenhouse gas emissions, improved air and water quality, reduced flooding, biodiversity, recreation, as well as improved physical and mental health. The results of this project will help each community guide development in a more sustainable manner by recognizing the added value and interconnected nature of these resources. We are excited to share the results of this project to provide additional tools and resources that will serve as a model for Nature-based Solutions in other communities throughout the Commonwealth."

- William Marshall, Chairman of the Devens Enterprise Commission

2

TOWN OF BOLTON ANALYSIS AND OPPORTUNITIES

Located in the Nashua and Concord River watersheds, yet lacking a major waterway that would attract industrialization, the Town of Bolton (Bolton) was colonized in the 18th and 19th centuries primarily as an agricultural community, and agriculture continues today. Residential development has increased significantly in Bolton over the years, as housing costs in Boston have soared and Route I-495, which passes directly through Bolton, has connected the town to other major transportation corridors. Nonetheless, Bolton relies entirely on wells and septic systems to manage its water and wastewater, necessitating larger lot sizes to accommodate this on-site infrastructure. Almost 1,200 acres of Bolton's natural landscape are now permanently protected, and the Town maintains a commitment to supporting sustainable development and the continued viability of Bolton's farms. Community members have expressed a strong desire to support a diverse community and ensure adequate affordable housing for low-income families, long-time residents, and for fixed-income retirees to age in place. Balancing competing land uses to meet community needs equitably while taking ambitious climate action will be a major challenge framing the future for Bolton and Apple Country as a whole.

The Town of Bolton achieved Municipal Vulnerability Preparedness (MVP) designation from the Commonwealth in 2020. The MVP planning process identified increased flooding from extreme precipitation events as a primary climate change concern. Many roadways already flood, including key regional evacuation routes that pass through town. Flooding is expected to worsen with climate change. Other top climate hazards include extreme weather events, pests and invasive species, and drought, all of which have significant implications for agriculture.

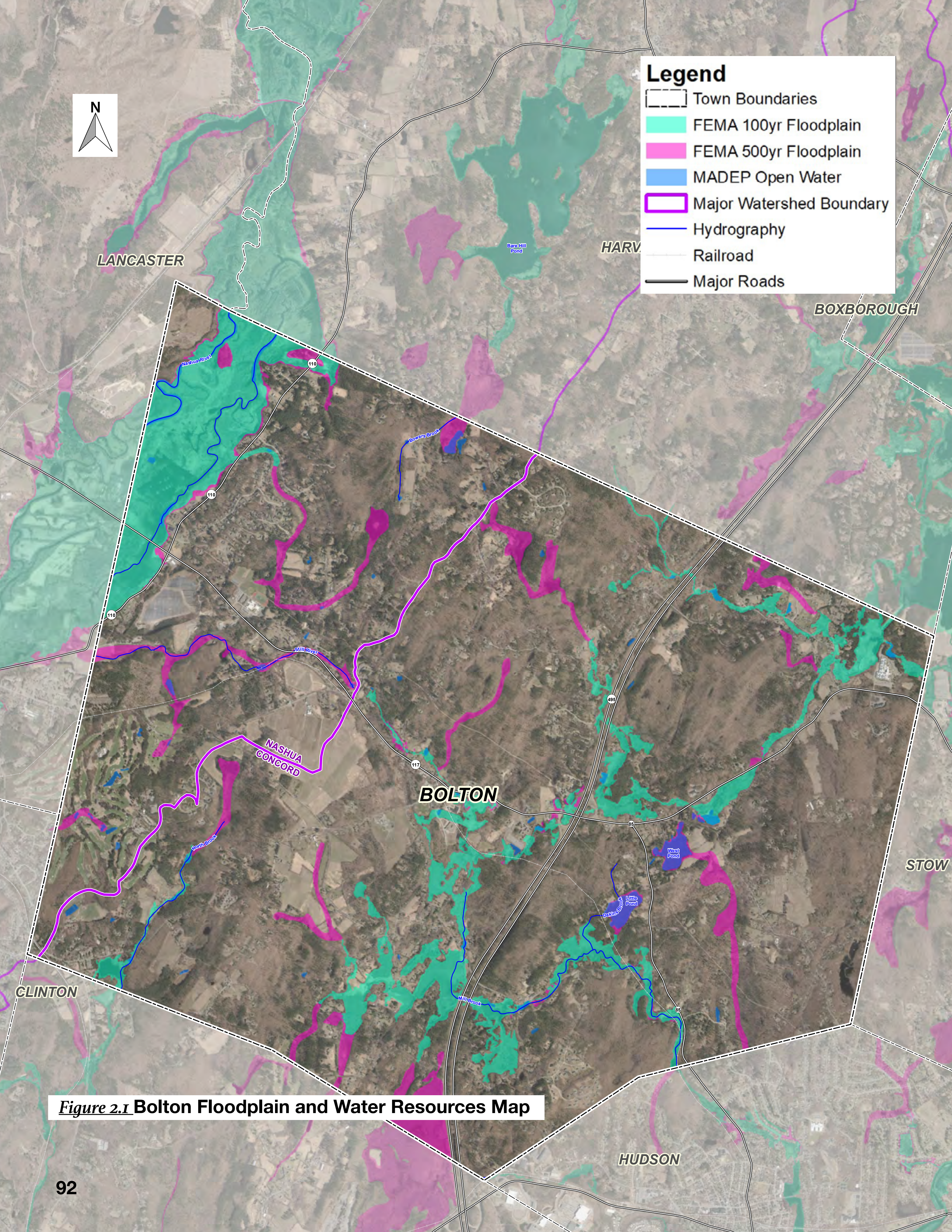


Figure 2.1 **Bolton Floodplain and Water Resources Map**

Bolton's landscape is largely forested. Increasing heat and frequency of drought will change ecosystem dynamics and potentially exacerbate water scarcity and flooding, as cycles of extreme precipitation and drought diminish the capacity of forest soils to store and infiltrate rainwater. Stormwater infrastructure is critical to Bolton's resilience strategy, and the current report presents Nature-based Solutions and low-impact development strategies to enhance resilience and land-based carbon sequestration across Bolton's different land use types.

Unique Features, Concerns & Opportunities

The Town of Bolton has many natural resources which contribute to water management, storm damage prevention, carbon sequestration, biodiversity and heat mitigation, including wildlife management areas, conservation areas, rivers, ponds, and other wetlands, and forests. At the first Core Team meeting for this project (see Appendix 1 for details about the public engagement process), participants were asked to share the most important natural features in the region to them. Bolton Flats, the Fyfeshire Dam area, Bowers Springs conservation area, the Nashua and Still Rivers, the region's apple orchards,

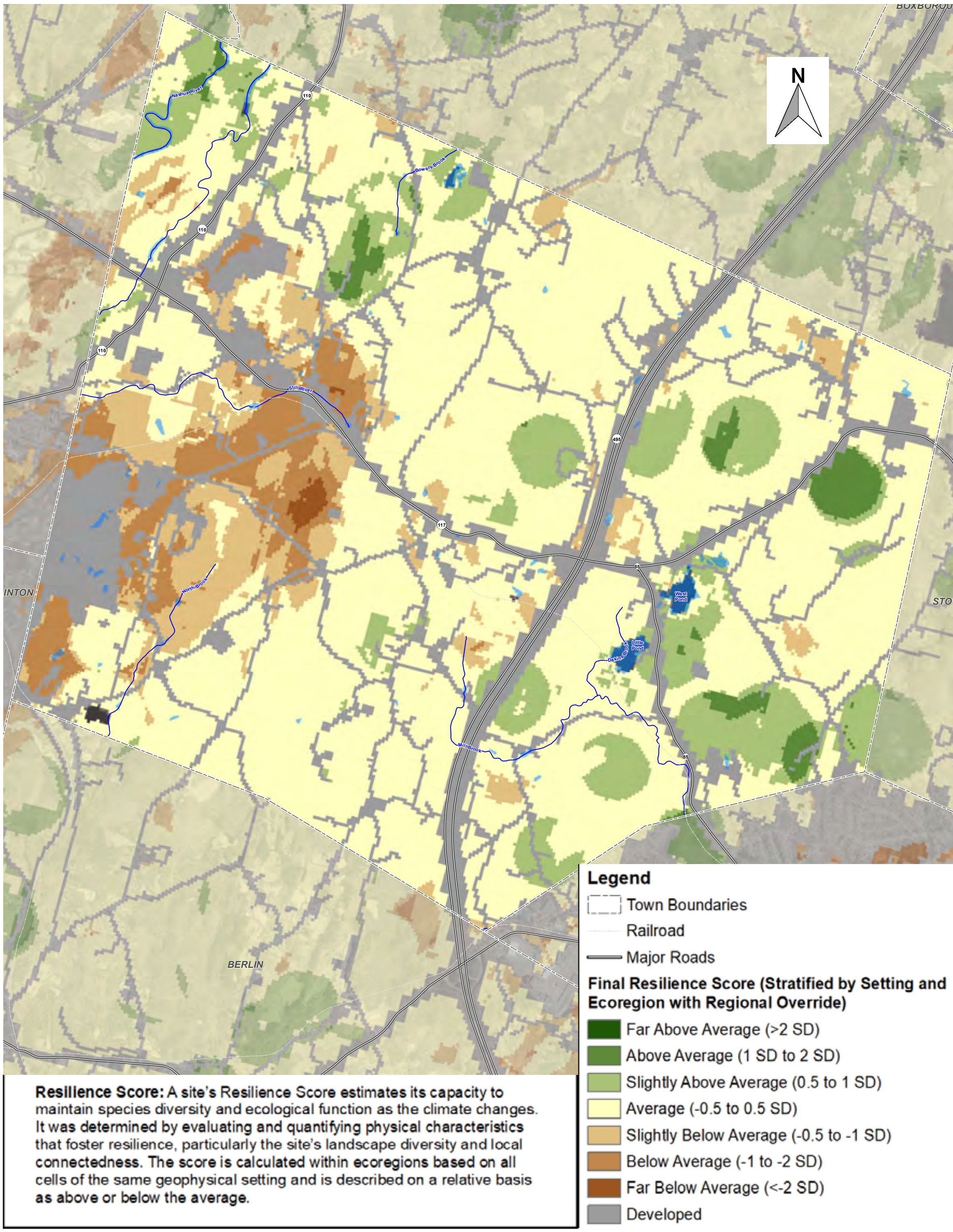


Figure 2.2 **Bolton Ecological Climate Resilience Map**

and the Vaughn Hill conservation area were among those identified. Many of these natural resources are, or include, wetlands, which provide a variety of ecological services as well as the capability to store more soil organic carbon than other land types. However, when discussing issues of concern, frequent flooding, due to undersized culverts, beaver activity, and restricted floodplains, emerged as a key vulnerability across a number of properties.

Key Nature-based Solutions opportunities exist for the Town through conservation of areas with high ecological climate resilience value (See Figure 2.2) and high soil and biomass carbon value, as well as wetland/floodplain restoration, reforestation and tree planting, and restoration of ecological and hydrologic connectivity, including improvement of culverts to meet Massachusetts stream crossing standards and accommodate future storm events. Many climate resilience improvements made in Bolton also provide benefits to downstream communities. The Nashua and Still Rivers and Bowers Brook/Cold Spring Brook and adjacent floodplains, wetlands and forests connect all three Apple Country communities and present an opportunity to protect and enhance regional resilience.

Bolton Soils

Bolton's gently rolling hills, abundant wetlands, streams, rivers, floodplains are host to a wide variety of soils. While each of these soil types exhibit unique properties and capabilities, the seven classes of drainage classification, Figure 2.3, can be used to reveal broader trends. The ridges and hillsides are dominated by well-drained and moderately well-drained sandy loams. The wetlands, both isolated and those hydrologically connected to waterbodies/waterways, tend to be underlain by poorly and very poorly drained soils with more abundant organic matter. At the margins between uplands and bottomlands, where hills meet rivers, the soils tend to be very sandy and excessively drained. As noted in the regional soils section, the interaction between drainage class and land cover shapes soil health, largely by influencing soil organic carbon stocks and flux.

The current soil organic carbon stock for Bolton overall is an estimated 1.275 million tons, equal to 4.7 million tons of CO_2e. The majority of this carbon stock is held in forest and wetland soils. In this analysis, forested wetlands are included in the "wetlands" category, and "forests" refers to upland forests.

Soil organic carbon, or SOC, is presented here in metric tons per acre. Each ton is equivalent to 3.677 tons of carbon dioxide. As most state-level carbon figures are presented in carbon dioxide equivalent (CO_2e), this convention is used here as well. SOC is not sequestered permanently but can be

Bolton Flats Case Study

The Bolton Flats State Wildlife Refuge is a large area around the Still and Nashua Rivers that is managed by the Massachusetts Department of Fisheries and Wildlife. The eastern edge of the reserve, at the Still River Road access point, provided the consultant team an opportunity to examine both the land cover and soils of a protected wetland area.

This examination is relevant to the specific location in Bolton Flats, as well as to the large number of similar areas throughout Apple Country in and adjacent to the floodplains and bordering wetlands of the Nashua and Still Rivers and Bowers Brook.

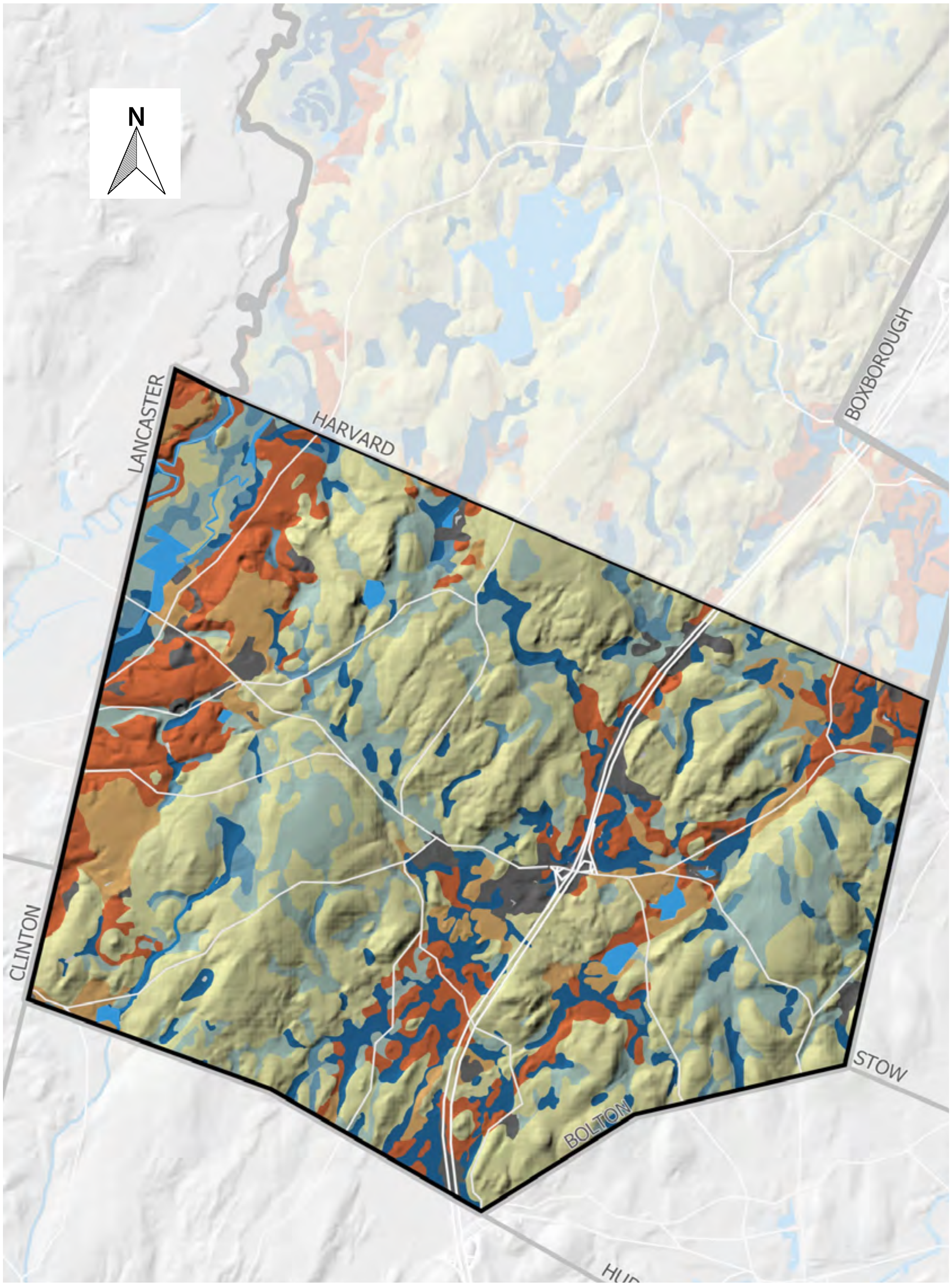


Figure 2.3. **Soil Drainage Classes of Bolton**

re-emitted through disturbances both natural (such as fire, storm damage, drought), and human-caused (such as development, timber harvest, tillage for agriculture). Nor does sequestration continue forever. In agricultural and residential landscapes it continues for several decades and then slows to near zero. In Massachusetts forests it continues to accumulate for perhaps 200 years. This means sequestration cannot be counted on to offset emissions forever. An exception is wetlands, which can continue to sequester carbon for millennia.

Table 2.1. **Estimated soil carbon stock for Bolton in 2021**

BOLTON	Acres	Metric tons SOC/acre	Current stock SOC (MT)	Current stock MT CO_2e
Impervious	779	22.29	17,359	63,829
Land & landscape	1,144	46.70	53,400	196,351
Cropland	345	36.75	12,664	46,565
Pasture & hay	533	47.31	25,226	92,754
Grassland	356	56.96	20,289	74,568
Trees	780	100.08	78,074	287,077
Forest	6,812	105.51	718,658	2,642,507
Wetlands	2,005	169.17	339,183	1,247,175
Water	98	58.12	5,683	20,896
Total acres	**12,850**		**1,270,527**	**4,671,727**

Priorities for Soil Carbon in Bolton

The consultant team used analysis and documentation of land cover, soil carbon stocks, land degradation potential, and soil type to create a new way of looking at land in Bolton. The map below, *High Value Soil Resources for Bolton, Figure 2.4,* shows specific areas of Bolton that have high soil conservation value, moderate conservation value, lower conservation value, and areas of high regeneration opportunity. The areas classified as having high or moderate conservation value are places with high SOC stocks and/or soils that have been designated as prime farmland. These soils must be protected to avoid significant carbon emissions through disturbance or conversion and loss of productive capacity for ecosystem services and agricultural production. *Soils of lower conservation value* have lower soil organic carbon stocks, either naturally or due to irreversible development impacts. These are the places where conversion through development or other high-impact land uses would not result in large losses of carbon stocks. Areas with the classification of *high regeneration opportunity* are those places where restoration efforts such as reforestation and wetland restoration, and better land management practices, could result in gains of carbon stock and improved carbon sequestration rates.

This analysis and map were put together to aid the Town in defining zoning or developing bylaws to protect specific important areas and to encourage development or use change in less valuable locations. The map also helps identify areas to prioritize for restoration or improved management practices. Overlaying additional layers that help illuminate the likelihood of development or identify networks of natural resources are some ways these maps could be used to aid in planning efforts.

Focusing conservation and regeneration efforts on increasing the size of and connectivity between larger patches of high-integrity natural resource areas is likely to provide the greatest benefit to soil health. Targeting more vulnerable soils like unforested floodplains for regeneration and better management are key ways to decrease soil vulnerability and increase resilience to climate change.

integrity natural resource areas is likely to provide the greatest benefit to soil health. Targeting more vulnerable soils like unforested floodplains for regeneration and better management are key ways to decrease soil vulnerability and increase resilience to climate change.

Map Descripton

Higher Soil Protection Priority = Wetlands or High SOC (LC16 adjusted >20k) or Prime Farmland
Lower Soil Protection Priority = Med SOC >15K or Farmland Of Statewide Importance
Regeneration Priority = High SOC (Pedon Adjusted >20k) and Reversible SOC Reducing Landcovers (Turf, Ag, Grasslands, Trees)

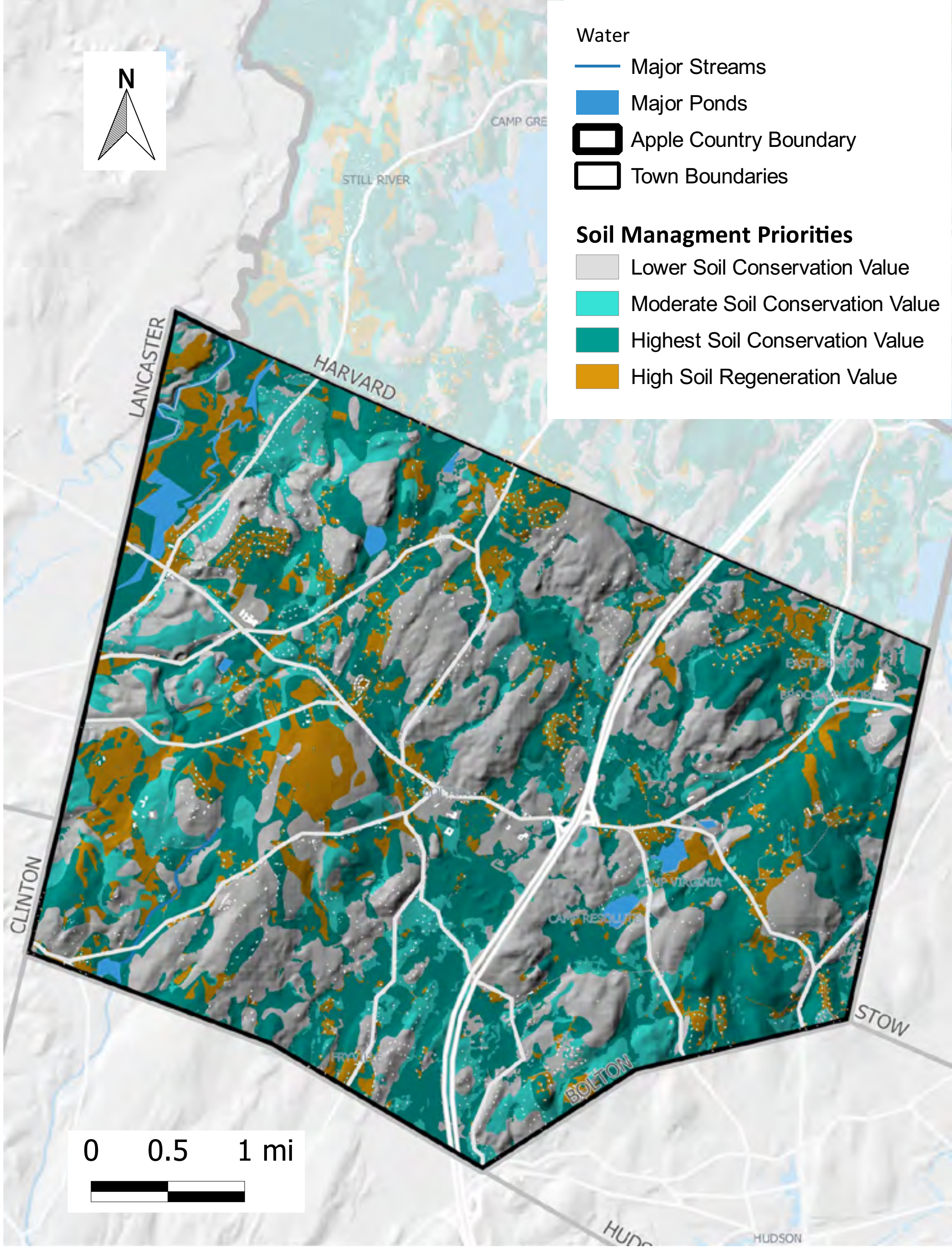


Figure 2.4. ***High Value Soil Resources for Bolton***
A map of Bolton soils showing areas of priority for soil carbon maintenance as well as areas of low priority for soil carbon maintenance, along with areas where soils could be regenerated.

Bolton Agriculture

The consultant team visited several farms and orchards in Bolton, among them, Schultz Farm, Bolton Springs Farm and Orchard, and the farming area around West Berlin Road. The importance of soil health varies quite a bit among Bolton farmers and growers. Schultz Farm is managed with soil health in mind. Other farms are less focused on soil health. The farmers with which the project team spoke were interested in working with the Worcester Conservation District and the Extension Service to get education and support to evolve farming practices to reduce tilling, use cover crops, and employ organic soil amendments.

The structure of orchards is suited to enhancing soil health and soil carbon in the long term. Adding organic soil amendments, tracking soil carbon, and building up soil are management practices that are well suited to perennial crops that involve no tilling.

Case Study: Schultz Farm

Justin Schultz has goals for his 105 acre farm in Bolton. Over the next ten years, Justin wants to enhance the health of the soil in his hay fields to be able to get 3 good cuts of hay each year. He wants to add some livestock and follow regenerative pasturing. And he wants to regain some of the fallow fields on the property. He wants to run a more diversified farm in a sustainable way for both his family and his valley. He is well on his way.

The Schultz Farm has been in Justin's family for five generations (the 6th generation was born last year.) As a kid, working with his grandfather, he got to know how the farm worked. He also grew to love the place. When it was his turn to take over, he set about making it better and more healthy. He started treating the hay fields with wood ash and watching carefully. He started keeping an eye on soil nutrients. While he does use some herbicides from time to time, he kept the chemical load very low. The result is a big improvement in productivity and some of the healthiest soil around.

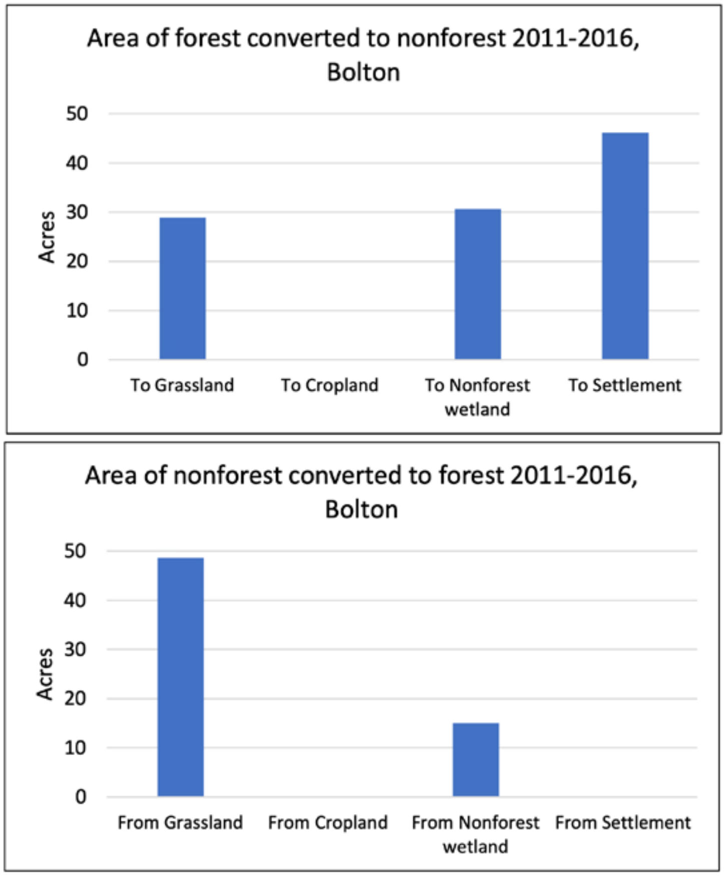
In an interesting visit to the Farm, the consultant team dug some soil pits in order to examine the depth and organic matter content of the productive soil on Schultz Farm. The results were dramatic. In areas that Justin had been managing, the soil A-Horizon was 12 to 14 inches deep and a dark brown color consistent with high organic matter levels. In a section of fields adjacent to the hay fields that Justin manages was a traditionally farmed corn field where the A-Horizon soil was 6 to 8 inches deep and a much lighter color. The difference in soils located less than 10 feet apart gave a strong picture of the important role that land management practices play in maintaining and improving soil health and soil carbon.

In another facet of his farm life, Justin has been managing a large lawn at the farmhouse in a completely sustainable way. No fertilizer, no irrigation, mower set at its highest, grass clipping left to mulch… and the lawn looks fabulous. Justin is convinced that natural lawn care is the way to go.

Images (from left to right) show the difference in ground height from the corn field to the hay field, soil in the hay field, soil in the corn field.

Bolton Forests

To understand trends in Bolton forest cover, land cover change between 2011 and 2016 was estimated from NLCD data (Figure 2.5). The most significant losses of forest were to developed, non-forested wetland, and grassland. The most significant gains of forest land were from grassland and non-forested wetland. More grassland was converted to forest than forest converted to grassland. The forest to and from non-forested wetland transitions were weighted to more non-forested wetland, suggesting that small increases in the area of tree cover caused the remote sensing classifications to detect more forested wetlands. This change could be from tree planting or from trees growing larger and having greater canopy area. More land shifted from grassland to forest than from forest to grassland. The loss of forest to settlement represented the greatest loss of forest, and so the total area of forest declined by 41 acres over the inventory period.



<u>Figure 2.5.</u> Area of forest converted to non-forest and non-forest converted to forest in Bolton, from 2011-2016 based on NLCD data. Note that in this graphic, "wetland" refers only to non-forested wetlands. "Forest" includes forested wetlands.

The average canopy area of trees outside forests in Bolton varies significantly by land cover class (Figure 2.7). Developed areas have the largest area of tree cover at about 900 acres. The percent cover by tree canopy is also greatest for developed areas at about 47%. The other land classes have a little over 10% tree canopy cover, and the average tree cover for all non-forest land classes is 33%. These estimates represent the average area of tree canopy over the inventory period of 2011-2016, which includes trees that were established before 2011 and trees that were established during the inventory period. The area of tree canopy loss during the inventory period was relatively small, only 18 acres according to the NLCD data, of which most of the loss was in developed and grassland areas.

Because of the relatively coarse 30-m resolution of NLCD data, the area of tree canopy was also estimated using high-resolution aerial photography and the i-Tree CANOPY software. These estimates were applied to the 3-m resolution Mass-GIS areas of land cover rather than the NLCD estimates. Based on this analysis, the average tree canopy of non-forest land in Bolton was 75%, significantly larger than the 33% estimate based on NLCD alone. The area of tree canopy loss over the inventory period based on the higher-resolution data was 42 acres instead of 18 acres from the NLCD data. The tree canopy estimates based on the higher-resolution data sets are used in the next section for calculating the net CO_2 emissions associated with trees outside forests.

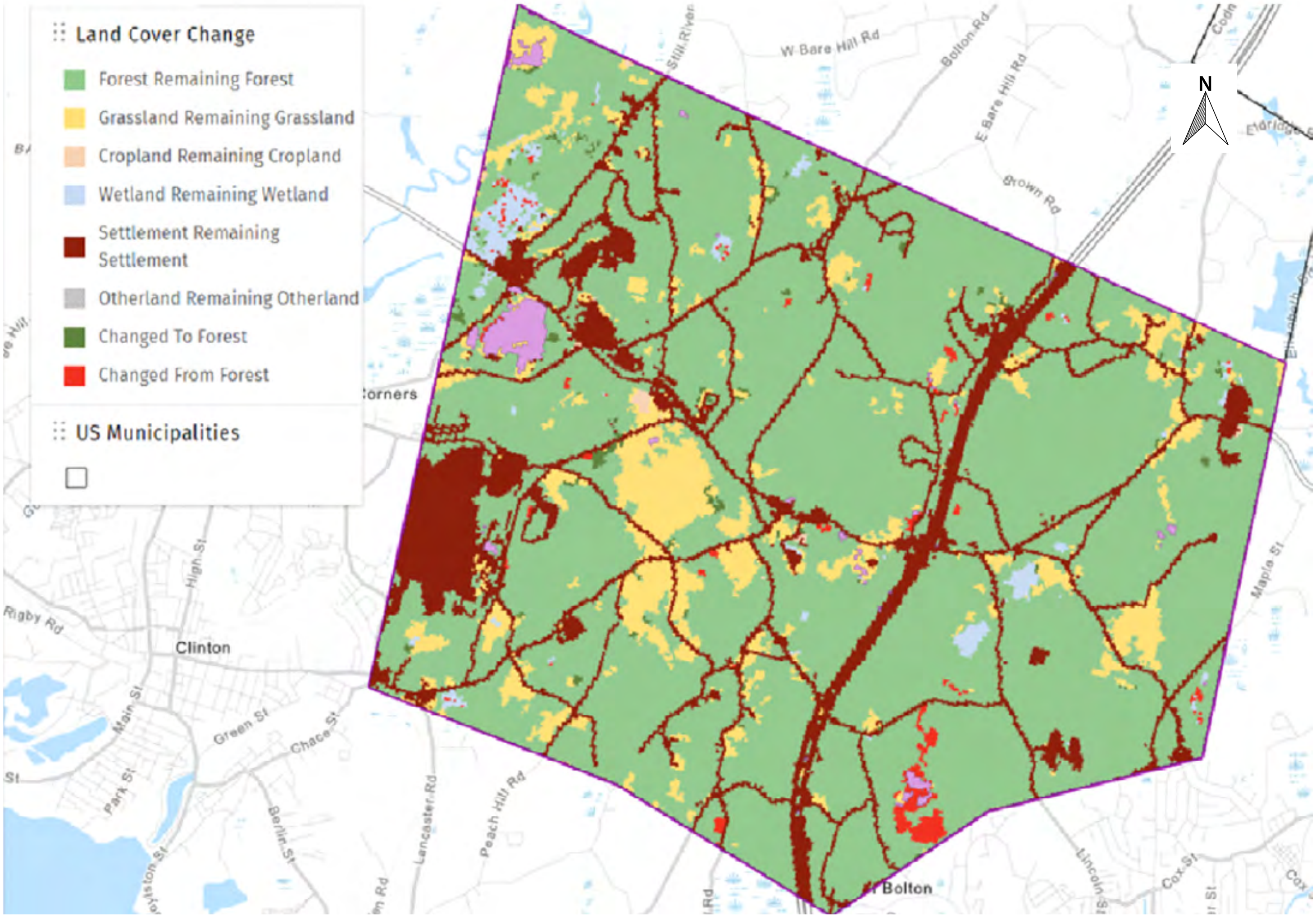


Figure 2.6. ***Areas of forest converted to non-forest from 2011-2016 based on NLCD data, Bolton.***

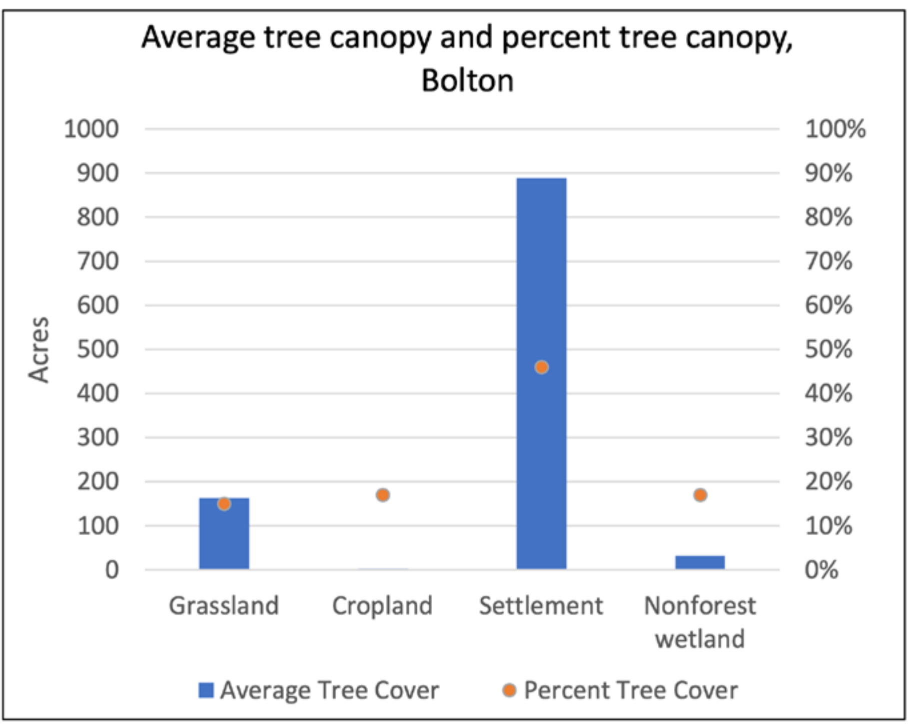


Figure 2.7. ***Average tree canopy area and percent tree cover of non-forest land based on NLCD data for Bolton, 2011-2016.***

Forests and trees outside forests of Bolton were a net sink of -30,762 metric tons CO2/yr from 2011 – 2016 (table 4). Trees outside forests were also significant land sinks of -11,753 metric tons CO2/yr. Removals of CO2 from the air were much higher than emission of CO2. Undisturbed forests and trees outside forests (primarily in settlement areas) represented the largest quantity of removals. The largest sources of emissions from forests and trees outside forests were loss of tree canopy of trees outside forests (1,517 metric tons CO2/yr) followed by conversion of forests to developed, forest harvesting, and conversion of forests to non-forested wetlands and grasslands.

Table 2.2. ***Net CO2 balance of forests and trees outside forests of Bolton, 2011-2016***

Source	Removals	Emissions
	(t CO_2e/year)	
Undisturbed Forest	-23,362	
Disturbance fire		0
Disturbance insect/ disease		0
Disturbance harvest/ other		688
Non-Forest to Forest	-181	
Forest to Cropland		0
Forest to Grassland		327
Forest to Non-forest Wetlands		509
Forest to Developed		1,493
Forest to Other Non-Forest		0
Trees outside of Forests	-11,753	1,517
Harvested wood products	0	
TOTAL	**-35,295**	**4,534**
Net GHG Balance	**-30,762**	

Bolton Wetlands

Within Bolton, there are many wetlands, streams, floodplains, and vernal pool/ ponded resource areas. The MassGIS 2016 Land Cover/Land Use dataset was used to summarize the presence of wetlands within the community. This land cover data was derived from NOAA's Coastal Change Analysis Program (C-CAP). Figures 2.8 and 2.9 below, in Appendix 4 and the project data viewer show the location and extent of wetland resource areas, as well as watershed boundaries and aquatic features in Bolton. More information on how the MassGIS 2016 data was summarized into different land cover classifications used for this analysis can be found online at: https://docs.digital.mass.gov/dataset/massgis-data-2016-land coverland-use.

Bolton lies within two major watersheds. The northwest third of the town lies within the Nashua River (and it's tributary, the Still River) watershed. The southeastern two-thirds of town are within the Concord River watershed, which is part of the larger Sudbury-Assabet-Concord River watershed. Mill Brook/ Danforth Brook and North Brook traverse this southeastern part of town. Wetlands in Bolton therefore contribute to the hydrology of two large river systems that join the Merrimack River miles apart from one another.

The Nashua River and Still River and their riparian corridor contain many of Bolton's wetland resource areas, and connect Bolton to upstream and downstream communities, including Harvard and Devens. The MassWildlife Bolton Flats Wildlife Management Area includes extensive wetlands and the Nashua River/Still River floodplain on the west side of Bolton. Bowers Brook flows northward into Harvard, connecting Bolton to Harvard and Devens. The MassWildlife Delaney Wildlife Management Area and Flood Control Project (Delaney), an area with extensive wetlands, floodplain and vernal pools, provides wildlife habitat as well as flood storage for Elizabeth Brook, a tributary to the Assabet River. The Assabet River eventually joins the Concord River. Delaney is a highly valued recreational resource offering recreational

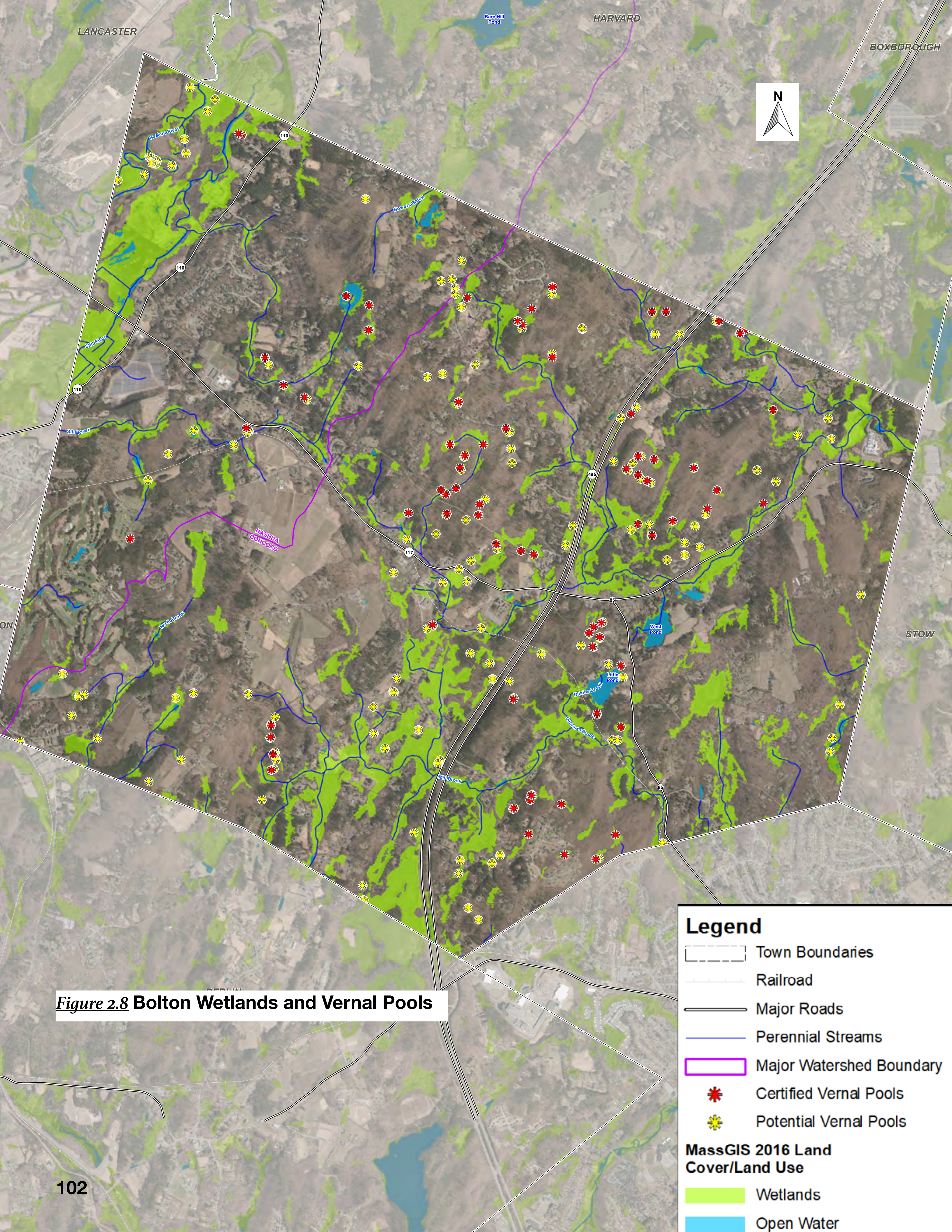


Figure 2.8 **Bolton Wetlands and Vernal Pools**

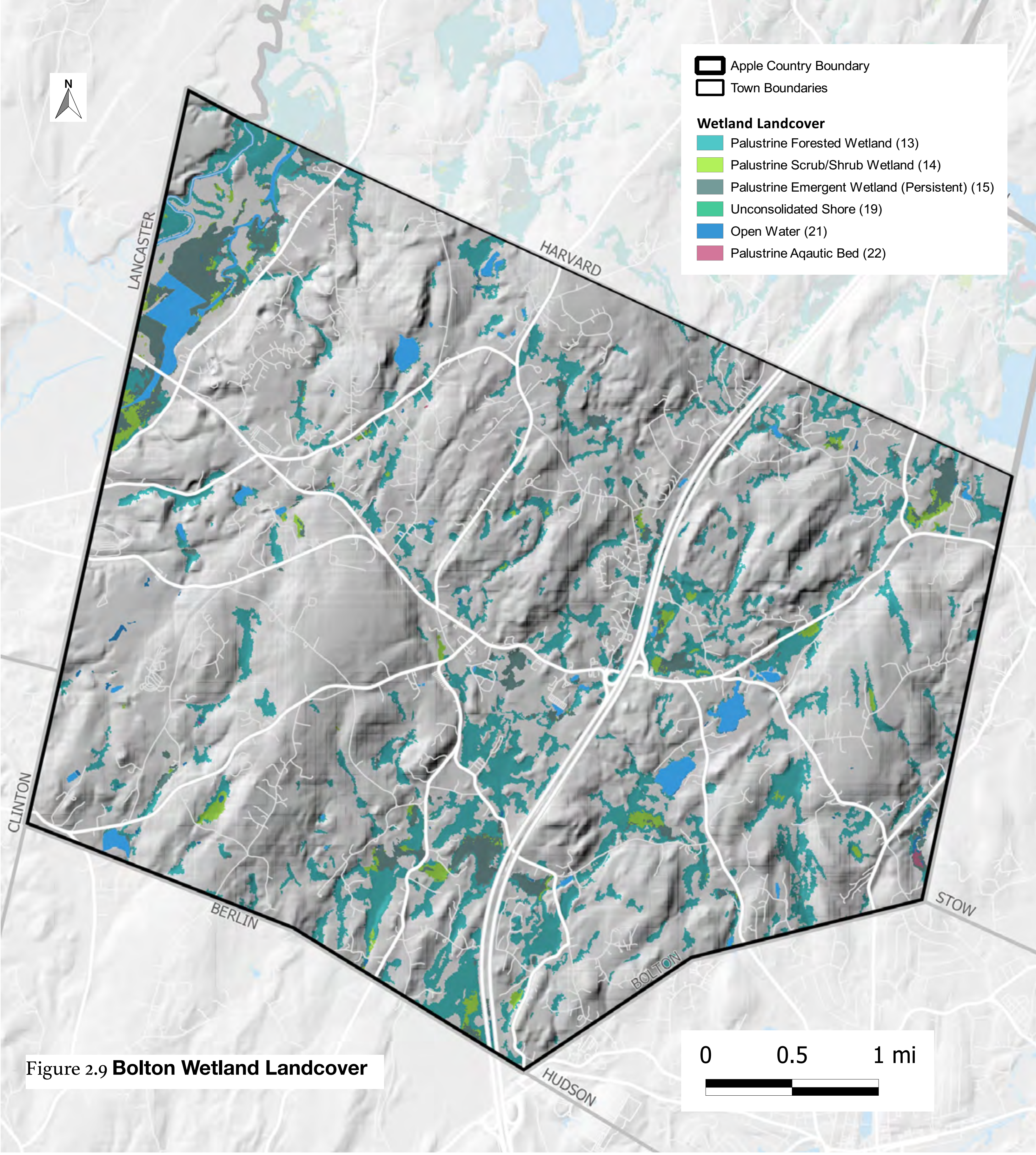


Figure 2.9 **Bolton Wetland Landcover**

Map Descripton

This map shows the Wetland Landcover C-CAP classes from the Mass GIS 2016 High Resolution Landcover Dataset

activities including hiking, mountain biking, bird watching, horseback riding, ice skating and ice fishing, canoeing and fishing, cross-country skiing, dog walking and more. Bolton's extensive wetland resources are significant and important contributors to biodiversity/wildlife habitat, carbon storage and sequestration, climate resilience and other important ecosystem services.

Bolton has 2,103 acres of wetlands comprising 16.4% of the land area and holding 25.3% of the total soil organic carbon of the town. This includes streams, rivers, swamps, marshes, lakes, ponds, and vernal pools. The wetlands are summarized using the classifications established by the C-CAP Program, found in the 2016 MassGIS Land Cover/Land Use data layer, in Table 2.3 on the following page.

Table 2.3. **Bolton wetlands and soil organic carbon stocks**

Wetland Classification	Area (Acres)	SOC Stocks (metric tons)
Palustrine Aquatic Bed	6.8	494
Palustrine Emergent Wetland	377.4	63,688
Palustrine Forested Wetland	1,503.6	220,949
Palustrine Scrub/Shrub Wetland	117.2	22,484
Water	97.9	4,297
Total	**2,103**	**311,912**

Rivers and Streams

The Nashua River and its tributary, the Still River, are the largest waterways in Bolton. These rivers flow along the western border with Lancaster, with a great deal of bordering marsh and forestland, much of which is within the Bolton Flats Wildlife Management Area. This is the wettest area in Bolton. A great many smaller perennial and intermittent headwater streams connect ponds, marshes and swamps, and ultimately join larger drainages within the watersheds. Bowers Brook flows from Bolton through Harvard, joining Cold Spring Brook as it flows into Devens. Along with the Nashua River and its tributary, the Still River, the Bowers Brook/Cold Spring Brook system serves as a hydrologic corridor and connection between these three communities, supporting a variety of wetland types.

Swamps and Marshes

Forested swamps are the predominant form of wetland in Bolton (71%), covering approximately 1,504 acres. Extensive swamps and marshes occur along the Still and Nashua Rivers at the north part of town, and other large concentrations of swamps and marshes occur along the Route 495 corridor. The remainder of Bolton is relatively dry, with pockets of forested wetlands throughout the remainder of the town.

Lakes and Ponds

A number of lakes and small ponds occur in Bolton, covering 97.9 acres of land.

Vernal Pools

Bolton has 151 Potential Vernal Pools, and a total of 73 vernal pools have been officially certified by the state Division of Fisheries & Wildlife. The vernal pool locations are shown on the Bolton Wetland and Vernal Pool Map (Figure 2.8 above and in Appendix 4).

Site-Specific Nature-Based Solutions

Core Team Meetings and Site Visit Summary

Bolton community representatives participated in four Core Team meetings (detail on these meetings can be found in Appendix 1). At the second meeting, Bolton representatives were tasked with identifying locations where Nature-based Solutions could protect, restore, or enhance ecological resilience. A site walk was held on December 16th to assess 11 locations throughout Bolton. At the third core team meeting, participants discussed observations from the site walk and potential recommendations for each location. Bolton's representatives noted that, while many opportunities related to wetland/floodplain restoration, habitat enhancements, and culvert improvements exist, many of the sites were in overall good condition and conservation of these wetlands, forests, and floodplains is likely the best action to protect existing beneficial attributes, both for Bolton and for communities located further downstream in the watershed. A summary of observations and analysis from the Bolton site walk and assessments follows.

Bolton NbS Site Walk Analysis and Reporting

A menu of planning level project descriptions (thumbnail project scopes and order of magnitude costs) are provided in the Opportunities Table and associated Memoranda and mapping (Appendix 10 and project website Nature-based Solutions page) that collectively indicate which NbS projects could be implemented in which locations within Bolton. Additionally, Appendix 10 provides a generalized outline of considerations for project planning and permitting. By implementing projects identified in the text and attachments that follow, cumulatively and over time, greater ecological function and climate resilience can be achieved in Bolton. Following the principles of ecological restoration, consideration of stressors and disturbance to the natural function of rivers, lakes, ponds, wetlands, forests and associated soils and floodplains, is a key component for this analysis. Discussion of potential NbS and climate resilience enhancement opportunities is provided below.

Brockway Corner at East End Road (near Delaney Wildlife Management and Flood Control Area)

Located at the Eastern corner of town, at the juncture of Stow and Harvard, Brockway Corner is at the south-western edge of the Delaney Wildlife Management Area and Flood Control Area (Delaney), which is managed by Massachusetts Department of Fisheries and Wildlife. Headwater tributaries to the Assabet River flow under East End Road and connect large blocks of protected open space. More than a dozen potential NbS projects have been identified in the vicinity of Delaney at Brockway Corner, where Sugar Road, East End Road and Main Street converge.

Potential NbS projects in this area include:

- Invasive species management in the wetland areas associated with the culverted crossing under East End Road
- Replace under-sized and compromised culverts under East End Road at two locations south of Sugar Road and one north of Sugar Road
- Construct and/or expand wetlands and floodplain in drainage system west of East End Road and south of Harris Farm Road
- Provide climate resilient redevelopment incentives for new development that may occur on land at the juncture of East End Road and Main Street (Route 117)
- Create road crossing protections for wildlife and habitat enhancements in the area where Sugar Road and East End Road meet

Bowers Brook at Bare Hill Road

Bowers Brook is located along the border with Harvard and is mostly contained in a large block of private protected open space. Several projects have been identified along and associated with Bowers Brook.

Potential NbS projects in this area include:

- Long-term protection of large adjacent parcels, such as land in the upper Bowers Brook watershed, that contribute to protection of open space through fee acquisition or Conservation Restriction
- Management /promotion of beaver activity east of Bare Hill Road
- MSCS Culvert improvement and replacement at Bare Hill Road
- Grassland meadow and wetland restoration and management along the stream course
- Upstream BMP’s such as bioswales
- Manage forests for old growth characteristics including snag creation and downed logs. Conserve the old growth characteristics of the forests that encourage reforestation and forest conservation at the edge of the edge the wetland
- Where appropriate, actively manage forests by looking at tree health and planning for succession.
- Promote reforestation and other best management practices in areas with higher soil carbon regeneration potential

Still River Floodplain at Still River Road (Route 110) in Vicinity of Vaughn Hill Road

The Still River floodplain crosses Still River Road (Route 110) near the intersection with Vaughn Hill Road, and extends eastward into protected open space.

Potential NbS projects in this area include:

- Upstream BMPs such as rain gardens and bioswales
- MA Stream Crossing Standards (MSCS)/future storm conditions culvert improvements
- Conservation purchases or restrictions
- Wetland and floodplain restoration or construction, including riparian and wetland buffer plantings
- Invasive species management
- Habitat enhancements
- Pocket forests

Still River Floodplain at Main Street (Route 117) and Still River Road (Route 110)

The Still River floodplain covers an expansive area on the west side of Bolton, along the border with Lancaster near the intersection of Main Street (Route 117) and Still River Road (Route 110). The forested lands south and west of this major intersection are identified as having moderate to high soil conservation value while the grassland is identified as having high soil regeneration potential. This large focus area has important biodiversity and landscape-scale connectivity significance as it is adjacent to the Bolton Flats Wildlife Management Area and the Still River. This and another site located slightly upriver are ideal locations for wetland restoration that could restore the carbon and other functions of wetland soils and build riparian tree cover along the Still River.

Potential NbS projects in this area include:

- Floodplain and wetland restoration, reforestation
- Invasive species management in several locations along Still River Road
- MSCS/future storms culvert improvement
- Wildlife crossing protections
- Green energy features
- Educational interpretation
- Pocket forests/Reforestation
- Best management practices in areas with higher soil carbon regeneration potential
- Work with abutters to improve turf and grassland management, including timing of cutting, mulching of cut grass, and adding specific native species to improve soil services, especially water retention and quality improvement for runoff.

__Figure 2.10.__ Current conditions (left) and graphic rendering of potential Nature-based Solutions (right) at Main Street and Still River Road.

Still River Floodplain at Forbush Mill Road

The south branch of the Still River runs down through forested wetlands along Forbush Mill Road and flows over a fieldstone dam, feeds a fire pond, then runs past agricultural and playing fields before entering the Bolton flats. Forbush Mill Road crosses the Still River at four locations, flowing through culverts that provide opportunities for improving streamflow characteristics/capacity to handle future storm events and wildlife connectivity. Much of the land south of the Still River is forested and protected open space but other contributing landscapes include Twin Springs Golf course and the town landfill.

Potential NbS projects in this area include:

- Wetland restoration and habitat enhancements
- MSCS/future storms culvert improvement
- Wildlife crossing protections
- Invasive species management
- River and pond bank revegetation
- Shade-habitat/infiltration tree plantings
- Pocket forests

North Brook at Wattaquadock Hill Road

North Brook crosses Wattaquadock Hill Road providing an important corridor linking protected open space at the southwest corner of Bolton. Stream crossings near Wattaquadock Hill Road and Sawyer Road with several small dams along its length. This provides opportunities for improving streamflow characteristics and wildlife connectivity.

Potential NbS projects in this area include:

- MSCS/future storms culvert improvement
- Install smart controls for dam weir
- Manage beaver with a Beaver Deceiver/Promoter
- Educational Interpretation
- Green energy features

South Bolton Road to Spectacle Hill Road

South Bolton Road meets Spectacle Hill Road in the vicinity of Wheeler Road and Mill Pond Road in Bolton's southern section with wetlands and the Mill brook stretching to Mill Rd. It includes large protected open space parcels and wetland areas interspersed with primarily residential housing with stream crossings at multiple driveways. Conservation of the whole wetland system here, and retention and protection of wetland soils, has high value for conservation of soil and biomass carbon, as well as provision of climate resilience, flood storage, and water supply ecosystem services.

Potential NbS projects in this area include:

- MSCS/future storm culvert improvements at multiple stream crossing points
- Invasive species management and shrubland/heath restoration and management
- New wetland and floodplain restoration/construction/expansion
- Upstream BMPs, including rain gardens, bioswales, etc.
- Beaver management with Beaver Deceiver/promotor
- Pocket forests
- Encourage residential abutters to adopt best management of lawn, turf and grasslands, higher mowing, mulching of cut grass, and adding specific native species to improve soil services, especially water retention and quality improvement for runoff.

Mill Brook at Century Mill Road

Mill Brook crosses Century Mill Road and has associated wetlands along its corridor. Large private parcels predominate in this area of Bolton, with little protected open space, but opportunities to pursue public/private partnerships abound.

Potential NbS projects in this area include:

- Wetland restoration and management
- MSCS/future storm culvert improvement
- Wildlife crossing protections
- Install smart controls for dam weir
- Resilient redevelopment incentive and green architectural enhancements
- Pocket forests

Danforth Brook at Hudson Road (Route 85)

Danforth Brook flows along the edge of a large block of protected open space along the Route 85 corridor in the south-eastern part of Bolton. Public use enhancement opportunities were identified along with several potential NbS projects.

Potential NbS projects in this area include:

- Soft trail with public gathering spaces and furnishings
- Educational interpretation
- Shade habitat/infiltration tree plantings
- Upstream BMPs including rain gardens, vegetated bioswales
- Wetland management and restoration
- Create post-development guidelines for soil management and enhancement to increase soil health where there has been development and decrease invasive species pressure.
- Strengthen forest/wetland edge by planning native bush and tree species along the edge of the field.

Route 117 and Sugar Road near Route 495

Located near the center of Bolton at the intersection of two major roads, Route 495 and Route 117 (Main Street), the Sugar Road area has a combination of built infrastructure, residential, business, and recreational uses. NbS could be used to protect these various uses and to minimize ongoing flooding at this critical intersection.

Potential NbS projects in this area include:

- Enlarge culverts associated with Route 495 crossings to meet MA Stream Crossing Standards and accommodate future flood conditions
- New wetland or floodplain construction/expansion
- Upstream BMPs such as rain gardens, bioswales, etc.
- Invasive species management
- Hedge row pollinator strip

Lacrosse Field and Ponds at Main Street/ Route 117

Located to the south of Route 117/Main Street at the juncture of Route 495, the Lacrosse Field and Ponds area is adjacent to protected open space further to the south and connected to the Sugar Road focus area. This area is also the sole access to adjacent cell towers and prone to flooding. Mixed uses including recreation and businesses and built infrastructure dominate this area.

Potential NbS projects in this area include:

- Enlarge culverts to meet MSCS/ future storms
- Wetland management and restoration
- Floodplain and wetland construction
- Public-private partnership opportunities
- Stream flow alteration and upstream BMPs including rain gardens, bioswales, etc.
- Hedgerow pollinator strip
- Educational interpretation
- Upgrade turf management at the lacrosse field to improve soil health.
- Add Organic soil amendments,
- Mulch grass clippings when possible,
- Add shrubs and trees to edges of the field away from the wetland.

Farms at West Berlin Road

A large agricultural area in central Bolton, the Farms at West Berlin Road present numerous opportunities to implement Nature-based Solutions and forward-thinking conservation efforts. Because the soils around the intersection show moderate to high soil carbon retention when farmed with typical practices, any SOC gains are likely to be more durable.

Potential NbS projects in this area include:

- Pocket forests
- Purchase of Conservation Restriction or public/private partnerships
- Dam weir smart controls
- Green energy features and architectural enhancements
- Zoning overlay or other regulations
- Control of beaver activity with Beaver Deceiver/Promotor
- Encourage agricultural practices that increase carbon sequestration such as adding trees to hay and pasture and reduced tillage.

Town-Wide Bolton Recommendations

In addition to recommendations provided in the Regional Recommendations Section of this report, the following Bolton-specific town-wide recommendations are provided. It is recommended that readers review the Regional Recommendations Section as well as the information below and the preceding site-specific NbS recommendations.

Key Nature-Based Solutions

- ***Still River Floodplain at Still River Road (Route 110) and Main Street (Route 117).*** The Still River runs through the MassWildlife Bolton Flats Wildlife Management Area which has statewide significance and a large number of opportunities for NbS. Many potential projects have been identified in the area of the Still River floodplain to improve ecosystem resilience and to benefit the community's long-term interests. A number of culvert replacements, stream flow improvements, and wetland restoration/enhancement opportunities exist. Educational interpretation and outreach in this area are recommended.

  Wetland restoration at this site would provide a way to enhance and expand wetland soils and habitat. This would increase soil carbon and other ecosystem services as well as creating expanded habitat areas adjacent to the Bolton Flats refuge.

  Main Street (Route 117) near Route 495. The intersection of Main Street/Route 117 and Route 495 near the physical center of Bolton is an area where major north-south and east-west roadways cross. There are municipal, residential, and business interests located within close proximity to wetland, floodplain, and open space resources. NbS opportunities in this area will be important to building resilience in a location that could be anticipated to experience increasing growth in the future.

- ***Restore hydrologic connectivity.*** Throughout Bolton, substandard, undersized and failing culverts have been identified as being in need of replacement and upgrade. Outdated and failing culverts present an opportunity to implement stream crossing designs that meet the Massachusetts Stream Crossing Standards and are designed to accommodate predicted future stormwater flows, rather than being limited by outdated 20th century capacity that has the potential to place infrastructure and adjacent properties at risk. Placing a focus on this feature of the landscape will help address a variety of vulnerabilities throughout the community.

- ***Conservation and Education.*** Throughout the Town of Bolton there are many locations and opportunities for the Bolton community to implement NbS and to provide education and interpretive media/signage that would help increase the use and understanding of NbS across the whole town. In addition, there is an existing strong network of conservation land located along riparian corridors and around wetlands. This conservation land could be expanded upon, and further conserved through private/public land partnerships, reduced development zoning overlays, or additional conservation land purchases.

SOILS

- **Prioritization of high regeneration opportunity soils***:* Focusing conservation and regeneration efforts on increasing the size of and connectivity between larger patches of high-integrity natural resource areas is likely to provide the greatest benefit to soil health. Targeting more vulnerable soils like unforested floodplains for regeneration and better management are key ways to decrease soil vulnerability and increase resilience to climate change.
-
- **Protect soil carbon stocks primarily in forested and wetland soils.** For Bolton, the most important soils to conserve and protect are in forests and wetlands. These areas contain the largest stocks of soil carbon in Bolton and contribute the most to carbon sequestration. The distribution of both soil protection and soil regeneration priorities are shown in Figure 2.4, *High Value Soil Resources for Bolton.* The distribution of wetlands is shown in Figures 2.8 and 2.9, maps of Bolton wetlands. The distribution of forests is shown in Figure 2.6 (map of forest converted to non-forest and non-forest converted to forest).

- **Implement practices that increase soil carbon sequestration on farms, lawns, and other landscapes.** Bolton has approximately 1,108 acres of agricultural land and 1,144 acres of ornamental or turf lands ("Land and landscape"), as shown in Table 2.1. In large part, these areas could benefit from improved management techniques. Along with the specific soil management recommendations shown for the locations visited during the site walks and tours, there are more general town-wide recommendations.

- **Create soil-smart management plans for public lands and share them with private landowners.** Better turf management on both public and private lands can play a big role in increasing carbon sequestration potential on those lands. Higher mowing, mulching clippings, and regular application of organic soil amendments, at least for 3 to 5 years, will have immediate effects on turf health, water retention, and soil carbon levels. Developing and publicly sharing management plans for the turf and ornamental landscapes managed by towns could immediately improve the soil health of public lands and accelerate adoption by private landowners.

- **Focus forest management on increasing the total carbon stock and biodiversity.** Forest management focused on increasing carbon stocks and biodiversity allows trees and forests to continue growing as much as possible. In some situations, careful thinning to allow for tree regeneration can improve forest health. Retaining tree slash, snags, and stumps in the forest to the greatest extent possible will promote accumulation of carbon in soils as well as provide good wildlife habitat. Careful small pilot planting projects to support forest transitions can help support stronger and more resilient forests, protecting the soil resources from natural hazards. A management plan for forested areas that could be shared with private, conservation, and public landowners would aid in transitioning forest management practices. While the primary emphasis for forests is conservation of existing carbon stocks, improved forest management practices can also increase forest health.

- **Promote and implement actions that restore lost or degraded soil function and actions that regenerate soil function to higher levels**, through implementation of Natural Climate Solutions. There are a few locations in Bolton where specific restoration or regeneration actions could provide upgrades to carbon pools. The suggested wetland/floodplain restoration project across the Route 110 road from Bolton Orchards and at a nearby property, adjacent to the Still River, would not only improve soil carbon and habitat in that location, but would also increase flood resilience and ground water retention. There are a few areas where planting trees along degraded riparian zones would increase carbon pools and aid in improving water quality. Planting trees at the edges of playing fields would improve soil carbon levels and provide shade in those locations.

- **Provide Education and Outreach for beneficial changes to policies and programs at the State and Federal levels.** Bolton could join with other municipalities in advocating for more and better technical support for farmers, and improved soil testing capabilities from the State. Advocating for a State carbon fund that would support better land management for forest and wetland owners and farmers would help conserve and enhance the soil functions of those land types. Advocating for inclusion of carbon functions and recognition of climate resilience functions in State and Federal level wetland regulations could lead to improved protection of wetland carbon and climate resilience ecosystem services, as could advocating for protection of forest carbon and climate resilience ecosystem functions.

- **Support and conduct research projects at the municipal level that could inform policies and actions and build knowledge of soil dynamics and ecosystem carbon.** Bolton is in a great position to monitor and collect data on the effects of restoration and land management approaches,such as the effects of farming techniques on soil carbon and other ecosystem services. Similarly, monitoring soil functions before and after a wetland restoration project would provide invaluable information.

Orchards

- ***Organic soil amendments to improve soil health and retain water.*** Many orchards do not use any soil amendments unless there is some specific tree health need identified. A more generalized annual application of compost or other soil amendment to increase soil organic carbon would help the soil retain water, especially in drought years, and improve productivity.

- ***Turning orchard trees that are removed into biochar and applying to soil.*** Open burning is restricted, which means that orchards are not generally allowed to burn trees and stumps that have been removed on-site, removing a good source of soil carbon. One way to create soil amendments internally is to turn removed tree material into biochar and apply that to the soil.

- ***Potential for carbon sequestration payments when Massachusetts institutes a carbon fund.*** Orchards are ideal land cover for management practices to increase soil carbon, since they are not regularly disturbed, but are closely managed. Climate legislation in Massachusetts calls for the creation of a carbon fund that will potentially be able to pay farmers (including orchards) for ongoing practices that add organic carbon to the soil.

Farms

- ***Create or Update Local Bylaws for siting ground mounted solar energy production facilities.*** Current research of co-locating solar arrays with farmland is beginning to show that this arrangement can be beneficial. Updating town bylaws to encourage this kind of land sharing, rather than cutting forests to site solar arrays, would be useful for both supporting farmers and for protecting forests.

- ***Create Prime Farmland Soils & High Carbon Soils Provisions.*** Given the unique character and dynamics of Apple Country, the farms and orchards of Bolton could participate in a pilot soil carbon market where Deven's industrial tenants voluntarily purchase carbon credits from participating farmers and forest owners. This hyper-local strategy allows Devens to reduce its emissions by incentivizing good soil stewardship, improving economic viability for farmers, and accelerating ecosystem restoration on degraded lands.

Forests

- ***Prioritize Conservation of Forests and Trees Outside of Forests.*** Reduce canopy loss from trees outside forests particularly in developed areas. Reducing the conversion of forest land to other land uses, and reducing harvesting of forests. Plant trees and facilitate natural regeneration of areas that are currently lacking tree cover. Improve the health and stocking of existing forests through improved silviculture and proactive pest management.

Wetlands and Floodplains

- ***Prioritize Conservation and Restoration of Floodplains and Wetlands***. Bolton's highest-functioning ecosystems are often concentrated along riparian corridors, floodplains and in wetlands (as well as in forests). These areas are often ranked the highest on maps (See Appendix 4 and Project Data Viewer) of ecological climate resilience, ecosystem carbon storage and sequestration, wildlife habitat/biodiversity value, and delivery of other ecosystem services. These areas should be prioritized for conservation and ecological restoration.

- ***Restore wetland buffers*** by planting native trees and shrubs, to serve as buffers for nearby wetlands, as well as other types of wetland//floodplain restoration, reforestation and tree planting, and restoration of ecological and hydrologic connectivity, including improvement of culverts to meet Massachusetts stream crossing standards and accommodate future storm events.

- ***See Regional Recommendations*** for recommendations pertaining to updating the Bolton Wetland Bylaw and associated regulations and implementation of Best Management Practices as they pertain to wetlands.

3

THE DEVENS REGIONAL ENTERPRISE ZONE ANALYSIS AND OPPORTUNITIES

The former Fort Devens Army Base was decommissioned in 1996 and taken over by MassDevelopment, the Commonwealth's finance and development agency. Now known as the Devens Regional Enterprise Zone (Devens), the carefully planned and regulated 4,400-acre site includes a mix of former military housing, newer conservation developments, dynamic industrial zones, and natural/open space. Devens has a smaller proportion of forested and other natural lands than surrounding communities (33% compared to Harvard and Bolton's 74%), but much of that (about 2/3) is permanently protected. The Devens Enterprise Commission is the regulatory and permitting authority for the community, and acts as a one-stop Planning Board, Conservation Commission, Board of Health, Zoning Board of Appeals, and Historic District Commission. This unique governance structure enables Devens to manage its redevelopment in holistic ways, emphasizing long-term sustainability, economic growth and development, and community resilience.

Devens has long been a leader in eco-industrial park development and has created programs and initiatives to support the continued proliferation of energy efficiency and renewable energy. The community received Leadership in Energy Efficiency and Design (LEED) Certification in 2018 and conducted a comprehensive climate vulnerability analysis and greenhouse gas inventory in 2018 and 2019, respectively. In 2020, Devens released its Climate Action and Resilience Plan, which builds upon the community's ongoing initiatives to decarbonize its buildings and economy and prepare for climate impacts. In terms of resilience, increased temperatures and precipitation present slightly different challenges for Devens than for its more rural/suburban and less industrial neighbors. All things being equal, increased temperatures

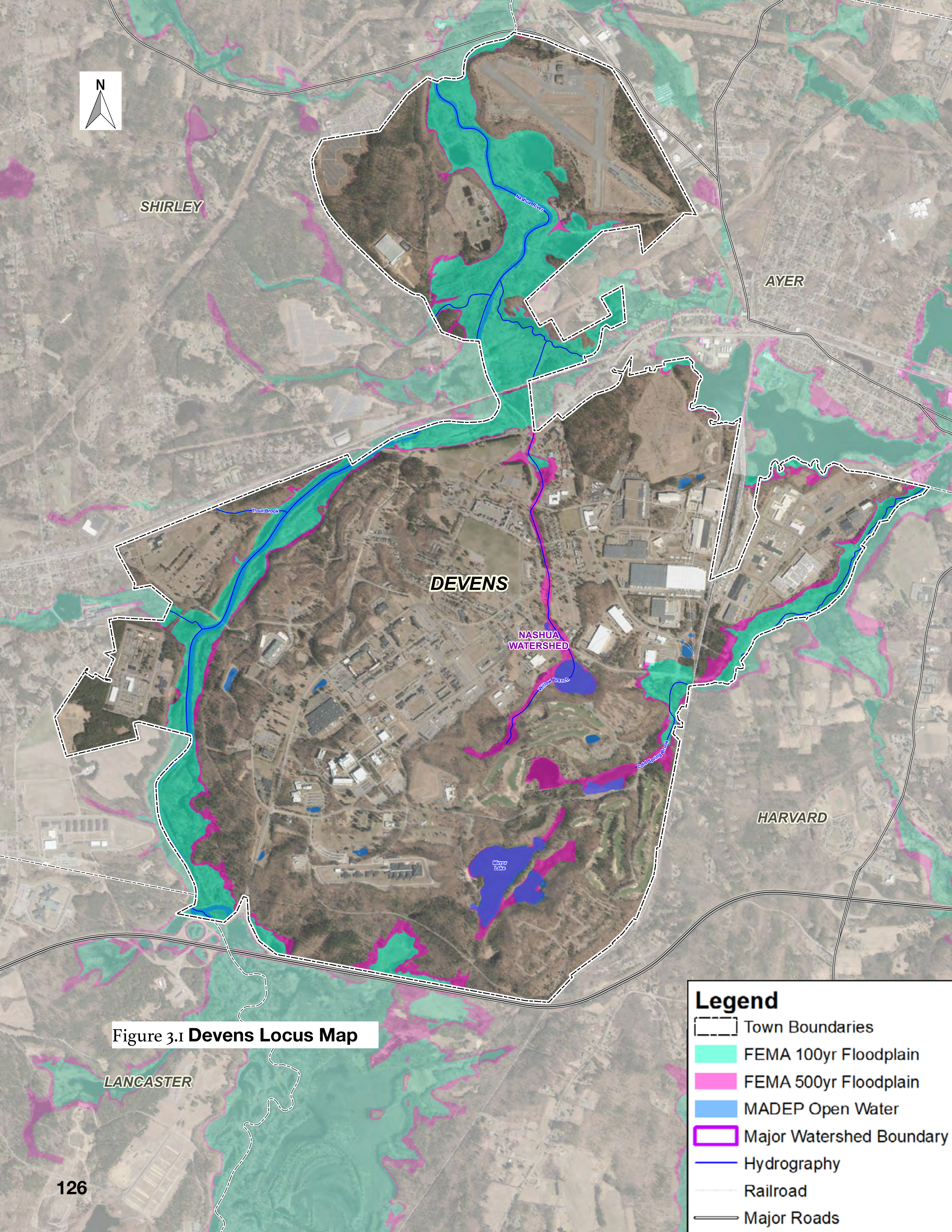


Figure 3.1 **Devens Locus Map**

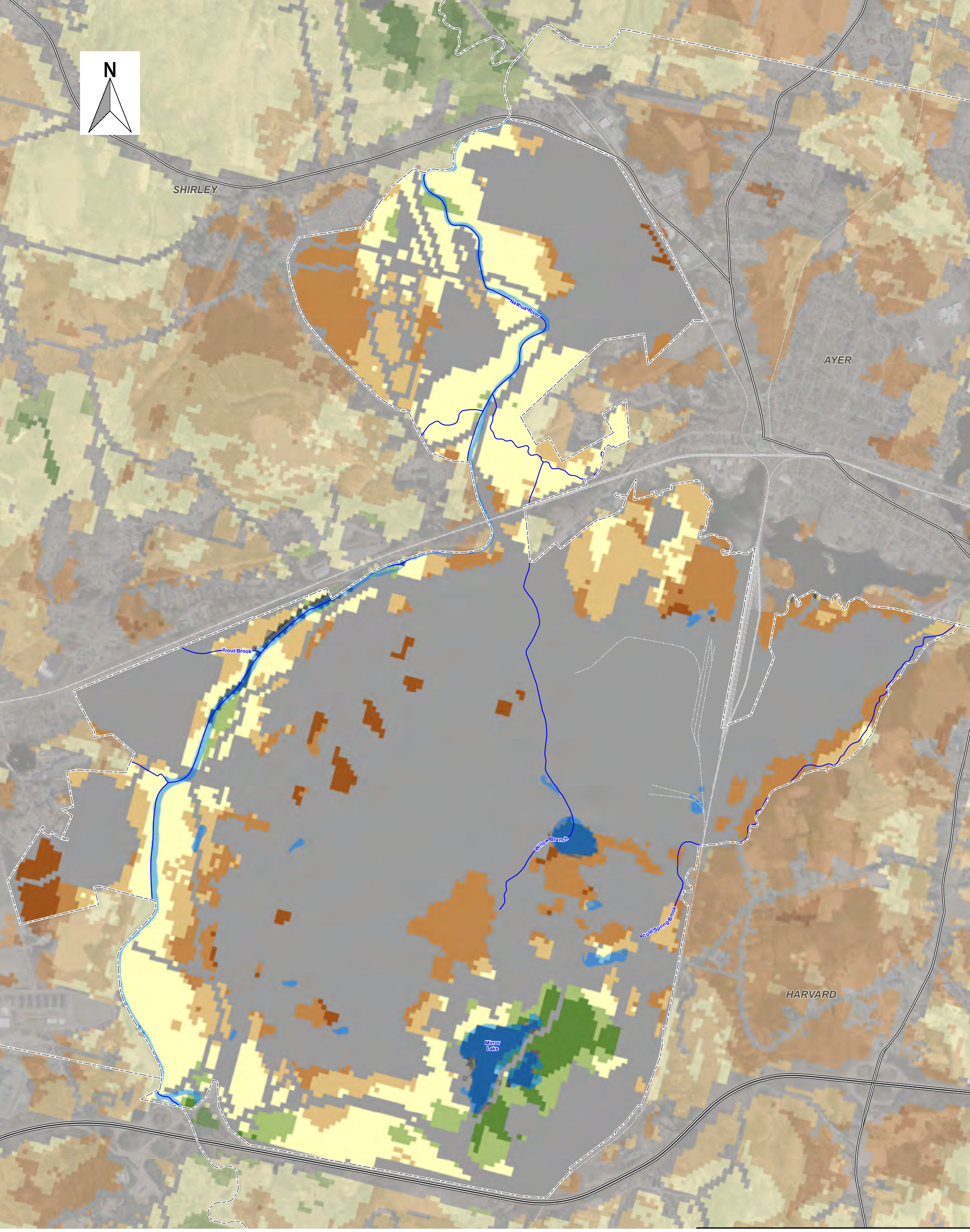


Figure 3.2 **Devens Ecological Climate Resilience**

Unique Features, Concerns & Opportunities

The Nashua River corridor and the Black Spruce Bog located near Mirror Lake are some of the most unique landscape features and plant communities in Devens, worthy of particular attention with regard to conservation and restoration efforts. Currently, these areas are some of the most important natural resources within the community, but they are sensitive and susceptible to changes or alterations to their surroundings and adjacent land uses. They also support high-quality wildlife habitat, which is significant due to the fragmented patchwork of habitat and forest cover throughout much of the community.

Key Nature-based Solutions opportunities exist for Devens through conservation of areas with high ecological climate resilience value (See Figure 3.2) and high soil and biomass carbon value, as well as wetland/

will produce greater urban heat island effects in areas with more impervious surface, while more extremes of precipitation will strain infrastructure and exacerbate impacts like stormwater flooding. The community's proactive approach to enhancing resilience will undoubtedly contribute to the resilience of the entire region, and Devens has been lauded as a national model for military base reuse.

floodplain restoration, reforestation and tree planting including planting of pocket forests, and restoration of ecological and hydrologic connectivity, including daylighting of streams and improvement of culverts to meet Massachusetts stream crossing standards and accommodate future storm events.The Nashua and Still Rivers and Bowers Brook/Cold Spring Brook and adjacent floodplains, wetlands and forests connect all three Apple Country communities and present an opportunity to protect and enhance regional resilience.

Devens Soils

The dominant soils of Devens are excessively drained, low carbon sandy loams located in the uplands with very poorly drained soils in low lying areas. Combined with the legacy of military use, the characteristics of these upland soils make them excellent for redevelopment and more intensive soil regeneration efforts.

The current soil organic carbon stock for Devens overall is an estimated 242,350 metric tons, equal to 891,120 metric tons of CO_2e. The majority of this carbon stock is held in forests and wetlands. Note that the estimate of forest carbon in the *Devens Forward Greenhouse Gas Inventory* did not include any estimate of soil based carbon.

Soil organic carbon, or SOC, is presented here in metric tons per acre. Each ton is equivalent to 3.677 tons of carbon dioxide. As most state-level carbon figures are presented in carbon dioxide equivalent (CO_2e), this convention is used here as well. SOC is not sequestered permanently but can be re-emitted through disturbances both natural (such as fire, storm damage, drought), and human-caused (such as development, timber harvest, tillage for agriculture). Nor does sequestration continue forever. In agricultural and residential landscapes it continues for several decades and then slows to near zero. In Massachusetts forests it continues to accumulate for perhaps 200 years. This means sequestration cannot be counted on to offset emissions forever. An exception is wetlands, which can continue to sequester carbon for millennia. In this analysis, forested wetlands are included in the “wetlands” category, and “forests” refers to upland forests.

Table 3.1. **Estimated soil carbon stock for Devens in 2021**

DEVENS	Acres	Metric tons SOC/acre	Current stock SOC (MT)	Current stock MT CO_2e
Impervious	809	22.31	18,038	66,327
Land & landscape	932	15.02	13,994	51,455
Cropland	0	25.77	0	0
Pasture & hay	4	20.62	73	270
Grassland	261	23.42	6,106	22,452
Trees	251	47.96	12,045	44,288
Forest	1,667	70.22	117,068	430,457
Wetlands	413	175.26	72,365	266,088
Water	94	28.42	2,660	9,781
Total acres	**4,430**		**242,350**	**891,120**

Priorities for Soil Carbon in Devens

The consultant team used analysis and documentation of land cover, soil carbon stocks, land degradation potential, and soil type to create a new way of looking at land in Devens. The map below, *High Value Soil Resources for Devens (Figure 3.3)* shows specific areas of Devens that have high soil conservation value, moderate conservation value, lower conservation value, and areas of high regeneration opportunity. The areas classified as high or moderate conservation value are places with high SOC stocks and/or soils that have been designated as prime farmland. These soils must be protected to avoid significant carbon emissions through disturbance or conversion and loss of ecological and agricultural production capacity. *Soils of lower conservation value* have lower soil organic carbon stocks, either naturally or due to irreversible development impacts. These are the places where conversion through development or other high-impact land uses would not result in large losses of carbon stocks. Areas with the classification of *high regeneration opportunity* are those places where restoration efforts such as reforestation, and better land management practices, could result in gains of carbon stock and improved carbon sequestration rates.
In Devens, areas of moderate to high soil conservation value are less abundant than in other Apple Country communities. These areas are limited, though important, in Devens.

The areas of lower soil conservation value are the places where conversion through development or other use changes would result in less significant not result in large losses of soil organic carbon stocks. Because of the prevalence of lower soil conservation areas in Devens, these areas might also be considered for regeneration opportunities. The areas of high regeneration value are places where concerted efforts at reforestation or other types of restoration, or better land management practices could result in gains of carbon stock and improved carbon sequestration. These areas are even more limited in Devens.

This analysis and map was put together to aid Devens in defining zoning or developing bylaws to protect specific important areas and to encourage development or use change in less valuable locations. The map also helps identify areas to prioritize for restoration or improved management practices.

As noted above, the greatest opportunities for increasing SOC and soil health in Devens can be realized through better turf and lawn management, the addition of trees to grass-dominated landscapes, and the protecting and regenerating soils in and around wetlands and riparian areas. Shaping soil management practices during construction and creating a post-construction standard for soil performance are two additional high-leverage opportunities to increase soil health in Devens.

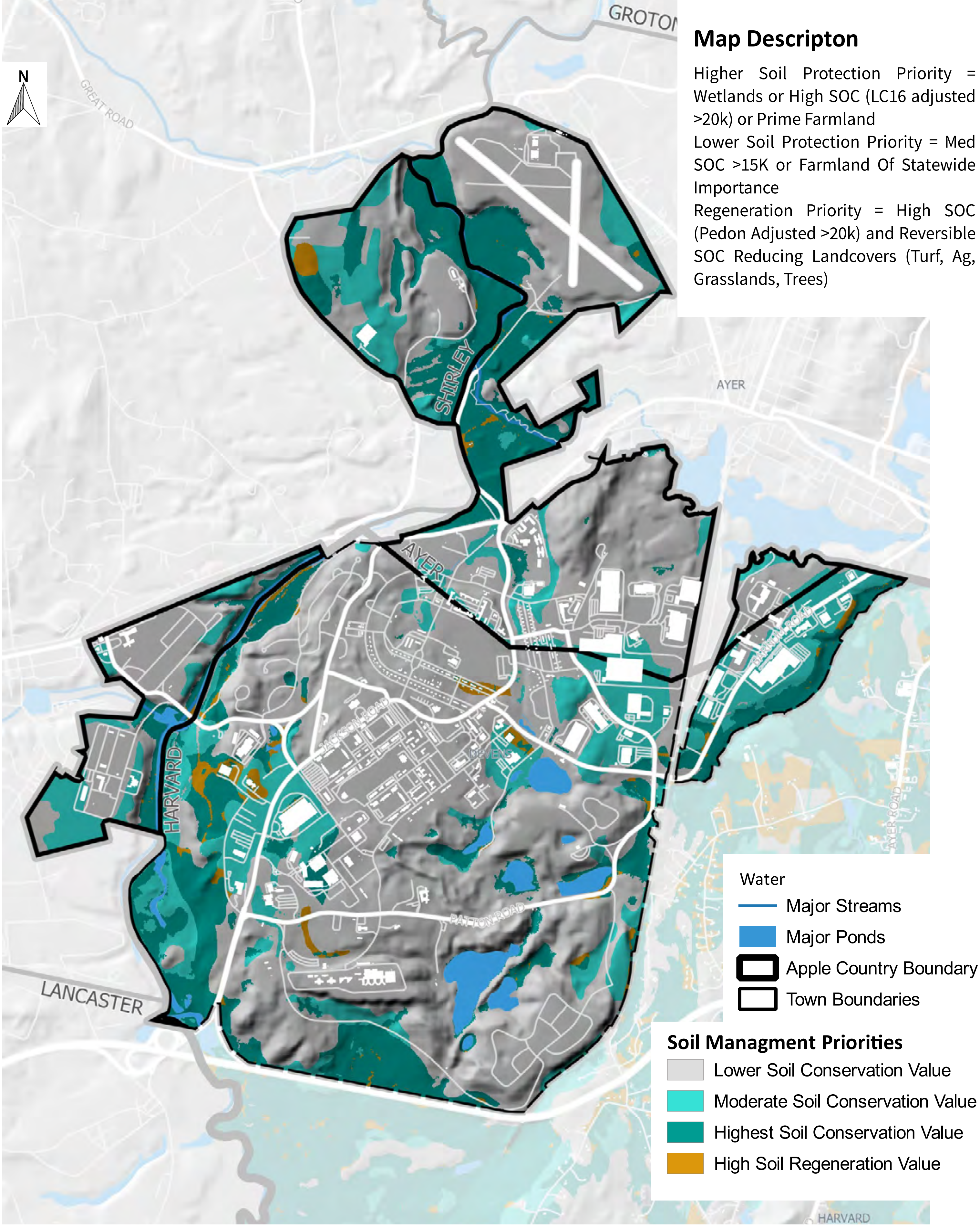


Figure 3.3. **High Value Soil Resources for Devens.** A map of Devens soils showing areas of priority for soil carbon maintenance as well as areas of low priority for soil carbon maintenance, along with areas where soils could be regenerated.

Devens Agriculture

Devens has almost no agricultural land, save the Little Leaf Farms industrial growing facility, which does not use soil in production. The biggest agricultural opportunity in Devens is the establishment of a temporary native species nursery to support local development projects. Devens does have some prime farmland soils (see Figure 3.4) which might support this sort of activity.

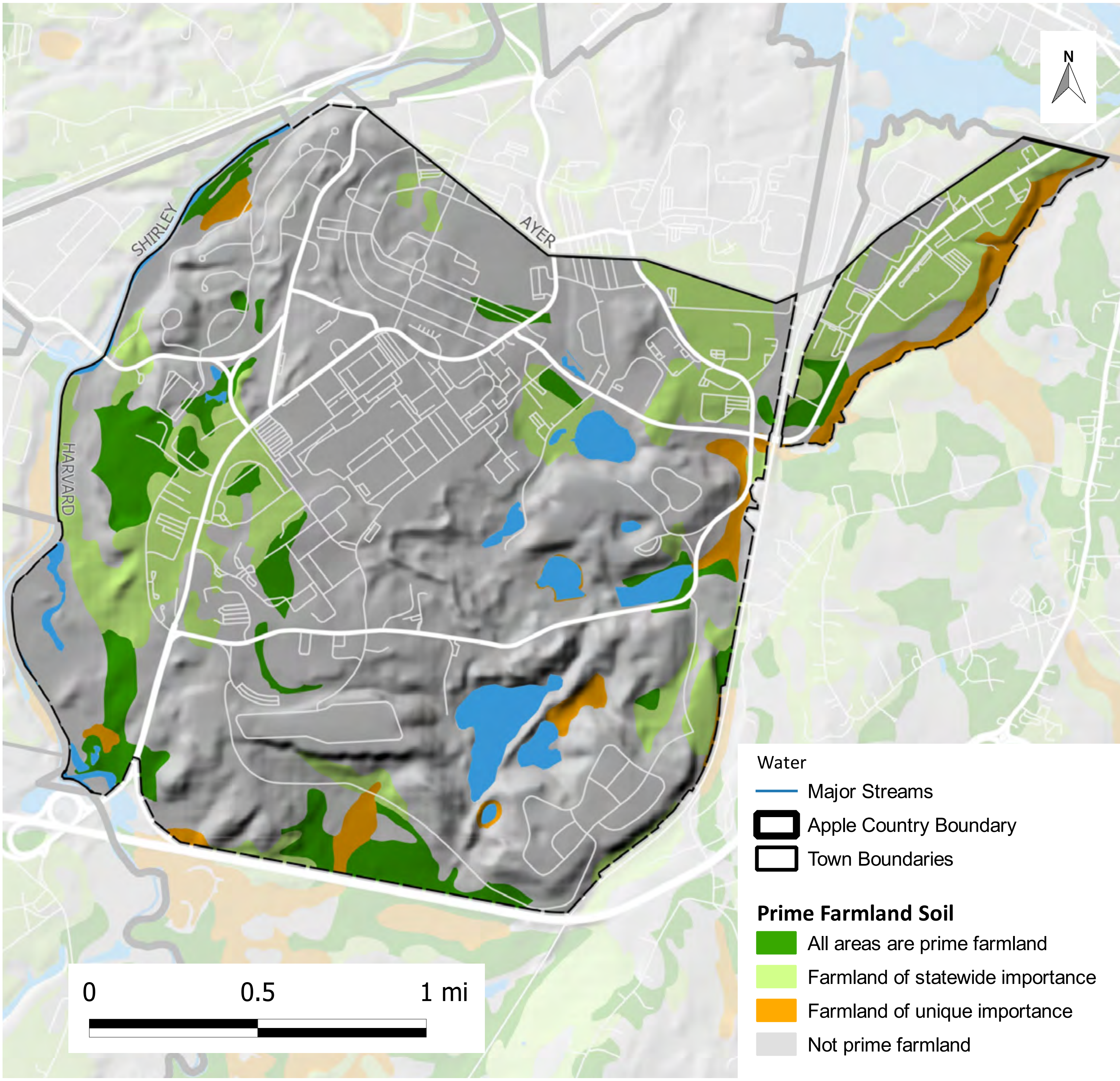


Figure 3.4. ***Prime farmland soils in the Devens Regional Enterprise Zone***

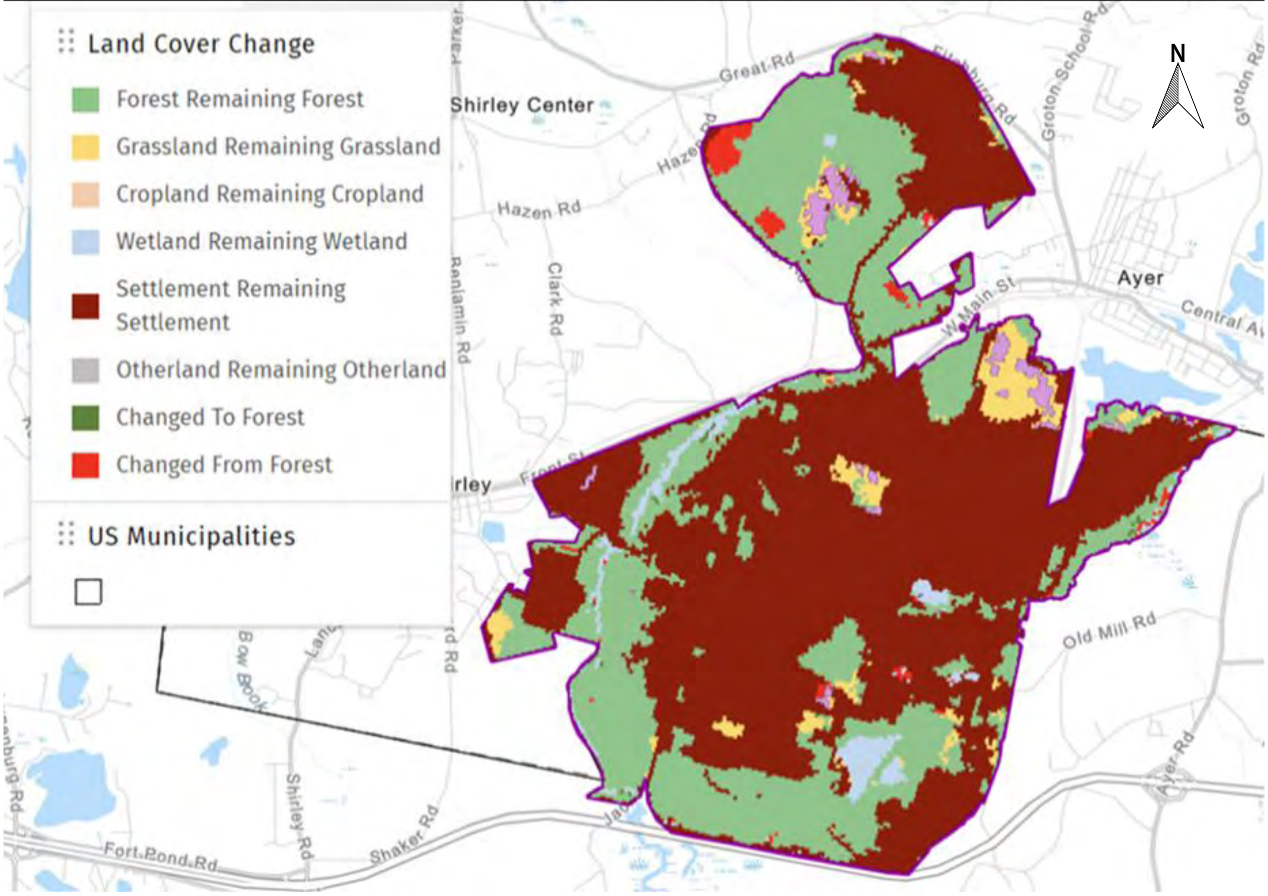


Figure 3.5. **Areas of forest converted to non-forest from 2011-2016 based on NLCD data, Devens**

Devens Forests

Land cover change between 2011 and 2016 was estimated from NLCD data (Figures 3.5, 3.6). Detailed land cover transitions are included in Appendix 13. There were significant losses of forest to grassland, non-forested wetland, and development, with only a small area of non-forested wetland becoming re-classified as forested wetland. More than 10 acres were lost to development and this is not likely to return to forest cover, though some trees may become established. The Massachusetts Department of Environmental Protection (MassDEP) found that conversion of forested wetlands to shrub swamp or marsh during the 1990 to 2017 time period was largely driven by beaver activity and also found that losses of wetlands due to human activity were largest for forested wetlands (Rhodes *et al.* 2019). Other causes for shifts from forest to non-forested wetland could result from

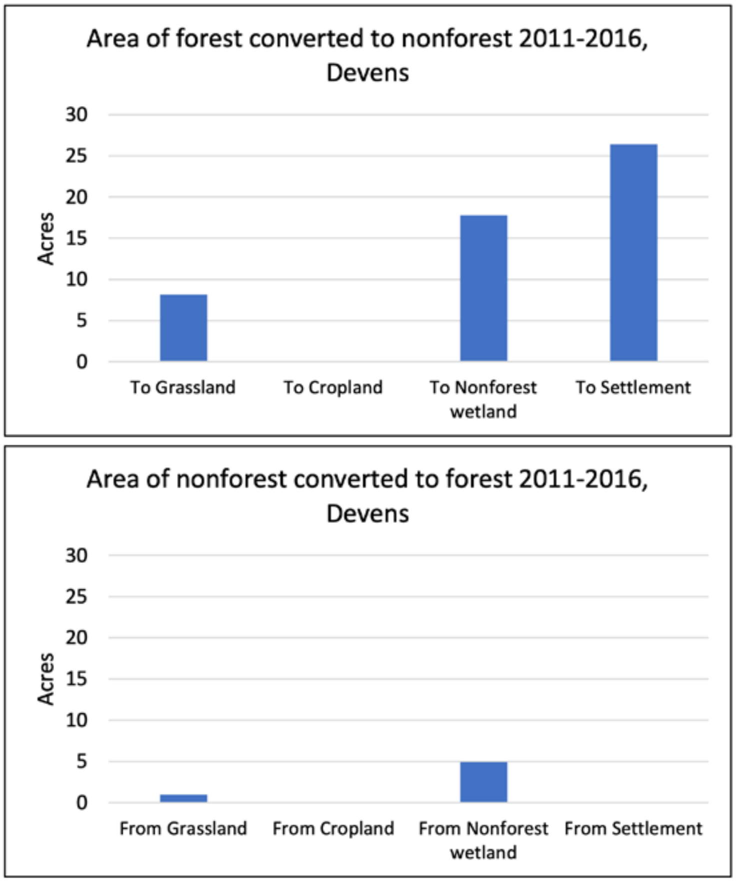


Figure 3.6. **Area of forest converted to non-forest and non-forest converted to forest in Devens, from 2011-2016 based on NLCD data.**

damaging wind or ice storms or other causes of tree damage or death. Forest increases could result from tree planting or from trees growing larger and having greater canopy area.

Because of these changes, the total area of forest declined by 46 acres over the inventory period.

The average canopy area of trees outside forests in Devens varies significantly by land cover class (Figure 9). Developed areas have the largest area of tree cover at about 600 hectares. The percent cover by tree canopy is also greatest for settlement areas at about 24%. Grassland and non-forested wetland classes have around 10% tree canopy cover,

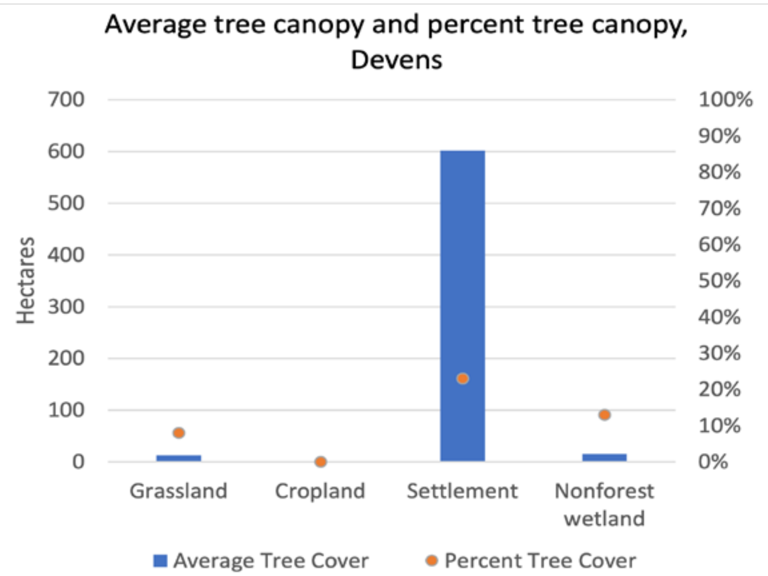


Figure 3.7. ***Average tree canopy area and percent tree cover of non-forest land based on NLCD data for Devens, 2011-2016.***

Table 3.2. **Net CO2 balance of forests and trees outside forests of Devens, 2011-2016**

Source	Removals	Emissions
	($t\ CO_2e$/year)	
Undisturbed Forest	-5,643	
Disturbance fire		0
Disturbance insect/ disease		0
Disturbance harvest/ other		137
Non-Forest to Forest	-20	
Forest to Cropland		0
Forest to Grassland		154
Forest to Non-forest Wetlands		200
Forest to Developed		738
Forest to Other Non-Forest		0
Trees outside of Forests	-5,390	364
Harvested wood products	0	
TOTAL	**-11,054**	**1,593**
Net GHG Balance	**-9,460**	

and the average tree cover for all non-forest land classes is 21%. These estimates represent the average area of tree canopy over the inventory period of 2011-2016, which includes trees that were established before 2011 and trees that were established during the inventory period. The area of tree canopy loss during the inventory period was relatively small, only 5 acres according to the NLCD data, of which most of the loss was in developed areas.

Because of the relatively coarse 30-m resolution of NLCD data, the area of tree canopy was also estimated using high-resolution aerial photography and the i-Tree CANOPY software. These estimates were applied to the 3-m resolution Mass-GIS areas of land cover rather than the NLCD estimates. Based on this analysis, the average tree canopy of non-forest land in Devens was 57%, significantly larger than the 21% estimate based on NLCD alone. The area of tree canopy loss over the inventory period based on the higher-resolution data was 10 acres instead of 5 from the NLCD data. The tree canopy estimates based on the higher-resolution data sets are used in the next section for calculating the net CO_2 emissions associated with trees outside forests.

Forests and trees outside forests of Devens were a net sink of -9,460 metric tons CO_2/yr from 2011 – 2016 (Table 3.2). Removals of CO_2 from the air were much higher than emission of CO_2. Undisturbed forests and trees outside forests (primarily in developed areas) represented the largest quantity of removals and were about equal in magnitude. The largest sources of emissions from forests and trees outside forests were conversion of forests to development (738 metric tons CO_2/yr) followed by loss of tree canopy of trees outside forests, forest harvesting, and conversion of forests to non-forested wetlands and grasslands.

Devens Wetlands

Within Devens, there are a number of wetlands, streams, and vernal pool/ponded resource areas. The MassGIS 2016 Land Cover/Land Use dataset was used to summarize the presence of wetlands within each community. This land cover data was derived from NOAA's Coastal Change Analysis Program (C-CAP). Figures 3.8 and 3.9 below, along with the project website data viewer, show the location and extent of wetland resource areas, aquatic features and major watersheds in Devens. More information on how the MassGIS 2016 data was summarized into different land cover classifications used for this analysis can be found online at: https://docs.digital.mass.gov/dataset/massgis-data-2016-land coverland-use.

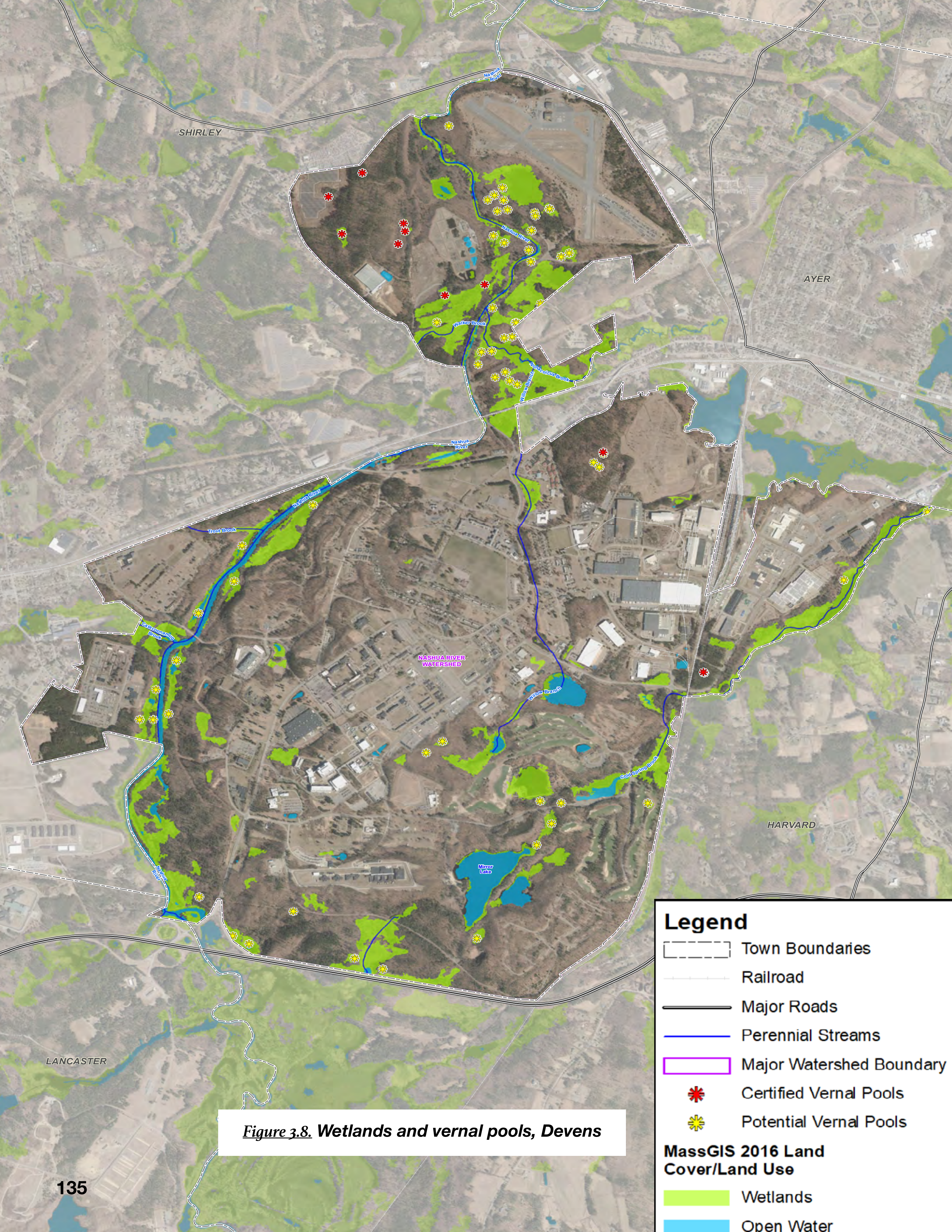


Figure 3.8. **Wetlands and vernal pools, Devens**

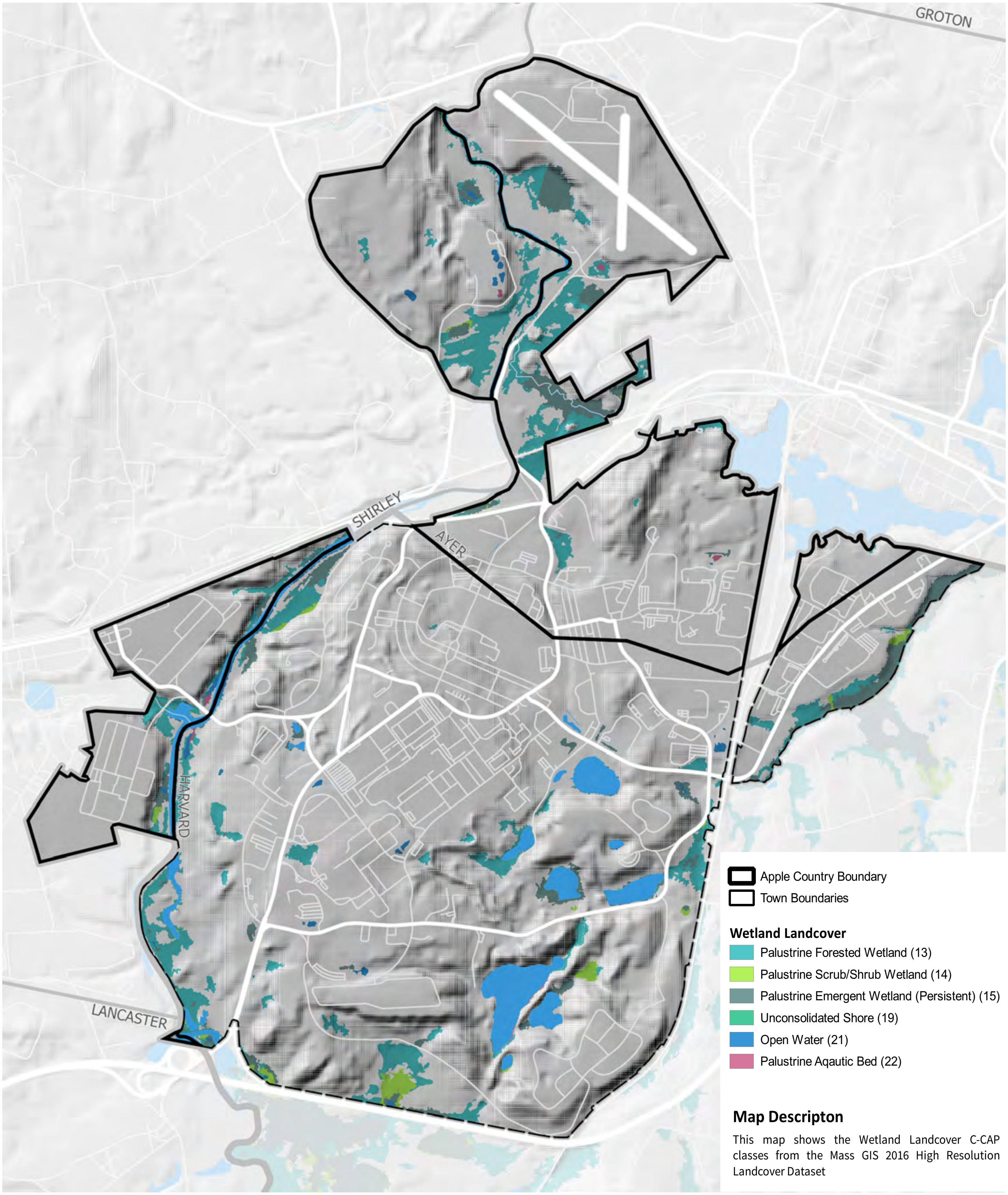


Figure 3.9. ***Wetland land cover types, Devens***

Devens is located entirely within the Nashua River watershed. The Nashua River and its riparian corridor contain many of the wetland resource areas in this community, including a black spruce (*Picea mariana*) bog near Mirror Lake. Black spruce bogs are an uncommon type of wetland in Massachusetts. In addition, Mirror Lake and Little Mirror Lake are two open water ponded systems located in Devens, and together, represent some of the largest wetland areas. The Devens wetland resources are significant and important contributors to biodiversity/wildlife habitat, carbon storage and sequestration, climate resilience, flood storage, water quality, and other ecosystem services. They are particularly valuable due to the extent of previous development, habitat loss, and paving of adjacent upland areas associated primarily with the development of the Fort Devens military base.

Devens is approximately 4,473.4 acres in total land size, therefore, the mapped wetlands provided in the MassGIS Land Cover/Land Use data layer, make up approximately 11.6% of the total land area. Together the soils of these wetlands hold 27.5% of all soil organic carbon in Devens. The wetlands are summarized using the classifications established by the C-CAP Program. The summary of wetlands located within the Devens is shown in the following table:

Table 3.3 **Devens wetlands**

Wetland Classification	Area (Acres)	SOC Stocks (metric tons)
Palustrine Aquatic Bed	6.7	254
Palustrine Emergent Wetland	117.5	21,873
Palustrine Forested Wetland	268.7	33,536
Palustrine Scrub/ Shrub Wetland	22.1	4,735
Water	105.8	1,747
Total	**520.8**	**62,145**

Rivers and Streams

Rivers and streams are flowing-water wetlands that may be permanent or run only temporarily during the year. The Nashua River divides the Devens community and represents an important corridor for natural resources within the entire watershed. Bowers Brook flows from Bolton through Harvard, joining Cold Spring Brook as it flows into Devens. Along with the Nashua River and its tributary the Still River, the Bowers Brook/Cold Spring Brook system serves as a hydrologic corridor and connection between these three communities, supporting a variety of wetland types. Willow Brook flows through a heavily developed section of Devens, and in some locations has been piped below ground. Recently, a section of Willow Brook has been daylighted and restored. Other sections offer additional opportunities for this type of stream and wetland restoration.

Swamps and Marshes

There are 520.8 acres of wetlands, streams/ river corridors, and ponds located within Devens. Forested wetlands make up the majority of the wetlands (52%) with 268.7 acres. Scrub/shrub wetlands and marshes and bogs cover nearly as much land area, at 252.1 acres.

Lakes and Ponds

Lakes and ponds cover a total of 105.8 acres of land in Devens.

Vernal Pools

Devens has 62 Potential Vernal Pools, and a total of 10 vernal pools that have been officially certified by the MA Division of Fisheries & Wildlife. The vernal pool locations are shown on the Devens Wetland and Vernal Pool Figure 3.8 above and in Appendix 4.

Site-Specific Nature-Based Solutions

Core Team Meetings and Site Visit Summary

Devens community representatives participated in four Core Team meetings (detail on these meetings can be found in Appendix 1). At the second meeting, Devens representatives were tasked with identifying locations where Nature-based Solutions (NbS) could protect, restore, or enhance ecological resilience. A site walk was held on December 15th to assess 10 locations throughout Devens. At the third Core Team meeting, participants discussed observations from the site walk and potential recommendations for each location. Given that Devens is a highly developed community, much of the discussion focused on ways to restore natural features to the community including tree planting as well as restoration and management of open spaces to provide increased wildlife habitat value. Additionally, several of the locations visited in Devens are not under the direct control of the community and would require coordination with landowners to implement solutions. A summary of observations and analysis from the Devens site walk and assessments follows.

Devens NbS Site Walk Analysis and Reporting

A menu of planning level project descriptions (thumbnail project scopes and order of magnitude costs) are provided in the Opportunities Table and associated Memoranda and mapping (Appendix 11 and project website NbS page) that collectively indicate which NbS projects could be implemented in which locations within Bolton. Additionally, Appendix 11 provides a generalized outline of considerations for project planning and permitting. By implementing projects identified in the text below and attachments that follow, cumulatively and over time, greater ecological function and climate resilience can be achieved in Devens. Following the principles of ecological restoration, consideration of stressors and disturbance to the natural function of rivers, lakes, ponds, wetlands, forests and associated soils and floodplains, is a key component for this analysis. Discussion of potential NbS and climate resilience enhancement opportunities is provided below.

Old Airfield Off Fitchburg Road

The inactive airfield in Devens, situated on a high point/ridge, contains large areas of paved impervious surfaces surrounding the buildings and along the runways. Adjacent grassy areas were historically mowed on a regular basis, and tree or shrub cover is very limited as a result. The old airport is slated for light industrial and other large commercial uses. The site is currently used for highway equipment testing, state police equipment and vehicle storage, and subsurface hazardous chemical remediation. The Nashua River, which flows from south to north and ultimately joins the Merrimack River in Nashua, New Hampshire, is located north and west of the ridge. The river floodplain extends to the bottom of the ridge slope, and extensive wetlands occur within the floodplain. Stormwater from the airfield flows downslope towards the Nashua River. While waiting for development to happen in this area, Devens could create a soil health/carbon test zone where multiple management regimes could be tried, tested, and measured for several years.

Potential Nature-based Solutions in this location include:

- Pervious paving/parking and walking trails
- Resilient redevelopment incentive
- Green architecture
- Upstream BMPs to improve stormwater quality (vegetated bioswales/rain gardens)
- Pocket forests
- Tree plantings
- Conservation purchase/restriction
- Hedgerows & pollinator strips /wildlife habitat enhancement
- Grassland/meadow restoration and enhancement
- Restore forested buffer area outside of developable area for enhancing soil and forest carbon sequestration (among other ecosystem services)
- Enhance meadow growth outside of developable area with native plantings and long term application of compost
- Develop soil management and engineered soil replacement guidelines for the development process to ensure optimum soil health, planting productivity, and restored ecosystem services after development.

Willow Brook at West Main Street (Route 2A)

Willow Brook is a perennial stream that flows into the Nonacoicus Brook (a tributary to the Nashua River). Willow Brook has been piped and covered in this location before it flows through two small diameter culverts, located under Main Street, into the Nonacoicus Brook. Stormwater flow from the adjacent paved roadways and developments is directed into this brook. Other sections of the brook, located to the south, have previously been restored, day-lighted, and connected to bordering vegetated habitat.

Potential Nature-based Solutions in this location include:

- Day-light piped stream, such as by creating tree lined banks on the parts of Willow Brook that are currently piped. This would help both soil and habitat regeneration in the area and provide support for a small forest.
- Stream bank revegetation
- Pocket forests
- Adjacent grassland meadow restoration
- Tree and shrub plantings
- Bordering wetland/floodplain restoration
- Stream flow alteration (add sinuosity)
- Upstream BMPs (rain gardens, vegetated bioswales)
- Improve/widen culverts to meet MA Stream Crossing Standards (MSCS) and to accommodate future storm flows, rather than historical flows
- Added forest area along Main Street around and to the east of Willow Brook to increase soil health and ecosystem services.
- Plant native grasses and manage the area for soil health in areas on both sides of Jackson Road at Main Street.

Willow Brook at Cavite Street

Willow Brook at Cavite Street is a location where Willow Brook was previously daylighted, restored, and re-connected to bordering vegetated wetland habitat. This location is located south of the Main Street crossing discussed above. This location is a good example of successful NbS, but there are opportunities to expand and improve upon what was previously accomplished. These areas include the content of adjacent potentially buffering parcels, and interim stages of habitat establishment.

Potential Nature-based Solutions in this location include:

- Pocket Forests
- Grassland meadow management and habitat enhancement
- Stream flow alteration (add sinuosity)
- Tree and shrub plantings
- Bordering wetland/floodplain restoration
- Upstream BMPs (rain gardens, vegetated bioswales)
- Improve/widen culvert to meet MA Stream Crossing Standards, and to accommodate future storm flows, rather than historical flows

Roadside Fields Along Saratoga Blvd

Saratoga Boulevard in this location is an open road corridor situated between industrial and residential land uses. Mowed turf is the primary land use in this location. Some of the adjacent industrial building complexes have stormwater treatment onsite, including vegetated swales.

Potential Nature-based Solutions in this location include:

- Grassland meadow management and habitat enhancement
- Pocket forests
- Tree and shrub plantings
- Upstream BMPs (rain gardens, vegetated bioswales)
- Hedgerow habitat/pollinator strips
- Lighting modifications/upgrades
- Plant more native grass species in the meadow areas and mow at longer intervals to encourage soil depth and health;
- Plant more trees in areas where possible to drive greater carbon sequestration.

Railroad Crossing at Patton Road (Cold Spring Brook)

Cold Spring Brook is a perennial stream that flows under Patton Road in this location, prior to flowing through a narrow, old stone culvert located under a tall railroad bed. Enlarging the culvert to meet MA Stream Crossing Standards and to accommodate future stormwater flows, adding stream bank shrub and tree plantings, and roadside stormwater BMPs are all possibilities in this location. It will require working with the railroad owner (PanAm) to increase the size of the culvert as noted, and to reduce flooding risks that may be associated with the railroad bed. Multiple beaver dams were located on the west side of Patton Road across a small stream that flows into Cold Spring Brook also in this location. Floodplain expansion and flood storage opportunities exist in this area. Stormwater flow from the adjacent paved roadways is directed into this brook, which flows east into a large wetland complex that surrounds the confluence of Bowers Brook and Cold Spring Brook. The mapped (FEMA) flood risk associated with the brook at this location is high.

Potential Nature-based Solutions in this location include:

- New wetland or floodplain construction/ expansion
- Stream flow alteration/improvement
- Widen culverts to meet MA Stream Crossing Standards and to accommodate future storm flows, rather than historical flows
- Stormwater BMPs (rain gardens, vegetated bioswales)
- Strategically placed beaver deceiver or promoter
- Public/private land swap or partnership

Devens Commerce Center near Givry Street

The Devens Commerce Center, near Givry Street, is comprised of commercial buildings surrounded by managed turf/parks. Some tree cover exists along the edges of the park areas. Areas adjacent to the commercial buildings are paved for parking. There are no wetland or other sensitive resource areas in the vicinity of the Commerce Center, however, there are several opportunities to improve the existing conditions and to incorporate NbS and upstream BMPs.

Potential Nature-based Solutions in this location include:

- Grassland/meadow restoration and management, such as by improving soil health and usability of grassy areas with higher mowing, mulching clippings when possible, and application of organic soil amendments.
- Pollinator or hedgerow habitat strips
- Pocket forests
- Upstream stormwater BMPs (rain gardens, vegetated bioswales)
- Pervious pavement/hardscape surfaces
- Shade and habitat tree plantings
- Public/private land swap or partnership
- There is potential for a temporary native species nursery at this location that could both supply the new developments and improve the soil health of the area in the short term.

USFWS Oxbow National Wildlife Refuge (NWR) and Hospital Road

The US Fish and Wildlife Service (USFWS) Oxbow NWR is situated along an important forested riparian corridor associated with the Nashua River. The primary objective at this location is to preserve and enhance existing natural areas along the Nashua River to the greatest extent practicable. The Nashua River is dammed downstream from this location on Hospital Road. Although this dam was not visited during the Devens site visit, it should be considered for removal to improve floodplain riparian habitat and floodplain wetlands' flood-storage opportunities. The Hospital Road location is an active canoe/kayak launch and parking area for visitors, and it provides good access to the river.

Potential Nature-based Solutions in this location include:

- Invasive species management
- Educational interpretation and signage
- Expanded walking trails
- Floodplain and wetland restoration
- Upstream stormwater BMPs
- Public/private land swap or partnership

Mount Wachusett Community College and Jackson Road

The Mount Wachusett Community College is located off of Jackson Road and just east of, and adjacent to, the Nashua River forested riparian corridor. The school previously installed stormwater BMPs in the main parking area, which have made positive contributions to managing stormwater. Several additional opportunities exist to expand and enhance the NBS on the property.

Potential Nature-based Solutions in this location include:

- Additional tree and shrub plantings to increase shade/forest cover
- Educational interpretation and signage
- Pocket forests
- Lighting modifications/upgrades
- Additional upstream stormwater BMPs (rain gardens/vegetated bioswales)
- Hedgerow and pollinator habitat plantings
- Resilient redevelopment and architecture incentives
- Develop soil management and engineered soil replacement guidelines for the development process to ensure optimum soil health, planting productivity, and restored ecosystem services after development.

Mirror Lake and Black Spruce Bog

Mirror Lake and Little Mirror Lake are important bodies of water and habitat areas, mostly surrounded by forest, but with some encroachment by development and deforestation near the lake. These are important water bodies and watersheds to continue to conserve. Protection of the surrounding forest should be expanded. An intact black spruce bog occurs southeast of Mirror Lake. Spruce-Tamarack bogs are an uncommon wetland plant community in Massachusetts and are ranked as Imperiled S2 Priority for Conservation by NHESP (NHESP Classification of the Natural Communities of Massachusetts). Level-bogs are ranked S3 Vulnerable, and also contain black spruce trees as a dominant species (NHESP Classification of the Natural Communities of Massachusetts). Spruce bogs contribute habitat for breeding birds such as Canada warbler (Muscicapa canadensis cinerea**,** northern waterthrush (Parkesia noveboracensis), purple finch **(**Carpodacus purpureus)**,** and red-breasted nuthatch (Sitta canadensis). (NHESP Classification of the Natural Communities of Massachusetts. Appendix 1). The public beach access for Mirror Lake is located downhill from a paved parking area, which is located off of Mirror Lake Road. The trail down to the beach from the parking area is also paved.

Potential Nature-based Solutions in this location include:

- Invasive species management
- Forest enhancement, management, restoration
- Species monitoring
- Install pervious pavement and remove existing pavement
- Upstream stormwater BMPs

Rogers Field / Devens Parade Ground

Rogers Field is located on 44 acres of land and is a former military parade ground. The field is maintained as a large open park primarily used for team sports (e.g., lacrosse and soccer) and other recreational activities and events. Located in the center of Devens, there are no wetland or other sensitive resource areas in the immediate vicinity. The Nashua River is approximately one half-mile to the west, however, and fragmented forest exists in between the two areas. Additional pocket forest cover could be established to enhance and reinforce the habitat connectivity to the Nashua River in this location. In addition, paved parking areas and parking lots used by visitors are located around the perimeter of the field, and these paved areas are connected to stormwater sewers. Rogers Field is an excellent example of a turf system where the management appears to have increased the depth and carbon content of the soil. The play fields are healthy, with deep rich soil. Learning from the results of the last 15 years of management could provide replicable lessons and guidelines for other turf managers.

Potential Nature-based Solutions in this location include:

- Hedgerow and pollinator habitat strips, such as planting trees and pollinator-attracting species around the perimeter of Rogers field to provide shade, store more carbon and water and attract pollinators.
- Manage edges and nearby fields and roadside areas for soil health.
- Change grass types and reduce mowing of roadside areas around Rogers Field.
- Consider amending soils with organic amendments on a several year on/several year off cycle.
- Forest enhancement, management, restoration, including installation of Pocket Forests
- Upstream stormwater BMPS (rain gardens and vegetated bioswales)
- Install pervious pavement and removal of pavement
- Resilient redevelopment incentives
- Review and analyze soil test results for trends
- Index these against management notes
- Rogers Field Turf Management: Provide summary of findings. If strong correlation between management and soil attributes are found, conduct training of local turf managers in Apple Country.

Town-wide Devens Recommendations

In addition to recommendations provided in the Regional Recommendations Section of this report, the following Devens-specific recommendations are provided. It is recommended that readers review the Regional Recommendations Section as well as the information below.

Key Nature-Based Solutions

- ***Devens Old Airfield.*** The redevelopment potential at the retired Devens Airfield creates multiple opportunities for NbS. The paved areas and much of the grassland will be replaced by new development, but with proper planning new development could include features like green roofs, native plant-based meadow habitat, pocket forest cover, stormwater BMPs, and educational opportunities. The airfield directly abuts the Nashua River and its forested riparian corridor (located along the western side of the airfield). Connectivity to this important riparian corridor could be enhanced and expanded. Native plant-community restoration and restored habitat opportunities could be incorporated with future redevelopment plans for the site.

  This is also a place where development guidelines focused on soil health and soil carbon would have a large impact. Guidelines should specify soil management practices during development and specify depth and organic matter content of engineered replacement soil, as well as native plant types.

Figure 3.10 **Devens Old Airfield Potential Nature-based Solutions**

Willow Brook at West Main Street (Route 2A). Willow Brook flows under West Main Street through a buried pipe. There are many opportunities available at this location to incorporate NbS that would contribute to the resilience of the landscape within Devens. Daylighting the stream, restoring sections of floodplain and bordering wetlands, and improving wildlife connectivity are a few possible opportunities that exist. Fish and wildlife connectivity through the culvert, which crosses under West Main Street, could also be enhanced by enlarging its size to meet the MA Stream Crossing Standards and to accommodate future storm events, rather than being sized for 20th century events, as is the case now.

Trees in the areas around the daylighted stream would help cool stream waters and would also help improve soil health through adding soil carbon and enhancing water infiltration.

- ***Other Opportunities.*** Throughout Devens, there are many opportunities that exist to create a more resilient landscape. Removing paved surfaces, incorporating pervious pavement/hardscapes, planting and expanding pocket forests, installing stormwater BMPs, and restoring/managing meadow habitat would all have significant long-term positive impacts and contributions towards this goal. In select locations it may also be possible to expand floodplains or encourage beaver activity to expand floodplains to increase the duration and scale of infiltration without impairing infrastructure.

- ***Restore hydrologic connectivity.*** Throughout Devens, substandard, undersized and failing culverts have been identified as being in need of replacement and upgrade. Outdated and failing culverts present an opportunity to implement stream crossing designs that meet the Massachusetts Stream Crossing Standards and are designed to accommodate predicted future stormwater flows, rather than being limited by outdated 20th century capacity that has the potential to place infrastructure and adjacent properties at risk. Placing a focus on this feature of the landscape will help address a variety of vulnerabilities throughout the community.

- ***Education.*** Throughout Devens there are many locations and opportunities to implement NbS and to provide education and interpretive media/signage that would help increase the use and understanding of NbS across the whole community.

Soils

- **Prioritization of *high regeneration opportunity soils:*** the greatest opportunities for increasing SOC and soil health in Devens can be realized through better turf and lawn management, the addition of trees to grass-dominated landscapes, and the protecting and regenerating soils in and around wetlands and riparian areas. Shaping soil management practices during construction and creating a post-construction standard for soil performance are two additional high-leverage opportunities to increase soil health in Devens. (See Figure 3.3 Priority Soils for Protection).

- ***Conservation and Land Protection.*** Protect soil carbon stocks by conserving forested and wetland soils. For Devens, the largest existing pools of carbon storage are in forests and wetlands. These areas also contribute the most to carbon sequestration. However, because a large amount of the land in Devens is classified as impervious or landscaped, the role of conservation plays a smaller role than in the other Apple Country communities. The distribution of both soil protection and soil regeneration priorities are shown in Figure 3.3.

- ***Better Land Management.*** Support and implement practices that improve sequestration of carbon in soil and thus improve soil based ecosystem services, primarily on agricultural and ornamental lands. Devens has almost no agricultural land, but does have 929 acres of ornamental or turf lands, as shown in Table 3.1. These areas could benefit from improved management techniques. Some specific management recommendations are called out for the specific sites that were visited.

    » In general, for Devens, better turf management on both public and private lands can play a big role in increasing carbon sequestration potential on those lands. Higher mowing, mulching clippings, and regular application of organic soil amendments, at least for 3 to 5 years, will have immediate effects on turf health, water retention, and soil carbon levels. A management plan for turf and ornamental landscapes that could be shared with private landowners would aid in transitioning private land management practices.

    » A management plan for both forested areas and landscaped areas that could be shared with private and public landowners would aid in transitioning management practices.

- ***Regeneration and Restoration.*** Support and implement actions that restore lost or degraded soil function and actions that regenerate soil function to higher levels, through implementation of Natural Climate Solutions. There are a number of locations in Devens that could support new trees or pocket forests. Transformation of previously disturbed land such as these would have a large positive effect of carbon sequestration and overall soil health and ecosystem regeneration. Transformation of areas along roadways to more native grasses would have a smaller, but similar effect, for a relatively low investment.

- ***Outreach and Education.*** Advocate for beneficial changes to policies and programs at the State and Federal levels. Devens could advocate for improved soil testing capabilities from the State. Advocating for a State carbon fund that would support better land management for forest and managed landscape owners would help conserve and enhance the soil functions of those land types. Advocating for inclusion of carbon functions and recognition of climate resilience functions in State and Federal level wetland regulations could lead to improved protection of wetland carbon and climate resilience ecosystem services, as could advocating for protection of forest carbon and climate resilience ecosystem functions.

- ***Research and Data Collection.*** Support and conduct research projects at the municipal level that could inform policies and actions and build knowledge of soil dynamics. Devens has a couple of opportunities to support research into land management practices, The former air base site is a very good location for large scale soil management research. The Willow Branch area and others present opportunities to plant and monitor pocket forests.

Agriculture

- ***Prime Farmland Soils & High Carbon Soils Provisions.*** Given the unique character and dynamics of Apple Country, the farms and orchards of Bolton and Harvard could participate in a pilot soil carbon market where Deven's industrial tenants (or MassDevelopment) voluntarily purchase carbon credits from participating farmers and forest owners. This hyper-local strategy allows Devens to reduce its emissions by incentivizing good soil stewardship, improving economic viability for farmers, and accelerating ecosystem restoration on degraded lands.

Forests

- ***Prioritize Conservation of Forests and Trees Outside of Forests.*** Reduce canopy loss from trees outside forests particularly in developed areas. Reducing the conversion of forest land to other land uses, and reducing harvesting of forests. Plant trees and facilitate natural regeneration of areas that are currently lacking tree cover. Improve the health and stocking of existing forests through improved silviculture and proactive pest management.

Wetlands and Floodplains

- ***Prioritize Conservation and Restoration of Floodplains and Wetlands***. Devens' highest-functioning ecosystems are often concentrated along riparian corridors, floodplains and in wetlands (as well as in forests). These areas are often ranked the highest on maps (See Appendix 4 and website data viewer) of ecological climate resilience, ecosystem carbon storage and sequestration, wildlife habitat/biodiversity value, and delivery of other ecosystem services. These areas should be prioritized for conservation and ecological restoration.

- ***Restore wetland buffers*** by planting native trees and shrubs, to serve as buffers for nearby wetlands, as well as other types of wetland//floodplain restoration, reforestation and tree planting, and restoration of ecological and hydrologic connectivity, including improvement of culverts to meet Massachusetts stream crossing standards and accommodate future storm events.

- ***See Regional Recommendations*** for recommendations pertaining to updating the Devens Bylaws and associated regulations and implementation of Best Management Practices as they pertain to wetlands.

4

TOWN OF HARVARD ANALYSIS AND OPPORTUNITIES

The Town of Harvard (Harvard) has a population of 6,600 people, and is defined by its traditional village settlements intermixed with active agriculture, conservation areas, and historic resources. Wetlands are prevalent in the landscape and play an important role in regulating downstream water quality and flooding, which benefits residents of both Harvard and downstream communities. Water bodies such as the impoundment in the MassWildlife Delaney Wildlife Management Area and Flood Control Project (which straddles Harvard, Bolton, and Stow) and Bare Hill Pond, both popular local recreation destinations, are highly valued by the community, and the town prides itself on its abundant natural lands, rural agricultural heritage, and resulting scenic character.

Harvard also has a strong legacy of land protection. The Conservation Commission, Harvard Land Trust, and other local partners have helped to protect over 1,900 acres of conservation land directly, with an additional 523 acres under protection through the Conservation Restriction and Agricultural Preservation Restriction programs. There are a handful of larger (> 50 acre) farms in town, with most local farmers farming non-commercially on less than 10 acres. Town-wide forest management has also been identified as a priority by several of the Town's recent planning efforts.

The Town's 2016 Master Plan includes a Development Suitability Analysis, which identifies constraints and areas where development can be undertaken in alignment with environmental and housing goals. Development-limiting soils and the overall reliance on individual wells and septic systems place significant restrictions on Harvard's development potential, yet much of the town's current agricultural land is suitable for

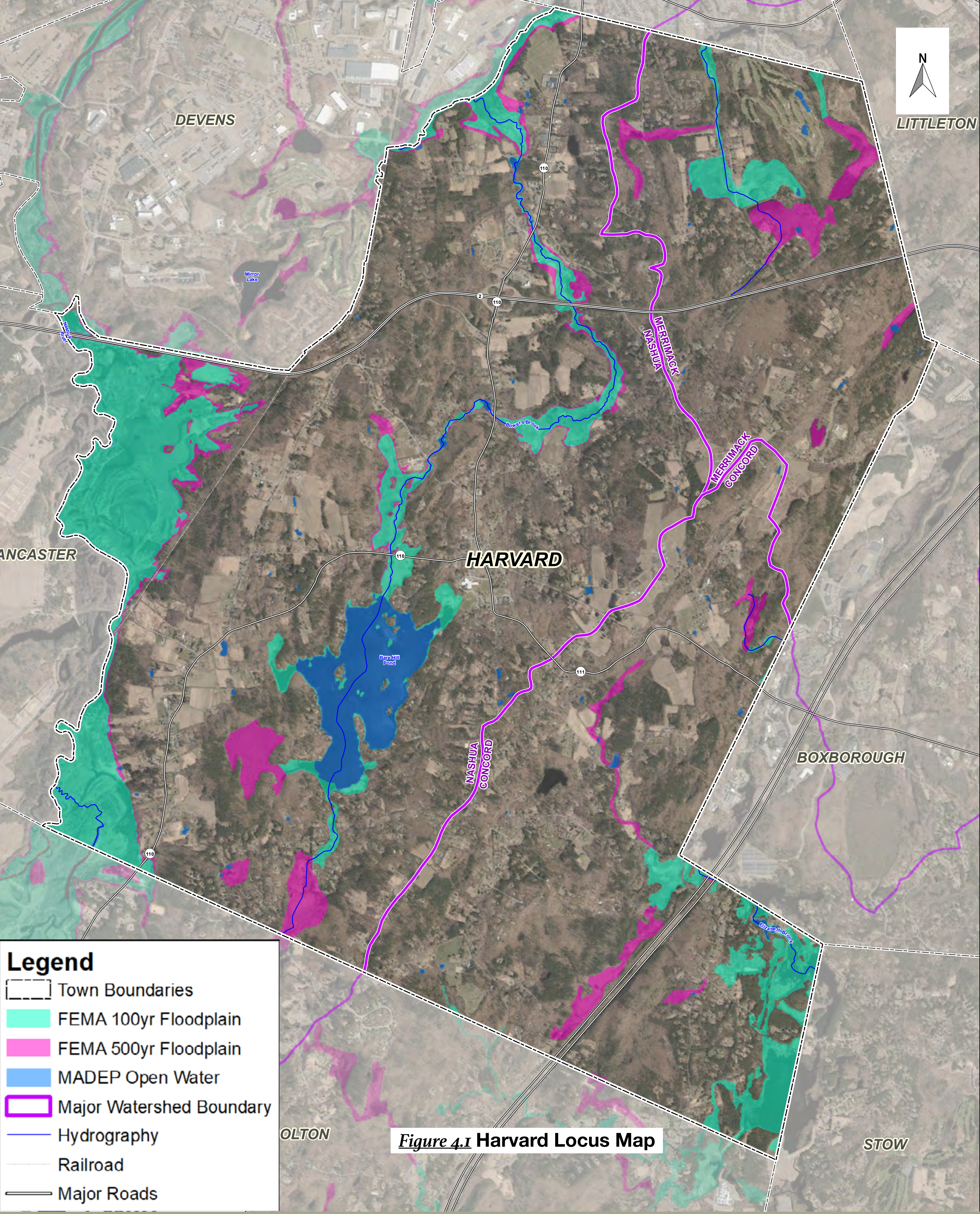
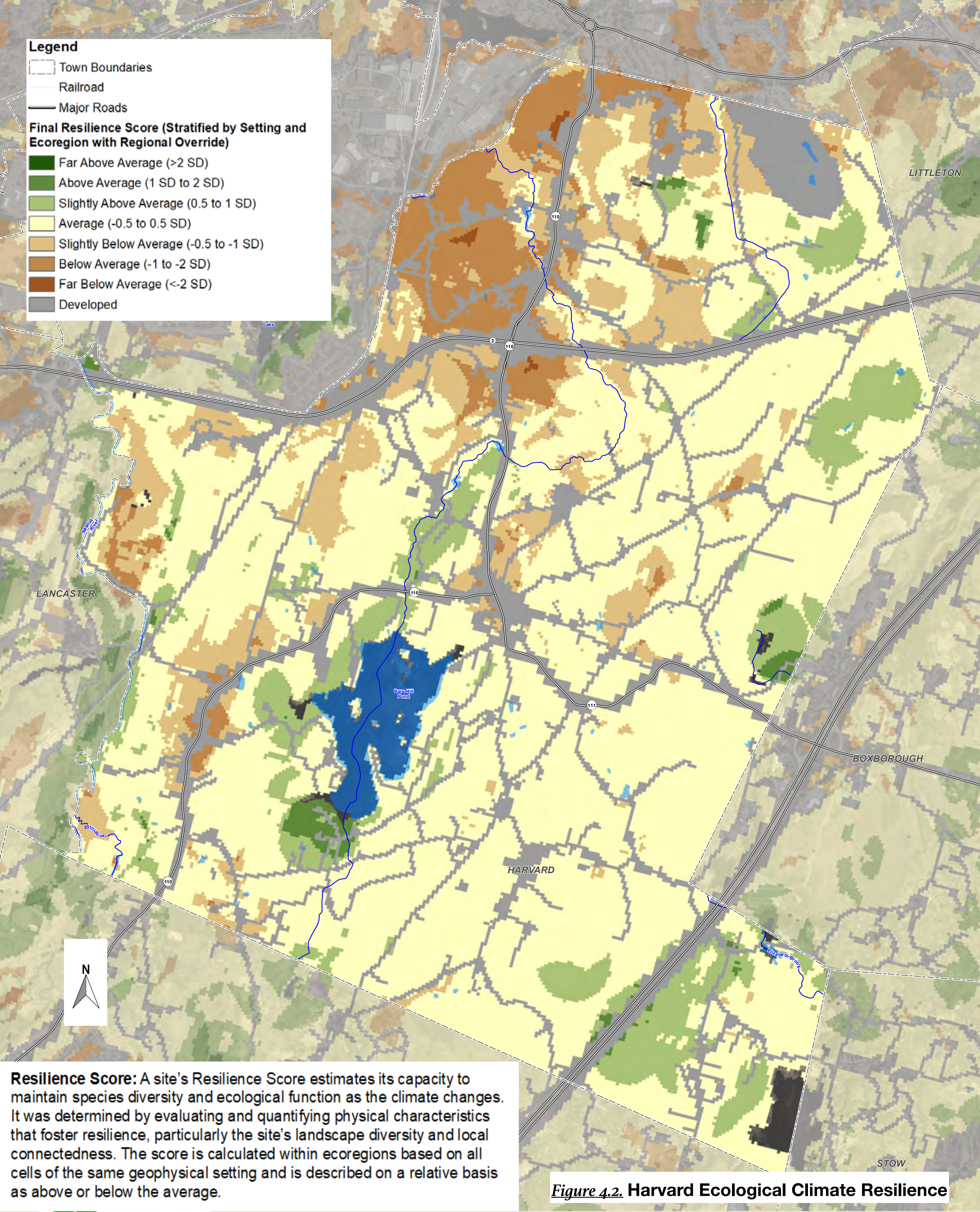


Figure 4.1 **Harvard Locus Map**



Resilience Score: A site's Resilience Score estimates its capacity to maintain species diversity and ecological function as the climate changes. It was determined by evaluating and quantifying physical characteristics that foster resilience, particularly the site's landscape diversity and local connectedness. The score is calculated within ecoregions based on all cells of the same geophysical setting and is described on a relative basis as above or below the average.

Figure 4.2. **Harvard Ecological Climate Resilience**

development and therefore vulnerable. The Development Suitability Analysis encourages revisions to the Town's zoning bylaw to allow for denser mixed-use development in the Town Center and protection of environmentally sensitive and/or climate resilient lands in other areas of town.

Climate change is expected to bring increased extreme precipitation events and extreme temperatures, along with shifting seasonal weather patterns, to the Northeastern United States. In Harvard, and Apple Country generally, historically agricultural lands face dual threats from climate change and development, as Boston's exurban ring continues to grow outward and as the Worcester area suburbs/exurbs continue to develop. The Town undertook an Agricultural Climate Action Plan in 2019, which recommends healthy soils practices as a key strategy to address Harvard's climate vulnerabilities. The current project builds from these recommendations to target specific opportunities to enhance soil health for carbon sequestration and ecological resilience.

Unique Features, Concerns & Opportunities

The Town of Harvard is characterized by diverse natural resources including a variety of wetlands, forests, and agricultural lands. Community representatives and landowners were eager to share the changes they are seeing on their lands, the ways they manage their lands, and to learn from others. At the first Core Team meeting, participants identified the Prospect Hill viewshed, the region's apple orchards, High Ridge (a priority habitat area), and the Harvard Shaker Village historic district as some of the most important natural features and places in the community.

A theme in Harvard's Core Team discussions was the connection between abutting parcels of land and how changes on one parcel could positively or negatively impact the neighboring parcel. Key conservation opportunities exist for the Town related to conservation of areas with high ecological climate resilience value (See Figure 4.2) and high soil and biomass carbon value, including seeking conservation status for parcels that would connect to nearby resilient lands. Other opportunities for increasing resilience include restoring wetland buffers by planting native trees and shrubs, to serve as buffers for nearby wetlands, as well as other types of wetland/floodplain restoration, reforestation and tree planting, and restoration of ecological and hydrologic connectivity, including improvement of culverts to meet Massachusetts stream crossing standards and accommodate future storm events. The Nashua and Still Rivers and Bowers Brook/Cold Spring Brook and adjacent floodplains, wetlands and forests connect all three Apple Country communities and present an opportunity to protect and enhance regional resilience.

Harvard Soils

Harvard's gently rolling hills, abundant wetlands, streams, rivers, floodplains are host to a wide variety of soils. While each of these soil types exhibit unique properties and capabilities, the seven classes of drainage classification, as shown in Figure 4.3 (next page), can be used to reveal broader trends. The ridges and hillsides are dominated by well-drained and moderately well-drained sandy loams. The wetlands, both isolated and those hydrologically connected to waterbodies and waterways, tend to be underlain by poorly and very poorly drained soils rich in organic matter and clay. At the margins between uplands and bottomlands, where hills meet rivers, the soils tend to be very sandy and excessively drained due to glacially deposited parent material.
As noted in the regional soils section, the

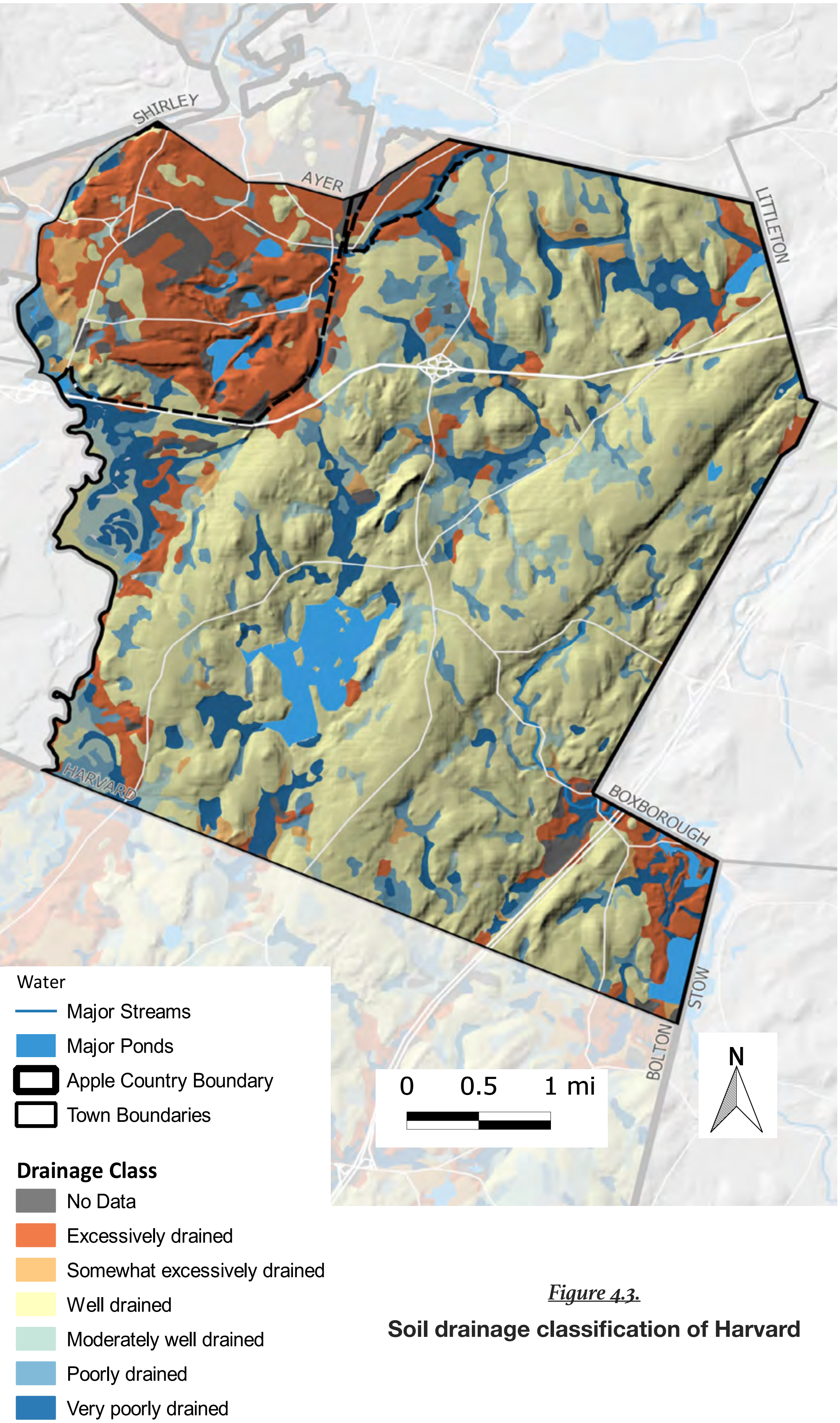


Figure 4.3.

Soil drainage classification of Harvard

interaction between drainage class and land cover shape soil health, largely by influencing soil organic carbon stocks and flux.

The current soil organic carbon stock for Harvard overall is an estimated 1.415 million metric tons, equal to 5.2 million metric tons of CO_2e. The majority of this carbon stock is held in forests and wetlands. In this analysis, forested wetlands are included in the "wetlands" category, and "forests" refers to upland forests.

Soil organic carbon, or SOC, is presented here in metric tons per acre and total for the Town. Each ton is equivalent to 3.677 tons of carbon dioxide. As most state-level carbon figures are presented in carbon dioxide equivalent (CO_2e), this convention is used here as well. SOC is not sequestered permanently but can be re-emitted through disturbances both natural (such as fire, storm damage, drought), and human-caused (such as development, timber harvest, tillage for agriculture). Nor does sequestration continue forever. In agricultural and residential landscapes, it continues for several decades and then slows to near zero. In Massachusetts forests it continues to accumulate for perhaps 200 or more years.

Table 4.1. **Estimated soil carbon stock for Harvard in 2021**

HARVARD	Acres	Metric tons SOC/acre	Current stock SOC (MT)	Current stock MT CO_2e
Impervious	780	22.30	17,391	63,947
Land & landscape	1,109	42.66	47,335	174,052
Cropland	543	33.31	18,079	66,478
Pasture & hay	560	45.90	25,685	94,443
Grassland	359	49.80	17,855	65,653
Trees	876	94.36	82,623	303,806
Forest	7,542	99.53	750,595	2,759,937
Wetlands	2,543	171.81	436,934	1,606,605
Water	389	48.48	18,884	69,436
Total acres	**14,700**		**1,415,383**	**5,204,363**

This means sequestration cannot be counted on to offset emissions forever. An exception is wetlands, which can continue to sequester carbon for millennia.

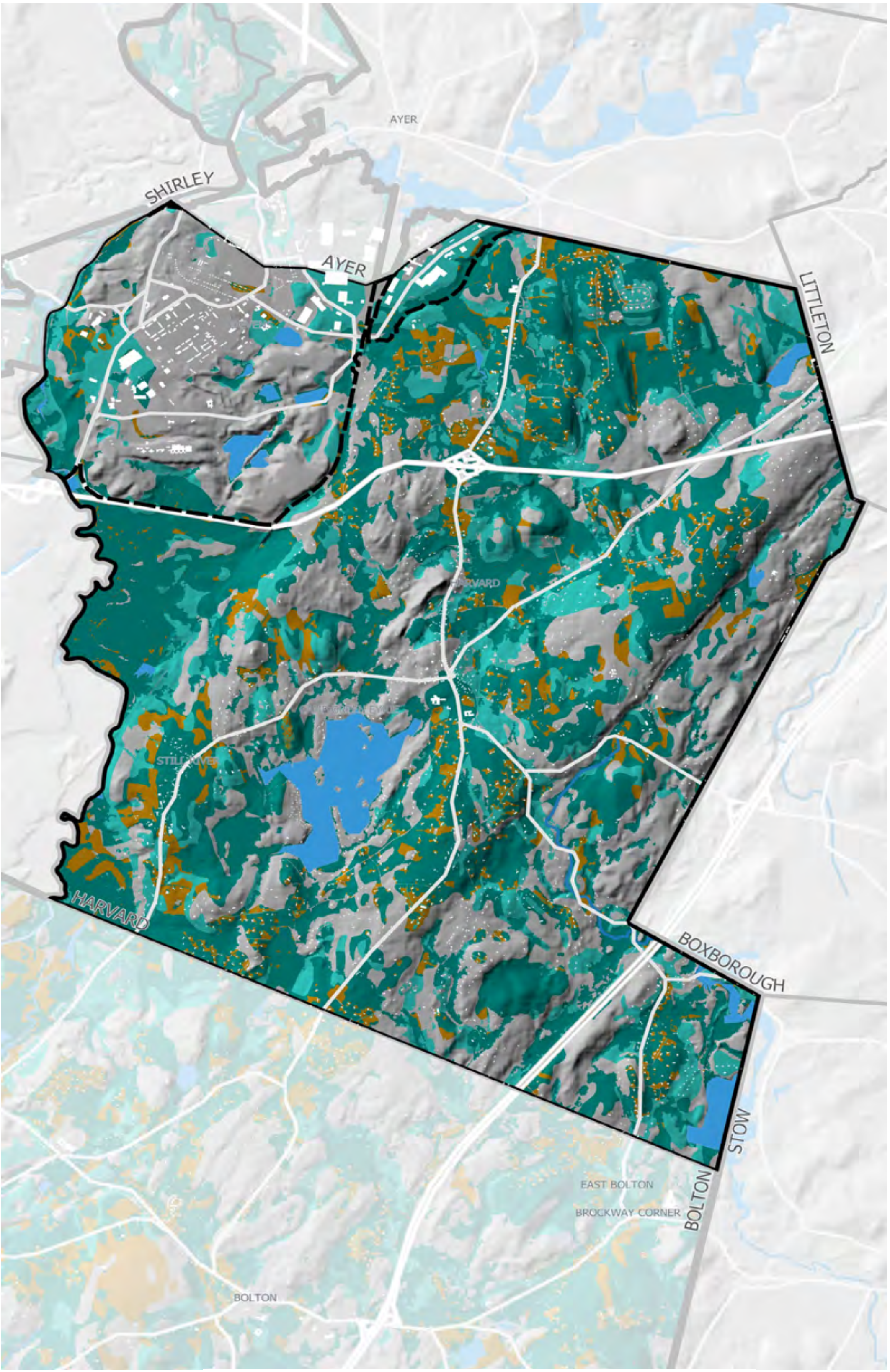
The consultant team used analysis and documentation of land cover, soil carbon stocks, land degradation potential, and soil type to create a new way of looking at land in Harvard. Figure 4.4, *High Value Soil Resources for Harvard* (next page), shows specific areas of Harvard have high soil conservation value, moderate conservation value, lower conservation value, and areas of high regeneration opportunity. The areas classified as having high or moderate conservation value are places with high SOC stocks and/or soils that have been designated as prime farmland. These soils must be protected to avoid significant carbon emissions through disturbance or conversion and loss of ecological ecosystem services and agricultural production capacity. *Soils of lower conservation value* have lower soil organic carbon stocks, either naturally or due to irreversible development impacts. These are the places where conversion through development or other high-impact land uses would not result in large losses of carbon stocks. Areas with the classification of *high regeneration opportunity* are those places where restoration efforts such as reforestation, wetland restoration, and better land management practices, could result in gains of carbon stock and improved carbon sequestration rates.

This analysis and map were put together to aid the Town in defining zoning or developing bylaws to protect specific important areas and to encourage development or use change in less valuable locations. The map also helps identify areas to prioritize restoration or improved management practices. Overlaying additional layers that help illuminate the likelihood of development or identify networks of natural resources are some ways these maps could be used to aid in planning efforts.

Focusing conservation and regeneration efforts on increasing the size of and connectivity between larger patches of high-integrity natural resource areas is likely to provide the greatest benefit to soil health. Targeting more vulnerable soils like unforested floodplains for regeneration and better management are key ways to decrease soil vulnerability and increase resilience to climate change.

Harvard Agriculture

The Impact of Climate Change on Agriculture report for the Town of Harvard provides a series of recommendations, beginning with a recommendation to improve soil health in order to improve resilience to changes in precipitation patterns and temperatures and moving on with more specific actions for farmers to take, such as regular soil testing,



Map Descripton

Higher Soil Protection Priority = Wetlands or High SOC (LC16 adjusted >20k) or Prime Farmland

Lower Soil Protection Priority = Med SOC >15K or Farmland Of Statewide Importance

Regeneration Priority = High SOC (Pedon Adjusted >20k) and Reversible SOC Reducing Landcovers (Turf, Ag, Grasslands, Trees)

0 0.5 1 mi

N

Figure 4.4. **High Value Soil Resources for Harvard.** *A map of Harvard soils showing areas of priority for soil carbon maintenance as well as areas of low priority for soil carbon maintenance, along with areas where soils could be regenerated.*

Community Voices

"According to the last Massachusetts Agricultural Census (2017) about 68 % of all farms in the state have less than 50 acres and about a third of all farms even less than 10 acres. Small farms are more likely to use organic growing methods than large farms, and therefore soil quality and other environmental aspects benefit. However, when we talk about agriculture, environment and sustainability, the needs of small farms are largely overlooked. Squeezed between rising property tax, lack of access to state grants and other financial aid available to larger farms, and rising costs, operating a small farm gets more difficult by the day. This affects the entire community, not just the farmer. Last summer, during the pandemic residents of our towns enjoyed buying fresh produce locally, at established farm stores but also at small roadside farm stands...Land...may be lost as green pastures, for growing vegetables or as orchards if the farmers can't continue and must sell the land. If we are serious about protecting land and agriculture, then more must be done by the state and local communities to save small farms."

- Christiane Turnheim, Farmer, Agriculture Advisor Commission, & Community Resilience Working Group, Harvard, MA

integrated pest management, and researching more robust cultivars.

This Apple Country Natural Climate Solutions report looks more deeply into soil health as a driver of productivity and a tool for enhancing resilience on farms, especially orchards. Based on discussions during this project, soil health is not of primary interest among growers. However, the structure of orchards is suited to enhancing soil health and soil carbon in the long term. Adding organic soil amendments, tracking soil carbon, and building up soil are well suited to perennial crops that involve no tilling.

Harvard Forests

Land cover change between 2011 and 2016 was estimated from NLCD data (Figures 4.5, 4.6). The most significant losses of forest were to grassland and non-forested wetland, with only a small loss to development. The most significant gains of forest land were from grassland and non-forested wetland. The forest-wetland transitions were approximately in balance, suggesting that small changes in the area of tree cover caused the remote sensing classifications to shift between these two cover types. The Massachusetts Department of Environmental Protection (MassDEP) found that conversion of forested wetlands to shrub swamp or marsh during the 1990 to 2017 time period was largely driven by beaver activity and also found that losses of wetlands due to human activity were largest for forested wetlands (Rhodes *et al.* 2019). Other causes for shifts from forest to non-forested wetland could result from damaging wind or ice storms or other causes of tree damage or death. Forest increases could result from tree planting or from trees growing larger and having greater canopy area.

More land shifted from grassland to forest than from forest to grassland. Overall, the total area of forest increased by 91 acres over the inventory period.

The average canopy area of trees outside forests in Harvard varies significantly by land cover class (Figure 4.7). Developed areas have the largest area of tree cover at about 1,000 acres. The percent cover by tree canopy is also greatest for developed areas at about 55%. The other non-forest land classes have around 10% tree canopy cover, and the average tree cover for all non-forest land classes is about 33%. These estimates represent the average area of tree canopy over the inventory period of 2011-2016,

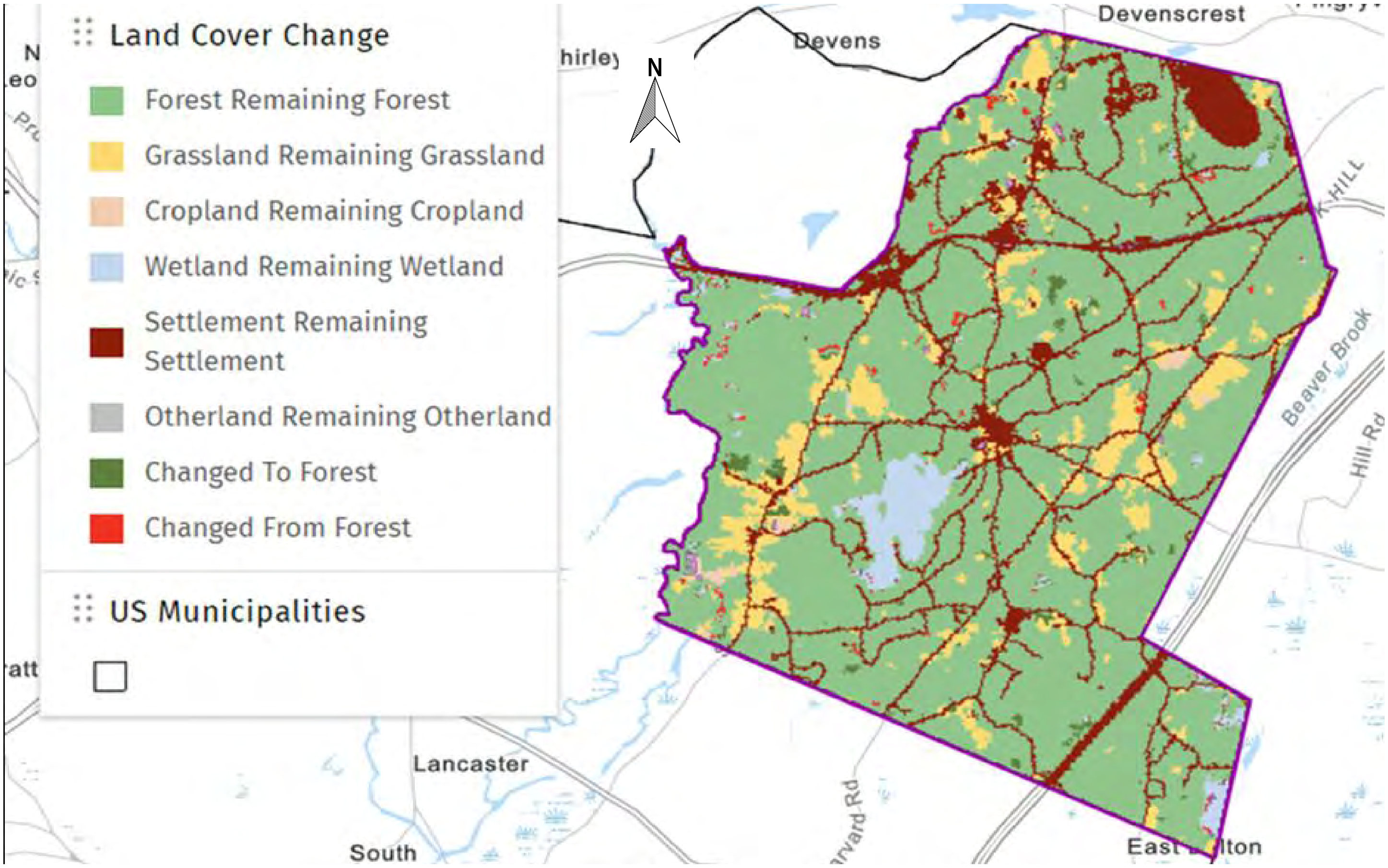


Figure 4.5. ***Areas of forest converted to non-forest from 2011-2016 based on NLCD data, Harvard***

which includes trees that were established before 2011 and trees that were established during the inventory period. The area of tree canopy loss during the inventory period was relatively small, only 7 acres according to the NLCD data, of which most of the loss was in grassland.

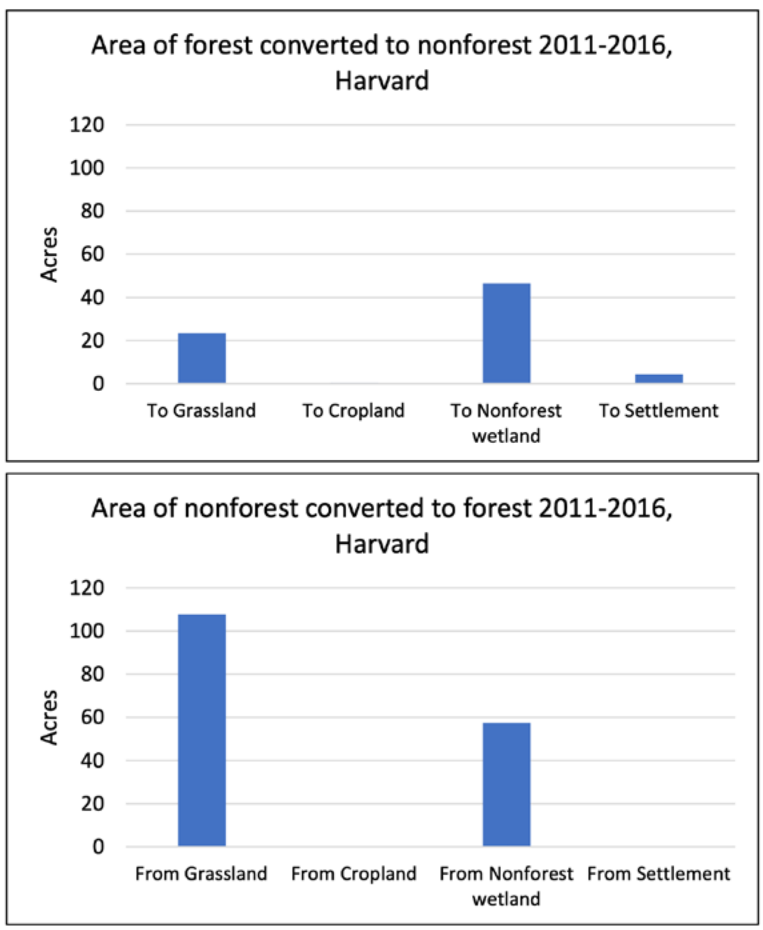


Figure 4.6. ***(right) Areas of forest converted to non-forest from 2011-2016 based on NLCD data, Harvard***

Because of the relatively coarse 30-m resolution of NLCD data, the area of tree canopy was also estimated using high-resolution aerial photography and the i-Tree CANOPY software. These estimates were applied to the 3-m resolution Mass-GIS areas of land cover rather than the NLCD estimates. Based on this analysis, the average tree canopy of non-forest land in Harvard was 73%, significantly larger than the 33%

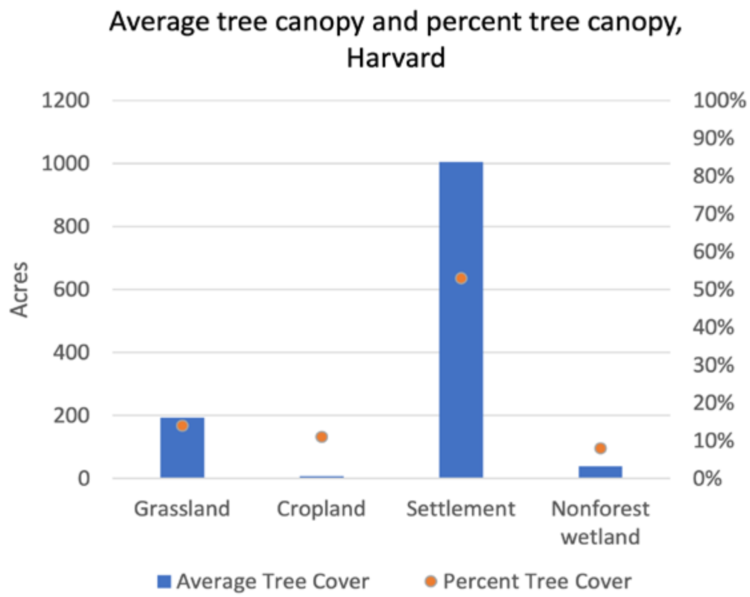


Figure 4.7. **(above) Average tree canopy area and percent tree cover of non-forest land based on NLCD data for Harvard, 2011-2016.**

Table 4.2. **Net CO2 balance of forests and trees outside forests of Harvard, 2011-2016**

Source	Removals (t CO_2e/year)	Emissions (t CO_2e/year)
Undisturbed Forest	-27,195	
Disturbance fire		0
Disturbance insect/ disease		0
Disturbance harvest/ other		1,261
Non-Forest to Forest	-488	
Forest to Cropland		2
Forest to Grassland		359
Forest to Non-forest Wetlands		731
Forest to Developed		106
Forest to Other Non-Forest		0
Trees outside of Forests	-14,006	1,325
Harvested wood products	0	
TOTAL	**-41,689**	**3,784**
Net GHG Balance	**-37,904**	

estimate based on NLCD alone. The area of tree canopy loss over the inventory period based on the higher-resolution data was 37 acres instead of 7 from the NLCD data. The tree canopy estimates based on the higher-resolution data sets are used in the next section for calculating the net CO_2 emissions associated with trees outside forests.

Forests and trees outside forests of Harvard were a net sink of -37,904 metric tons CO_2/yr from 2011 – 2016 (Table 4.2). Removals of CO_2 from the air were much higher than emission of CO_2. Undisturbed forests and trees outside forests (primarily in developed areas) represented the largest quantity of removals. The largest sources of emissions from forests and trees outside forests were loss of tree canopy of trees outside forests (1,325 metric tons CO_2/yr) followed by harvesting, conversion of forests to non-forested wetlands and grasslands, and conversion of forests to development.

Harvard Wetlands

Within Harvard, there are a number of wetlands, streams, and vernal pool/ponded resource areas. The MassGIS 2016 Land Cover/Land Use dataset was used to summarize the presence of wetlands in Harvard. This land cover data was derived from NOAA's Coastal Change Analysis Program (C-CAP). Figures 4.8 and 4.9 below, in Appendix 4 and on the project website dataviewer show the location and extent of wetland resource areas, aquatic features and the major watershed boundaries in Harvard. More information on how the MassGIS 2016 data was summarized into different land cover classifications used for this analysis can be found online at: https://docs.digital.mass.gov/dataset/massgis-data-2016-land coverland-use.

Harvard is located within the Nashua River, Concord River, and Merrimack River watersheds. Wetlands in Harvard therefore contribute to the hydrology of two large river systems (Nashua River and Concord River) that then join the Merrimack River miles apart from one another. The Still River joins the Nashua River in the southwest corner of Harvard in the MassWildlife Bolton Flats Wildlife Management Area. The Nashua River and Still River and their riparian corridor contain many of the wetland resource areas, and connect Harvard to upstream and downstream communities, including Bolton and Devens. The U.S. Fish and Wildlife Service Oxbow National Wildlife Refuge includes extensive wetlands and Nashua River floodplain on the west side of Harvard. Bowers Brook flows through the center of Harvard and through Bare Hill Pond, connecting Harvard to Bolton and Devens. The MassWildlife Delaney Wildlife Management Area and Flood Control Project (Delaney), an area with extensive wetlands, floodplain and vernal pools, provides wildlife habitat and flood storage for Elizabeth Brook, a tributary to the Assabet River that eventually joins the Concord River. Delaney is a highly valued recreational resource offering recreational activities including hiking, mountain biking, bird watching, horseback riding, ice skating and ice fishing, canoeing and fishing, cross-country skiing, dog walking and more. Harvard's extensive wetland resources are significant and important contributors to biodiversity/wildlife habitat, carbon sequestration and climate resilience. There are approximately 2,928 acres of

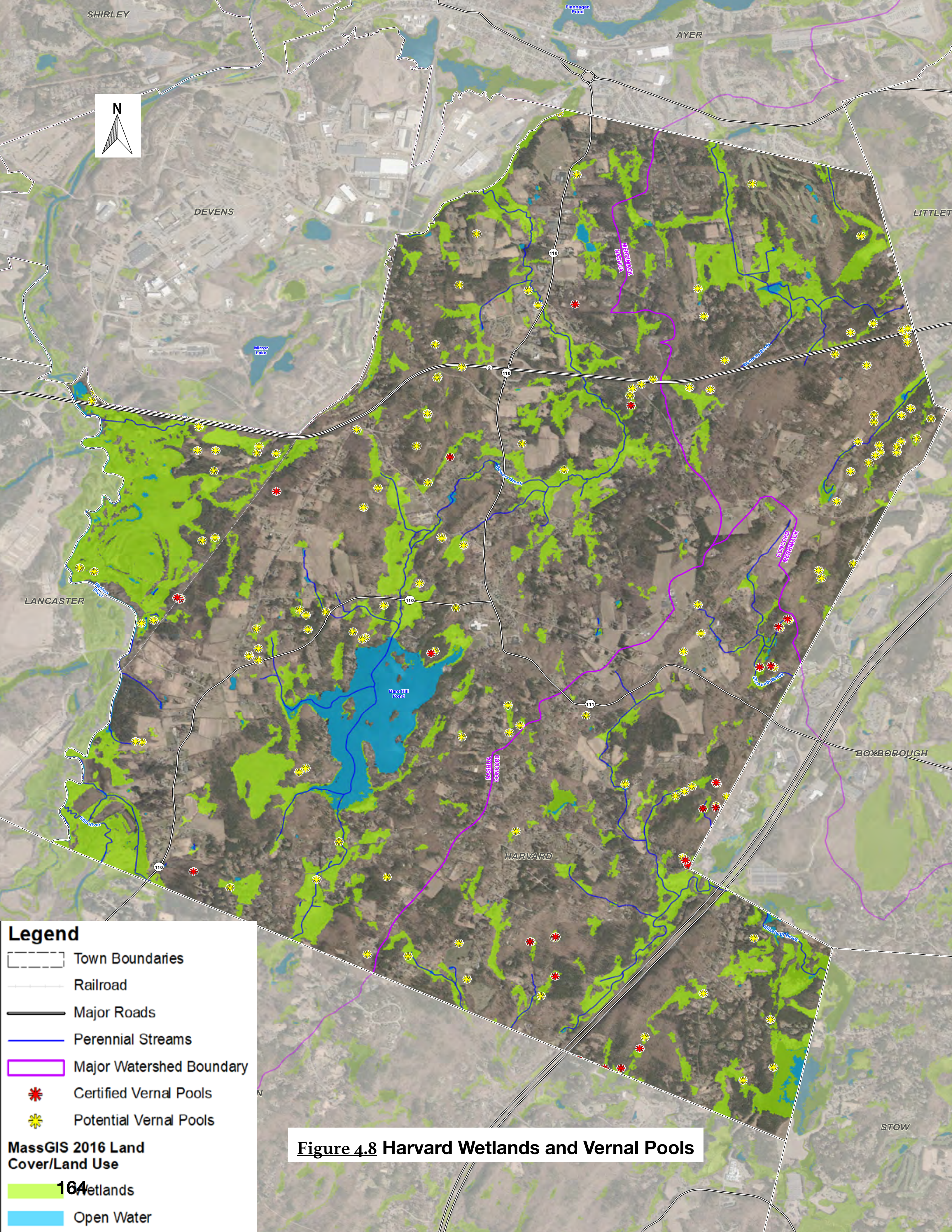


Figure 4.8 Harvard Wetlands and Vernal Pools

wetlands, streams/river corridors, and ponds located within Harvard. Harvard is approximately 14,678.5 acres in total land size. Therefore, the mapped wetlands provided in the MassGIS Land Cover/Land Use data layer make up approximately 19.9% of the total land area and hold 29.3% of the total soil organic carbon of the town. The wetlands are summarized using the classifications established by the C-CAP Program.

The summary of the wetlands located within the **Town of Harvard** is shown in Table 4.3 below.

Table 4.3 **Wetland classifications of Harvard**

Wetland Classification	Area (Acres)	SOC Stocks (metric tons)
Palustrine Aquatic Bed	88.6	7,346
Palustrine Emergent Wetland	655.4	135,585
Palustrine Forested Wetland	1,653.2	220,103
Palustrine Scrub/ Shrub Wetland	146.2	25,181
Unconsolidated Shore	0.1	3
Water	384.7	5,532
Total	**2,928.2**	**393,750**

Rivers and Streams

The Nashua River and its riparian corridor contain many of the wetland resource areas in the town. In addition, Bowers Brook flows from Bolton through Harvard, joining Cold Spring Brook as it flows into Devens. Along with the Nashua River and its tributary the Still River, the Bowers Brook/Cold Spring Brook system serves as a hydrologic corridor and connection between these three communities, supporting a variety of wetland types. As mentioned above,Elizabeth Brook flows through Delaney, where a flood control impoundment has created a large, shallow pond.

Swamps and Marshes

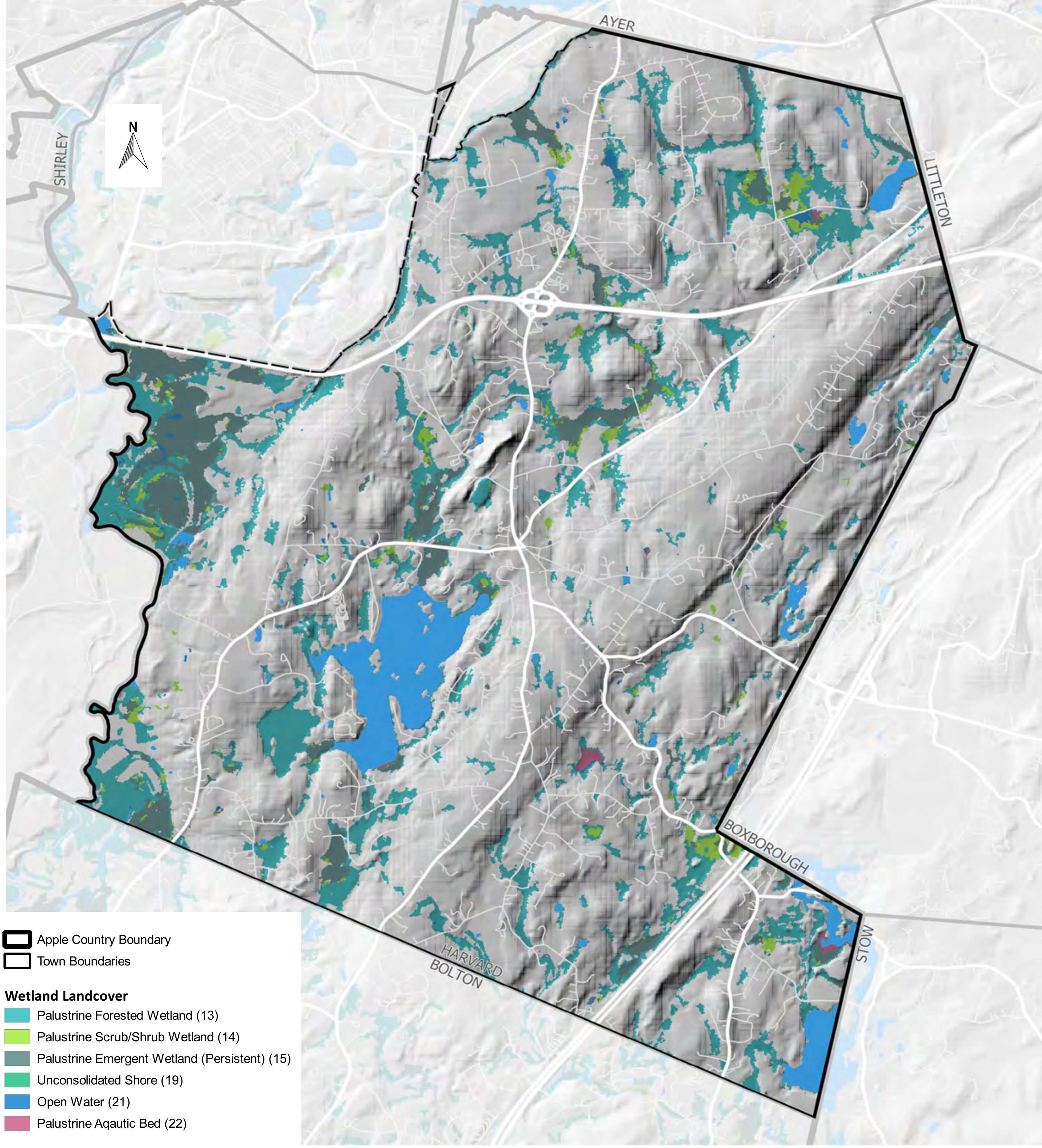
Forested wetlands make up the majority of the wetlands (56.5%) located within the town with approximately 1,653.2 acres. Scrub-shrub wetlands, marshes and bogs together make up approximately 890.2 acres in total.

Lakes and Ponds

Bowers Brook also flows through Bare Hill Pond, which is an impounded body of water. Bare Hill Pond is the largest open water wetland in town. The ponds component of Harvard's wetlands covers approximately 384.7 acres.

Vernal Pools

Harvard has 132 Potential Vernal Pools, and a total of 22 vernal pools that have been officially certified by the MA Division of Fisheries & Wildlife. The MassDEP vernal pool locations are shown on the Harvard Wetland and Vernal Pool Figure X above and in Appendix X.



Map Descripton

This map shows the Wetland Landcover C-CAP classes from the Mass GIS 2016 High Resolution Landcover Dataset

Figure 4.9. ***Wetland land cover types, Harvard***

Harvard Recommendations

Site-Specific Nature Based Solutions

Core Team Meetings and Site Visit Summary

Harvard community representatives participated in four Core Team meetings (detail on these meetings can be found in Appendix 1). At the second meeting, Harvard representatives were tasked with identifying locations where Nature-based Solutions could protect, restore, or enhance ecological resilience. A site walk was held on December 10th to assess 11 locations throughout Harvard. At the third Core Team meeting, participants discussed observations from the site walk and potential recommendations for each location. Opportunities for Nature-based Solutions (NbS) in Harvard were varied and included seeking conservation status for parcels that would link existing pieces of conservation land, invasive species management activities, streambank restoration, tree and native species planting, and soil restoration. A summary of observations and analysis from the Harvard site walk and assessments follows.

Harvard NbS Site Walk Analysis and Reporting

A menu of planning level project descriptions (thumbnail project scopes and order of magnitude costs) are provided in the Opportunities Table and associated Memoranda and mapping (Appendix 12 and project website) that collectively indicate which NbS projects could be implemented in which locations within Harvard. Additionally, Appendix 12 provides a generalized outline of considerations for project planning and permitting. By implementing projects identified in the text and attachments that follow, cumulatively and over time, greater ecological function and climate resilience can be achieved in Harvard. Following the principles of ecological restoration, consideration of stressors and disturbance to the natural function of rivers, lakes, ponds, wetlands, forests and associated soils and floodplains is a key component for this analysis. Discussion of potential NbS and climate resilience enhancement opportunities is provided below.

Oak Hill Conservation Areas and Neighboring Properties

The Oak Hill Conservation Areas and the neighboring properties include wooded uplands and wetlands, interspersed with residential properties, orchards, agricultural ponds and drainage, and the Harvard University observatory with its surrounding forest. Water for agriculture is from wells, soils are characterized by well drained sandy loam. Geographically, this area is located on a high plateau providing milder and more consistent growing conditions. Agricultural and residential cleared lands fragment forestlands. Invasive species occur in many locations. Climate legislation in Massachusetts calls for the creation of a carbon fund that will potentially be able to pay farmers (including orchards) for ongoing practices that add organic carbon to the soil.

Potential NbS in this location include:

- Invasive species management (Bittersweet (*Celastrus orbiculatus*) vine, monitor for Tree of Heaven (*Ailanthus altissima*))
- Forest - shrubland heath management or restoration
- Habitat and meadow enhancements/ pollinator or hedgerow strips
- Shade-habitat/ infiltration street tree plantings
- Species crossing protections
- Conservation purchase/ restriction
- Public - private partnership (agro-business land management that increases and protects habitat/pocket-forest-woodlot or pasture)
- Resilient redevelopment incentive
- Green energy features (terrain may serve wind farming)

Black Pond to High Ridge Conservation Areas

This area includes forest, pasture, and agricultural lands with single and clustered residences. Geographically, this area is defined by steep hillsides and cliffs above broad flats dominated by agriculture. A pond, its associated adjacent wetland, and Elizabeth Brook follow the foot of the steep ridgeline to the west below Oak Hill and Shaker Hills. The stream is partly channelized and crossed by multiple driveways. Soils are characterized by rocky hillsides and well drained sandy loam in the valley. The forests are split by agricultural and residential cleared lands. New residential developments include invasive tree of heaven (*Ailanthus altissima*), which hosts the spotted lantern fly (*Lycorma delicatula*), which is a threat to orchards and forests in the vicinity. Portions of the agricultural land here are under development restrictions and efforts should be emphasized to prevent future residential development on developable agricultural land.

Potential NbS in this location include:

- Invasive species management
- Grassland meadow management restoration
- Wetland management restoration
- Habitat enhancements/ pollinator or hedgerow habitat strips
- Educational interpretation
- Conservation purchase/ restriction
- Public - private partnership (agro-business land management that increases and protects habitat/pocket-forest-woodlot or pasture)
- Resilient redevelopment incentive
- Create post-development guidelines for soil management and enhancement to increase soil health where there has been development and decrease invasive species pressure.

Shaker Hills and Bennett's Brook (North)

This area includes pine forests, residences, a golf course, and wetlands. The wetlands and associated streams follow the foot of the steep ridgeline to the east below Shaker Hills. The stream was channelized for agricultural drainage, and soils are characterized by rocky hillsides and sandy loam in the valley. This area includes historic homes, but very little agricultural land remains open. To the north road elevations are very close to water levels.

Potential NbS in this location include:

- Habitat enhancements
- New wetland or floodplain construction/ expansion
- Stream flow alteration (increase sinuosity)
- Species monitoring protocol
- Upstream BMPs rain garden, bioswale etc.
- MA Stream Crossing Standards (MSCS)/ future storm capacity culvert improvement
- Educational interpretation
- Conservation purchase/ restriction
- Connect wetland areas together and protect wetland soils by adding interstitial wetland areas to conservation land.

Shaker Hills and Bennett's Brook (South)

This area includes old, south facing pastures on the eastern hill, and flats with significant wetlands surrounding the southern and western edges where the stream crosses the road. This area is prone to flooding including damage to historic structures. Soils are characterized by deep loam in the valley. Rock fences and wide shoulders provide a swale and buffer between the road, wetland, and fields. This area also includes a fire pond, which if modified and enhanced, could provide habitat co-benefits. Unfortunately, this area is also occasionally flooded or affected by beaver activity.

Potential NbS in this location include:

- Invasive species management
- River/ pond bank revegetation
- Habitat enhancements
- New wetland or floodplain construction/ expansion/restoration
- Stream flow alteration
- Species monitoring protocol
- Pollinator/Hedgerow habitat strips
- Shade-habitat/Infiltration tree plantings
- MA Stream Crossing Standards/future storm capacity culvert improvement.

Old Mill Road Mill Pond / Bowers Brook

This area includes the dammed mill pond at Bowers Brook surrounded by forests. Old Mill Road crosses the brook at a bridge (reconstruction pending). A wetland and riparian floodplain corridor occurs downstream from the bridge. The area between the dam and the bridge includes multiple eroded channels. Bank erosion protection could be installed, along with riverbank plantings. A fish by-pass/ladder system could also be installed. The adjacent culvert could be improved to accommodate future storm flows and meet MA Stream Crossing Standards.

Potential NbS in this location include:

- Invasive species management
- Stream flow alteration (add sinuosity to stream and bank stabilization)
- MA Stream Crossing Standards/future storm capacity culvert improvement
- Dam weir smart controls/fish bypass or fish ladder to get around the dam
- Beaver deceiver/ promoter
- Educational interpretation
- Public - private partnership
- Consider how to connect the whole of Bowers Brook wetland/brook to protect the high soil organic carbon wetland soils.

Depot Road Fields / Bowers Brook

This area includes the athletic fields (Ryan Land Park) on Depot Road. The Harvard Department of Public Works yard, some private residential properties, and an extensive network of conservation land and open space surround the athletic fields. The conservation land includes both upland forests and riparian corridor cover types along Bowers Brook. Along the field edges, invasive plant species are established, which could spread further and negatively impact the habitat quality of the surrounding conservation lands.

Potential NbS in this location include:

- Street tree plantings /shade habitat in open areas
- Habitat improvements/pollinator or hedgerow habitat strips
- Invasive plant species removal and management
- MA Stream Crossing Standards/future storm capacity culvert improvement
- Floodplain or wetland expansion/ construction
- Upstream BMPs along Depot Road (rain garden or vegetated bioswales)
- Species monitoring and study protocol in conservation land
- Adjust management of the turf area by mowing higher, leaving grass to mulch when possible, and applying compost or other natural soil amendments.
- Plant some trees at the parking edge of the field to provide shade and increase carbon sequestration in trees and soil.

Town Center
(Schools, Common, Cemetery)

The Harvard town center includes buildings and paved parking for commerce, municipal buildings (including schools and library), town greens, and a cemetery. Bare Hill Pond is located to the southwest of the town center. Bare Hill Pond is surrounded by intact forest, with some residential development present around the pond, and the watershed for the pond extends into the town center. Existing stormwater management in the area utilizes storm sewers and catch basins, which deliver water to the Bare Hill pond system. Existing impervious surfaces and stormwater management are important factors to consider when implementing NBS in the town center area. Invasive plant species were also observed throughout different areas of the forest surrounding Bare Hill Pond.

Potential NbS in this location include:

- Street tree plantings shade habitat in open areas
- Meadow habitat improvements/pollinator or hedgerow habitat strips
- Invasive plant species removal and management
- Pervious parking/paving
- Upstream BMPs along roadsides (rain garden or vegetated bioswales)
- Street tree and shade habitat enhancement
- This is a location for a coordinated effort to reclaim some areas that are currently roadways and regenerate the soil, add some turf and ornamental native plantings, and add some trees to create a new active landscape in place of roadways and cut grass. The coordinated effort might include the traffic triangles, some extra-wide turning areas, and other roadside areas.
- In conjunction with the meadow/habitat improvements above, reduce paved roadway areas and replace with native meadow and bushes, along with adding street tree planting
- Constructed Wetland and Town Forest Behind the Bromfield School;
- Initiate a forest management pilot project to try adjusting tree and undergrowth species to be more adapted to climate change, building lasting soil health, so that soil can better support the forest and ecosystem services.

See next page for graphical representation of potential Nature-based Solutions at this site.

Figure 4.10. **Rendering of potential Nature-based solutions in the vicinity of Harvard Town Center**

Still River Road / Bowers Brook

Bowers Brook adjacent to Still River Road flows through a forested riparian corridor, with some adjacent agricultural fields and light residential land uses. There are two culverts under Still River Road and Under Pin Hill Road that allow Bowers Brook to flow under the roads. Bowers Brook flows from Bare Hill Pond through a dam system, located south of Still River Road. Smaller field stone dams are present along the brook as well.

Potential NbS in this location include:

- New wetland or floodplain expansion
- Species monitoring protocols
- Conservation purchase/restriction
- Invasive plant species removal and management
- Upstream BMPs along roadsides (rain garden or vegetated bioswales)
- Resilient redevelopment incentive
- Pollinator or hedgerow habitat strips in fields.

USFWS Oxbow National Wildlife Refuge & Floodplain / Still River Depot Road

The US Fish and Wildlife Service (USFWS) Oxbow National Wildlife Refuge in this location is situated along the Nashua River, and it includes a broad network of braided channels within the floodplain/riparian corridor, and old oxbows and side channels. This location is a popular boat/canoe launch spot and popular with swimmers. The boat launch is adjacent to an active railroad line, which utilizes a bridge crossing over the Nashua River just south of Still River Depot Road. A second bridge crossing, adjacent to the boat launch, is now closed except for service access. The river corridor in this area is comprised of riparian forest, but adjacent land uses include residential and cleared fields/pasture for agricultural uses. The floodplain could be expanded and reforested in certain areas, and floodplain wetlands could be restored/created. The Conservation meadows may be an opportunity for combination stormwater and habitat enhancements off of Depot Rd.

Potential NbS in this location include:

- New wetland or floodplain expansion
- Grassland/meadow enhancement or restoration
- Pollinator or hedgerow habitat strips in fields
- Educational interpretation
- Forest expansion/tree planting
- Invasive plant species removal and management
- Upstream BMPs along road that tie into adjacent fields (rain garden or vegetated bioswales)
- Transform parking, rail crossing area, and road banks with soil amendments (compost) and native plantings, along with regrading to enable these areas to provide enhanced ecosystem services.

Pine Swamp at Bare Hill

Pine Swamp west of Bare Hill Pond is a large wetland complex, comprised of both forested and emergent wetland cover-types. The wetlands are surrounded by intact forest, but encroachment threatens the forest edges. Currently residential and agricultural land uses are located on the edge. Many of the parcels that make up Pine Swamp already have conservation land status, but additional parcels surrounding the swamp (that contain intact forest) are privately held. Species monitoring and habitat studies should be considered. The adjacent upland and wetland forests in this area should continue to be protected, and additional conservation land should be added when possible. This conservation area is highly valuable for soil health and long-term carbon sequestration. It would be useful to conserve areas around the Sprague land by acquisition or working with land-owners to protect and strengthen nearby forests over time, thereby strengthening the Pine Swamp forest.

Potential NbS in this location include:

- Educational awareness / habitat studies
- Invasive plant species removal and management
- Habitat enhancement
- Conservation purchase/restriction
- Public/Private partnerships
- Soft trails to improve forest access.

Bowers Brook at Woodside Road to West Bare Hill Road

Bowers Brook flows north into Bare Hill Pond in this location. Residential development encroachment has occurred on both sides of Bowers Brook in this area. As a result, there is limited continuous forest cover within the riparian corridor along the brook, and the upland forest adjacent to the brook is primarily comprised of a network of forest patches. More intact forest cover within the Bowers Brook riparian corridor, and located south of Woodside Road, is currently managed as conservation land. Water levels in the wetlands adjacent to Bowers Brook often overtop and flood roads during periods of high-water could be upgraded to meet future storm flows and MA Stream Crossing Standards.

Potential NbS in this location include:

- Educational and awareness
- Invasive plant species removal and management
- Habitat enhancement
- Conservation purchase/restriction
- Public/Private partnerships
- Upgrade culverts to meet future storm flows and MA Stream Crossing Standards
- Create educational materials to help adjacent landowners to build soil health, reduce invasive plants, and work to protect the wetland areas.

Elizabeth Brook at Stow Road

Elizabeth Brook at Stow Road is adjacent to, and west of, Interstate 495. Elizabeth Brook flows through undersized culverts beneath the interstate. Residential developments along Stow Road and Jacob Gates Road have encroached on the Elizabeth Brook forested riparian corridor. South of these roads, conservation land includes more intact forest cover. Privately owned parcels are located south of Stow Road, adjacent to the brook. Culverts at roads and driveways could be upgraded to meet future storm flows and MA Stream Crossing Standards Invasive species could be replaced and managed, along roadsides.

Potential NbS in this location include:

- Educational and awareness
- Upstream BMPs along roadsides (rain garden or vegetated bioswales)
- Invasive plant species removal and management
- Habitat enhancement
- Conservation purchase/restriction
- Public/Private partnerships
- Upgrade culverts to meet future storm flows and MA Stream Crossing Standards.

Horse Meadow Knoll & Reservoir at Sherry Road

Horse Meadow Knoll and Horse Meadow Pond Reservoir are part of an existing open space and conservation land network that contains public walking trails. Intact forest surrounds Elizabeth Brook, but encroachment from private and public housing, public utility infrastructure, and agricultural land uses currently exist on the forest edges. Elizabeth Brook flows through a culvert under Sherry Road. Wetland and floodplain expansion of Elizabeth Brook could reduce downstream flooding concerns adjacent to public housing buildings.

Potential NbS in this location include:

- Upstream BMPs along roadsides (rain garden or vegetated bioswales)
- Meadow/grassland habitat enhancement (hedgerow/pollinator habitat strips)
- Conservation purchase/restriction
- Zoning overlay
- Public/private partnerships
- Upgrade culverts to meet future storm flows and MA Stream Crossing Standards
- Wetland expansion and management
- Initiate a forest management pilot project to try adjusting tree and undergrowth species to be more adapted to climate change, building lasting soil health, so that soil can better support ecosystem services.

Town-Wide Harvard Recommendations

In addition to recommendations provided in the Regional Recommendations Section of this report, the following Harvard specific recommendations are provided. It is recommended that readers review the Regional Recommendations Section as well as the information below.

Key Nature-Based Solutions

Harvard Town Center. The Harvard town center has great potential to incorporate NbS. The concentration of municipal and private buildings, paved parking areas, paved roads, and public open space all within close proximity to the forested watershed around Bare Hill Pond, would allow for the incorporation of NbS with positive effect. Appropriate NbS could include: Educational interpretation features, Green energy, Green Architecture, pollinator or hedgerow habitat strips added to town greens, pocket forest cover, roadside vegetated stormwater bioswales/rain gardens, pervious paving, and educational opportunities. Connectivity to the Bare Hill Pond forest and riparian area could be enhanced and expanded.

The soils in the area of the Town Center are noted as areas of high soil carbon, especially in the areas undisturbed by impervious cover, replacing some of the paved roadways with meadow and trees has the potential to greatly enhance the overall environmental quality of the Town Center and expand the ecosystem services provided right in the middle of town (see Figure X below).

Bowers Brook. Bowers Brook flows north through the Town of Harvard. There are many NbS opportunities and locations along the Bowers Brook stream corridor that would improve riparian and wetland habitat, habitat connectivity, reduce downstream flooding risks, and overall landscape resilience. There are multiple roads that cross Bowers Brook, and most of the crossings utilize undersized and outdated culverts. These culverts could be upgraded to accommodate future storm flows and meet

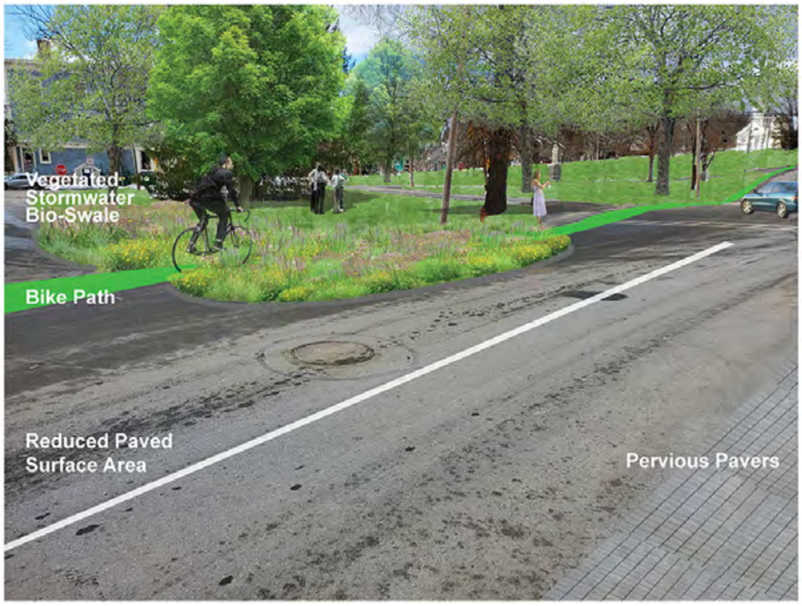


Figure 4.11 **Rendering of potential Nature-based Solutions in the vicinity of Harvard Town Center**

the MA Stream Crossing Standards, which would reduce flooding risk and improve habitat connectivity. Roadside BMPs, including vegetated bioswales, could be used to increase stormwater infiltration coming from paved roads. These BMPs treat and cool water before it flows into adjacent wetlands or streams. Adjacent residential areas and agricultural fields could increase their habitat potential and connectivity to the riparian corridor of Bowers Brook, through pocket forests or hedgerow/pollinator habitat strips. In select locations it may be possible to expand floodplains or encourage beaver activity to expand floodplains to increase the duration and scale of infiltration without impairing infrastructure.

Restore hydrologic connectivity. Throughout Harvard, substandard, undersized and failing culverts have been identified as being in need of replacement and upgrade. Outdated and failing culverts present an opportunity to implement stream crossing designs that meet the Massachusetts Stream Crossing Standards and are designed to accommodate predicted future stormwater flows, rather than being limited by outdated 20th century capacity that has the potential to place infrastructure and adjacent properties at risk. Placing a focus on this feature of the landscape will help address a variety of vulnerabilities throughout the community.

Conservation and Education. Throughout the Town of Harvard there are many locations and opportunities for the Harvard community to implement NbS and to provide education and interpretive media/signage that would help increase the use and understanding of NbS across the whole town. In addition, there is an existing strong network of conservation land located along riparian corridors and around wetlands. This conservation land could be expanded upon, and further conserved through private/public land partnerships, reduced development zoning overlays, or additional conservation land purchases.

Soils

Prioritization of high regeneration opportunity soils: Focusing conservation and regeneration efforts on increasing the size and connectivity between larger patches of high-integrity natural resource areas is likely to provide the greatest benefit to soil health. Targeting more vulnerable soils like unforested floodplains for regeneration and better management are key ways to decrease soil vulnerability and increase resilience to climate change. See page 159 for more about Priority Soils for Protection.

Conservation and Land Protection. Protect soil carbon stocks primarily in forested and wetland soils. For Harvard, the most important soils to conserve and protect are in forests and wetlands. These areas contain the largest stocks of soil carbon in Harvard and contribute the most to carbon sequestration. The distribution of both soil protection and soil regeneration priorities are shown in Figure 4.4, *High Value Soil Resources for Harvard*. Several areas of wetland have been identified in the material above, as high priority places for Harvard to protect in order to connect already conserved wetlands. By connecting currently protected wetlands, the integrity of the larger wetland systems, and their carbon pools and sequestration potential, can be safeguarded for future generations.

Better Land Management. Support and implement practices that improve sequestration of carbon in soil and thus improve soil-based ecosystem services, primarily on agricultural and ornamental lands. Harvard has approximately 1,488 acres of agricultural land and 1,109 acres of ornamental or turf lands, as shown in Table 4.1. In large part, these areas could benefit from improved management techniques. Along with the specific soil management recommendations shown for the locations visited during the site walks and tours, there are more general town-wide recommendations. Better turf management on both public and private lands can play a big role in increasing carbon sequestration potential on those lands. Higher mowing, mulching clippings, and regular application of organic soil amendments, at least for 3 to 5 years, will have immediate effects on turf health, water retention, and soil carbon levels. A management plan for turf and ornamental landscapes that could be shared with private landowners would aid in transitioning private land management practices.

While the primary emphasis for forests is conservation of existing carbon stocks, improved forest management practices can also increase forest health. Specifically, some of the conserved forests are less healthy than might be ideal, such as the Town Forest behind the Bromfield school (as noted above), which might benefit from a more active management plan. To maximize carbon sequestration and biodiversity, forests can be managed for old growth characteristics, including letting existing trees continue to grow whenever possible. In some situations, careful thinning to allow for tree regeneration can improve forest health. Wherever possible, allowing tree slash, snags, and stumps to remain in the forest enhances development of soil carbon and overall forest health. Careful small pilot planting projects to support forest transitions can enhance wildlife habitat value. These measures can build stronger and more resilient forests, protecting the soil resources from natural hazards. A management plan for forested areas that could be shared with private, conservation, and public landowners would aid in transitioning forest management practices.

Regeneration and Restoration. Support and implement actions that restore lost or degraded soil function and actions that regenerate soil function to higher levels, through implementation of natural climate solutions. There are locations in Harvard where specific restoration or regeneration actions could provide upgrades to carbon pools. The Town Center is a location where a coordinated plan for transformation of paved areas to native plantings, turf management focused on building soil health, and tree planting in specific areas could work to regenerate soil function and restore ecosystems services. Planting trees at the edges of playing fields would improve soil carbon levels and provide shade in those locations.

Outreach and Education. Advocate for beneficial changes to policies and programs at the State and Federal levels. Harvard could join with other municipalities in advocating for more and better technical support for farmers, and improved soil testing capabilities from the State. Advocating for a State carbon fund that would support better land management for forest and wetland owners and farmers would help conserve and enhance the soil functions of those land types. Advocating for inclusion of carbon functions and recognition of climate resilience functions in State and Federal level wetland regulations could lead to improved protection of wetland carbon and climate resilience ecosystem services, as could advocating for protection of forest carbon and climate resilience ecosystem functions.

Research and Data Collection. Support and implement research projects at the municipal level that could inform policies and actions and build knowledge of soil dynamics. Harvard has the opportunity to collect data on soil health and carbon content in the Town Center area to track the effects of any coordinated regeneration effort. This would be a great citizen science project for high school students nearby.

Orchards

Organic soil amendments to improve soil health and retain water: Orchards do not use any soil amendments unless there is some specific tree health need identified. A more generalized annual application of compost or other soil amendment to increase soil organic carbon would help the soil retain water, especially in drought years, and improve productivity.

Turning orchard trees that are removed into biochar and applying to soil*:* Orchards are not currently allowed to burn trees and stumps that have been removed on-site. One way to create soil amendments internally is to turn removed tree material into biochar and apply that to the soil.

Potential for carbon sequestration payments when Massachusetts institutes a carbon fund*:* Orchards are ideal land cover for management practices to increase soil carbon, since they are not regularly disturbed, but are closely managed. Climate legislation in Massachusetts calls for the creation of a carbon fund that will potentially be able to pay farmers (including orchards) for ongoing practices that add organic carbon to the soil.

Farms

- ***Create or Update Local Bylaws for siting ground mounted solar energy production facilities***.
    - Working Farms Provisions
    - Incentivize multi-use solar development on agricultural lands when it has clear benefits for farm viability and soil health

Create ***Prime Farmland Soils & High Carbon Soils Provisions***. Given the unique character and dynamics of Apple Country, this region could develop a pilot soil carbon market where Deven's industrial tenants voluntarily purchase carbon credits from participating farmers and forest owners in Harvard and Bolton, and from restoration efforts in Devens. This hyper-local strategy allows Devens to reduce its emissions, consistent with its 2020 CARP, by incentivizing good soil stewardship and improving economic viability on natural and working lands, and accelerating ecosystem restoration on degraded lands.

Forests

- ***Prioritize Conservation of Forests and Trees Outside of Forests.*** Reduce canopy loss from trees outside forests particularly in developed areas. Reducing the conversion of forest land to other land uses, and reducing harvesting of forests. Plant trees and facilitate natural regeneration of areas that are currently lacking tree cover. Improve the health and stocking of existing forests through improved silviculture and proactive pest management.

Wetlands and Floodplains

- ***Prioritize Conservation and Restoration of Floodplains and Wetlands***. Harvard's highest-functioning ecosystems are often concentrated along riparian corridors, floodplains and in wetlands (as well as in forests). These areas are often ranked the highest on maps (See Appendix 4 and website data viewer) of ecological climate resilience, ecosystem carbon storage and sequestration, wildlife habitat/biodiversity value, and delivery of other ecosystem services. These areas should be prioritized for conservation and ecological restoration.

- ***Restore wetland buffers*** by planting native trees and shrubs, to serve as buffers for nearby wetlands, as well as other types of wetland//floodplain restoration, reforestation and tree planting, and restoration of ecological and hydrologic connectivity, including improvement of culverts to meet Massachusetts stream crossing standards and accommodate future storm events.

- ***See Regional Recommendations*** for recommendations pertaining to updating the Harvard Wetland Protection Bylaw and associated Wetland Protection Bylaw Rules and implementation of Best Management Practices as they pertain to wetlands.

REFERENCES

Ament R., Callahan R., McClure M., Reuling M., and Tabor G. 2014. Wildlife Connectivity: Fundamentals for conservation action. Center for Large Landscape Conservation. Bozeman, Montana.

Anderson M.G., Barnett A., Clark M., Ferree C., Olivero Sheldon A., Prince J. 2016a. Resilient Sites for Terrestrial Conservation in Eastern North America. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, Massachusetts.

Anderson M.G., Barnett A., Clark M., Prince J., Olivero Sheldon A., Vickery B. 2016b. Resilient and Connected Landscapes for Terrestrial Conservation. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, Massachusetts.

Association of State Wetland Managers. 2015. Wetlands and Climate Change: Considerations for Wetland Program Managers. Windham, Maine.

Bradshaw C.J.A., Ehrlich P.R., Beattie A., Ceballos G., Crist E., Diamond J., Dirzo R., Ehrlich A.H., Harte J., Harte M.E., Pyke G., Raven P.H., Ripple W.J., Saltré F., Turnbull C., Wackernagel M. and Blumstein D.T. 2021. Understanding the challenges of avoiding a ghastly future. Frontiers in Conservation Science 1: 615419.

Bronick, C.J., and R. Lal. 2005. Soil structure and management: A review. Geoderma 124: 3-22.

Brooks R.T. 2005. A review of basin morphology and pool hydrology of isolated ponded wetlands: implications for seasonal forest pools of the northeastern United States. Wetlands Ecology and Management 13:335-348.

Brown O. 2008. Migration and Climate Change. International Organization for Migration. Switzerland.

Burne M.R. 2001. Massachusetts Aerial Photo Interpretation of Potential Vernal Pools. Natural Heritage & Endangered Species Program, Massachusetts Division of Fisheries & Wildlife. Westboro, Massachusetts.

Burne M.R. and Griffin C.R. 2005. Habitat associations of pool-breeding amphibians in eastern Massachusetts. Wetlands Ecology and Management 13:247-259.

Cartwright J., Grant E., and Morelli T.L. Mapping Climate Change Resistant Vernal Pools in the Northeastern U.S. USGS Technical Report.

Catanzaro P., D'Amato A., Huff E.S. 2016. Increasing Forest Resiliency for an Uncertain Future. University of Massachusetts Amherst, USA.

Chmura G.L., Anisfeld S., Cahoon D., Lynch J. 2003. Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical Cycles 17:22.1-22.12. doi:10.1029/2002GB001917

Cowardin, L.M., Carter, V., Golet, F.C., and LaRoe, E.T. 1979. Classification of Wetlands and Deepwater Habitats of the United States, FWS/OBS-79/31, Reprinted 1992, U.S. Fish and Wildlife Service, Washington, D.C.

Dahl T.E. 2011. Status and Trends of Wetlands in the Conterminous United States 2004 to 2009. U.S. Department of the Interior, Fish & Wildlife Service. Washington, D.C.

Davidson N.C. 2014. How much wetland has the world lost? Long-term and recent trends in global wetland areas. Marine and Freshwater Research 65:936-941.

Davidson N.C. and Finlayson C.M. 2018. Extent, regional distribution and changes in area of different classes of wetland. Marine and Freshwater Research 69:1525-1533.

Davidson N.C. and Finlayson C.M. 2019. Updating global coastal wetland areas presented in Davidson and Finlayson (2018). Marine and Freshwater Research 70:1195-1200.

Davidson N.C., Dinesen L., Fennessy S., Finlayson C.M., Grillas P., Grobicki A., McInnes R.J. and Stroud D.A. 2020. Trends in the ecological character of the world's wetlands. Marine and Freshwater Research 71:127-138.

Davies G.T., Kaplan M.G., Spokas M., and Toohill M. 2019. Enhancing wetland climate change resiliency and carbon mitigation on ROW Projects. Environmental Concerns in Rights-of-Way Management 12th International Symposium. Utility Arborist Association.

Davies G.T., Finlayson C.M., Pritchard D.E., Davidson N.C., Gardner R.C., Moomaw W.R., Okuno E. and Whitacre J.C. 2021. Towards a Universal Declaration of the Rights of Wetlands. Marine and Freshwater Research 72:593-600. https://doi.org/10.1071/MF20219.

Deutsch C.A. et al. 2018. Increase in crop losses to insect pests in a warming climate. Science doi/10.1126/science.aat3466.

Donahue Institute Online Mapping Tool. (http://www.pep.donahue-institute.org/) Accessed 13 April 2021.

Dupigny-Giroux L.A., Mecray E.L., Lemcke-Stampone M.D., Hodgkins G.A., Lentz E.E., Mills K.E., Lane E.D., Miller R., Hollinger D.Y., Solecki W.D., Wellenius G.A., Sheffield P.E., MacDonald A.B., and Caldwell C., 2018. Northeast. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., Avery C.W., Easterling D.R., Kunkel K.E., Lewis K.L.M., Maycock T.K., and Stewart B.C. (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 669–742. doi: 10.7930/NCA4.2018.CH18

Erwin K.L. 2009. Wetlands and global climate change: The role of wetland restoration in a changing world. Wetlands Ecology and Management 17:71–84. doi: 10.1007/s11273-008-9119-1

Euliss N.H. Jr., LaBaugh J.W., Fredrickson L.H., Mushet D.M., Laubhan M.K., Swanson G.A., Winter T.C., Rosenberry D.O., and Nelson R.D. 2004. The Wetland Continuum: A conceptual framework for interpretive biological studies. Wetlands 24:448-458.

Fargione J.E., Bassett S., Boucher, T., Bridgham S.D., Conant R.T., Cook-Patton S.C., Ellis P.W., Falcucci A., Fourqurean J.W., Gopalakrishna T., Gu H., Henderson B., Hurteau M.D., Kroeger K.D., Kroeger T., Lark T.J., Leaveitt S.M., Lomax G., McDonald R.I., Megonigal J.P., Miteva D.A., Richardson C.J., Sanderman J., Shoch D., Spawn S.A., Veldman J.W., Williams C.A., Woodbury P.B., Zganjar C., Baranski M., Elias P., Houghton R.A., Landis E., McGlynn E., Schlesinger W.H., Siikamaki J.V., Sutton-Grier A.E., Griscom B.W. 2018. Natural climate solutions for the United States. Sci. Adv. 4:1-14 eaat1869.

Ferrare, K., Sargis G., and Janowiak M. 2019. Keep Forests Healthy. Cornell Cooperative Extension. Onondaga County, New York.

Finlayson C.M., Capon S.J., Rissik D., Pittock J., Fisk G., Davidson N.C., Bodmin K.A., Papas P., Robertson H.A., Schallenberg M., Saintilan N., Edyvane K., and Bino G. 2017. Policy considerations for managing wetlands under a changing climate. Marine and Freshwater Research 68: 1803-1815. doi:

10.1071/MF16244

Fleming B., Weller R., Lillehei,X., Hammaker Z., Li X., Wang Q., Jabs N., Zhang A., Darling A., Creager R., McCullough A.L., Billingsley, J.A. 2020. The 2100 Project: An Atlas for the Green New Deal. The McHarg Center. https://mcharg.upenn.edu/2100-project-atlas-green-new-deal Accessed 13 April 2021.

Foster D.R. 2017. Wildlands and Woodlands, Farmlands and Communities: Broadening the Vision for the New England. Harvard Forest, Harvard University.

Fuss S., Jones C.D., Kraxner F., Peters G.P., Smith P., Tavoni M., van Vuuren D.P., Canadell J.G., Jackson R.B., Milne J., Moreira J.R., Nakicenovic N., Sharifi A., and Yamagata Y. 2016. Research priorities for negative emissions. Environ. Res. Lett. 11. doi:10.1088/1748-9326/11/11/115007

Griscom B.W., Adams J., Ellis P.W., Houghton R.A., Lomax G., Miteva D.A., Schlesinger W.H., Shoch D., Siikamaki J.V., Smith P., Woodbury P., Zganjar C., Blackman A., Campari J., Conant R.T., Delgado C., Elias P., Gopalakrishna T., Hamsik M.R., Herrero M., Kiesecker J., Landis E., Laestadius L., Leavitt S.M., Minnemeyer S., Polasky S., Potapov P., Putz F.E., Sanderman J., Silvius M., Wollenberg E., and Fargione J. 2017. Natural climate solutions. PNAS 114: 11645-11650

Harriman, C.D. 2019. The Impact of Climate Change on Agriculture: Harvard, Massachusetts.

IPBES. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES Secretariat. Bonn, Germany.

IPCC. 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte V., Zhal P., Portner H.O., Roberts D., Skea J., Shukla P.R., Pirani A., Moufouma-Okla W., Pean C., Pidcock R., Connors S., Matthews J.B.R. Chen Y., Zhou X., Gomis M.I., Lonnoy E., Maycock T., Tignor M., Waterfield T. (eds.)]. Geneva: World Meteorological Organization), 32.

IPCC. 2019. Climate and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. [Shukla P.R., Skea J., Calvo Buendia E., Masson-Delmotte V., Portner H.O., Roberts D.C., Zhai P., Slade R., Connors S., van Diemen R., Ferrat M., Haughey E., Luz S., Neogi S., Pathak M., Petzold J., Portugal Pereira J., Vyas P., Huntley E., Kissick K., Belkacemi M., Malley J. (eds.)] https://www.ipcc.ch/report/srccl/ Accessed 13 April 2021.

Irmak S. 2016. Impacts of Extreme Heat Stress and Increased Soil Temperature on Plant Growth and Development. University of Nebraska-Lincoln Institution of Agriculture and Natural Resources.

Janzen H.H. 2016. The soil remembers. Soil Science Society of Americal Journal 80:1429-1432. https://doi.org/10.2136/sssaj2016.05.0143

Keddy P.A. 2010. Wetland ecology: principles and conservation. Cambridge University Press.

Kenney L.P. and Burne M.R. 2009. A Field Guide to the Animals of Vernal Pools. MA Division of Fisheries & Wildlife, Westboro, MA.

Kimmerer R.L. 2013. Braiding Sweetgrass. Milkweed Editions. Minneapolis, MN.

Kumari R., Kanta, de Sherbinin A., Jones B., Bergmann J., Clement V., Ober K., Schewe J., Adamo S., McCusker B., Heuser S., and Midgley A. 2018. Groundswell: Preparing for Internal Climate Migration. The World Bank. Pg 2.

Lal R. 2008. Carbon sequestration. Philosophical Transactions of the Royal Society B 363: 815-830.

Lawler J.J. 2009. Climate change adaptation strategies for resource management and conservation planning. Annals of the New York Academy of Sciences 1162:79–98. doi: 10.1111/j.1749-6632.2009.04147.x

Leibowitz, S.G. and Brooks R.T. 2008. Hydrology and landscape connectivity of vernal pools. Chapter 3, Calhoun A.J.K. and de Maynadier P.G. (eds.), Science and Conservation of Vernal Pools in Northeastern North America. CRC Press – Lewis Publishers, Boca Raton, FL.

Leverett R.T., Masino S.A. and Moomaw W.R. 2021. Older eastern white pine trees and stands accumulate carbon for many decades and maximize cumulative carbon. Frontiers in Forests and Global Change. doi: 10.3389/ffgc.2021.620450

Logan W.B. 1995. Dirt: The Ecstatic Skin of the Earth. Penguin Putnam Inc. New York.

Secretariat of the Convention on Biological Diversity. 2020. Global Biodiversity Outlook 5 – Summary for Policy Makers. Montreal, Quebec.

Lustgarten, Abrahm. 2020. https://www.nytimes.com/interactive/2020/07/23/magazine/climate-migration.html Accessed 13 April 2021.

Marsh D. 2008. Metapopulation viability analysis for amphibians. Animal Conservation 11:463-465.

Massachusetts Office of Energy and Environmental Affairs and the Adaptation Advisory Committee. 2011. Massachusetts Climate Change Adaptation Report. Boston, Massachusetts.

McElfish J.M., Jr, Kihslinger R.L., Nichols S.S. 2008. Planner's Guide to Wetland Buffers for Local Governments. Environmental Law Institute. Washington, D.C.

Mildrexler D.J., Berner L.T., Law B.E., Birdsey R.A. and Moomaw W.R. 2020. Large trees dominate carbon storage in forests East of the Cascade Crest in the United States Pacific Northwest. Frontiers in Forests and Global Change. 3:594274. Doi: 10.3389/ffgc.2020.594274

Moomaw W.R., Chmura G.L., Davies G.T., Finlayson C.M., Middleton B.A., Natali S.M., Perry J.E., Roulet N. and Sutton-Grier A.E. 2018. Wetlands in a changing climate: Science, policy and management. Wetlands 38:183-205.

Moomaw W.R., Law B.E., Goetz S.J. 2020. Focus on the role of forests and soils in meeting climate change mitigation goals: Summary. Environmental Research Letters 15:045009. Doi.org/10.1088/1748-9326/ab6b38

Moomaw W.R., Masino S.A. and Faison E.K. 2019. Intact forests in the United States: Proforestation mitigates climate change and serves the greatest good. Front. For.

Glob. Change 2:27| https://doi.org/10.3389/ffgc.2019.00027

Nahlik A.M., Fennessy M.S. 2016. Carbon storage in US wetlands. Nature Communications 7:13835 1-6. doi:10.1038/ncomms13835

Nash R.F. 1989. The Rights of Nature, a History of Environmental Ethics. The University of Wisconsin Press; Madison, Wisconsin.

National Academies of Sciences, Engineering, and Medicine. 2018. Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. doi: https://doi.org/10.17226/25259.

NHESP Classification of the Natural Communities of Massachusetts. Appendix 1: NHESP Priority Types of Natural Communities. https://www.mass.gov/doc/nhesp-priority-natural-communities/download. Accessed 16 February 2021.

NHESP Classification of the Natural Communities of Massachusetts. Spruce-Tamarack Bog Community. https://www.mass.gov/files/documents/2016/08/wh/spruce-tamarack-bog-fs.pdf. Accessed 16 February 2021.

NHESP Classification of the Natural Communities of Massachusetts. Level Bog Community. https://www.mass.gov/files/documents/2016/08/wi/level-bog-fs.pdf. Accessed 16 February 2021.

Neubauer S.C. 2014. On the challenges of modeling the net radiative forcing of wetlands: Reconsidering Mitsch et al 2013. Landscape Ecology 29:571-577 doi: 10.1177/1077558711435365

Neubauer S.C. and Megonigal J.P. 2015. Moving beyond global warming potentials to quantify the climatic role of ecosystems. Ecosystems 18:1000-1013 doi: 10.1007/s10021-015-9879-4

Nobre A.D. 2014. The Future Climate of Amazonia, Scientific Assessment Report. Sponsored by CCST-INPE, INPA and ARA. Sao Jose dos Campos, Brazil. https://d2ouvy59p0dg6k.cloudfront.net/downloads/the_future_climate_of_amazonia_report.pdf. Accessed 13 April 2021.

Northeast Climate Adaptation Science Center. 2018. Massachusetts Climate Change Projections – Statewide and for Major Drainage Basins: Temperature, Precipitation, and Sea Level Rise Projections. Massachusetts Executive Office of Energy and Environmental Affairs. https://resilientma.org/resources/resource::2152. Accessed 15 February 2021

Ontl, T.A., Janowiak M.K, Swanston C.W., Daley J., Handler S., Cornett M., Hagenbuch S., Handrick C., Mccarthy L., Patch N. 2020. Forest management for carbon sequestration and climate adaptation, Journal of Forestry. 118:86–101, https://doi.org/10.1093/jofore/fvz062

Podesta J. Undated. The Climate Crisis, Migration, and Refugees. Brookings. https://www.brookings.edu/research/the-climate-crisis-migration-and-refugees/. Accessed 13 April 2021.

Portner H.O., Scholes R.J., Agard J., Archer E., Arneth A., Bai X., Barnes D., Burrows M., Chan L., Cheung W.L., Diamond S., Donatti C., Duarte C., Eisenhauer N., Foden Wl, Gasalla M.A., Handa C., Hickler T., Hoegh-Guldberg O., Ichii K., Jacob U., Insarov G., Kiessling W., Leadley P., Leemans R., Levin L., Lim M., Maharaj S., Managi S., Marquet P.A., McElwee P., Midgley G., Oberdorff T., Obura D., Osman E., Pandit R., Pascual U., Pires A.P.F., Popp A., Reyes-Garcia V., Sankaran M., Settele J., Shin Y.J., Sintayehu D.W., Smith P., Steiner

N., Strassburg B., Sukumar R., Trisos C., Val A.L., Wu J., Aldrian E., Parmesan C., Pichs-Madruga R., Roberts D.C., Rogers A.D., Diaz S., Fischer M., Hashimoto S., Lavorel S., Wu N., Ngo H.T. 2021. IPBES-IPCC co-sponsored workshop report on biodiversity and climate change. IPBES and IPCC. Doi: 10.5281/zenodo.4782538.

Ripple W.J., Wolf C., Newsome T.M., Galetti M., Alamgir M., Crist E., Mahmoud M.I. and Laurance W.F. 2017. World scientists' warning to humanity: A second notice. Bioscience 67:1026-1028.

Rhodes L., McHugh M., Gruszkos T. 2019. Inland and Coastal Wetlands of Massachusetts, Status and Trends. Massachusetts Department of Environmental Protection. Boston, MA.

Robinson C., Dilkina B., Moreno-Cruz J. 2020. Modeling migration patterns in the USA under sea level rise. PLoS ONE 15: e0227436. https://doi.org/10.1371/journal.pone.0227436

Secretariat of the Convention on Biological Diversity. 2020. Global Biodiversity Outlook 5 – Summary for Policy Makers. Montreal, Quebec.

Seddon N., Chausson A., Berry P., Girardin C.A.J., Smith A., Turner A. 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. Phil Trans R Soc B. 375: 20190120. http://dx.doi.org/10.1098/rstb.2019.0120

Seddon N., Smith A., Smith P., Key I., Chausson A., Girardin C., House J., Srivastava S., Turner B. 2021. Getting the message right on nature-based solutions to climate change. Global Change Biology 27:1518-1546 https://doi.org/10.1111/gcb.15513

Simard S.W., Perry D.A., Jones M.D., Myrold D.D., Durall D.M., and Molina R. 1997. Net transfer of carbon between ectomycorrhizal tree species in the field. Nature 388:579-582.

Song Y.Y., Simard S.W., Carroll A., Mohn W.W. and Zeng R.S. 2015. Defoliation of interior Douglas-fir elicits carbon transfer and stress signaling to ponderosa pine neighbors through ectomycorrhizal networks. Scientific Reports 5:8495 1-9.

Stone C.D. 2010. Should Trees Have Standing? Law, Morality, and the Environment. Oxford University Press: Oxford, UK.

Swanston C.W., Brandt L.A., Janowiak M.K., Handler S.D., Butler-Leopold P., Iverson L., Thompson F.R., Ontl T.A., and Shannon P.D. 2018. Vulnerability of forests of the Midwest and Northeast United States to climate change. Climatic Change 146:103–116.

Tate A.S. and Battaglia L.L. 2013. Community disassembly and reassembly following experimental storm surge and wrack application. Journal of Vegetation Science 24:46–57. doi: 10.1111/j.1654-1103.2012.01447.x

Tobin D., Janowiak M., Hollinger D.Y., Skinner R.H., Swanston C., Steele R., Radhakrishna R., and Chatrchyan A. 2015. Northeast and Northern Forests Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies. Anderson T. (ed.), United States Department of Agriculture.

United Nations. 2012. The Future We Want: Outcome Document of the United Nations Conference on Sustainable Development. Rio de Janeiro, Brazil.

United Nations. 2019. The Sustainable Development Goals Report. New York, N.Y.

United Nations. 2020. The Sustainable Development Goals Report. New York, N.Y. https://unstats.un.org/sdgs/report/2020/#sdg-goals

UNEP (United Nations Environment Programme). 2019. Emissions Gap Report 2019. United Nations Environment Programme, Nairobi, Kenya.

U.S. Environmental Protection Agency. 2016. National Wetland Condition Assessment 2011. Washington, D.C. https://www.epa.gov/sites/production/files/2016-05/documents/nwca_2011_public_report_20160510.pdf. Accessed 13 April 2021.

U.S. Global Change Research Program. 2018. Fourth National Climate Assessment. Washington, D.C. https://nca2018.globalchange.gov/. Accessed 13 April 2021.

Vepraskas M.J. and Craft C.B. (eds). 2015. Wetland Soils, Genesis, Hydrology, Landscapes, and Classification. Second Edition. CRC Press. Boca Raton, FL, USA.

Wohlleben P. 2016. The Hidden Life of Trees. Greystone Books. British Colombia, Canada.