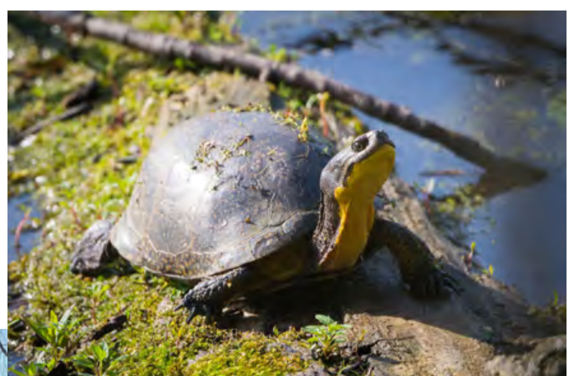
NASHUA RIVER WATERSHED ASSOCIATION

Climate Impact Website Content

Action Changes Things



Action Changes Things

June 2021

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Written by the
Nashua River Watershed Association
Climate Impact Committee

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NASHUA RIVER WATERSHED ASSOCIATION

Protecting our water, our land, our communities

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Introduction

The changing climate of New England is profoundly affecting the Nashua River watershed. Although climate news often centers on increased storms and sea level rise around the globe, impacts to our local rivers, wetlands, and ecosystem - the core of the extraordinary landscape in our watershed - require our attention now. These are areas in which the NRWA has unique expertise and experience.

The information and links on this website focus on local impacts, actions that local communities can take to reduce impacts and prepare for the future, and the NRWA's role as a regional environmental leader. Over the last 50 years, the NRWA has directly and indirectly helped to mitigate the impacts of a changing climate through a wide range of programs.

Climate Change and the NRWA

The NRWA is committed to working with communities, organizations, and individuals throughout our watershed to build a more resilient and sustainable landscape that is better able to adapt to a changing climate. The NRWA Board adopted the following policy to reflect this commitment:

> ***NRWA Climate Change Policy:*** *"The Nashua River Watershed Association recognizes the adverse impacts of climate change to the natural systems that sustain life on our planet. It is the policy of the NRWA to promote and undertake local and regional actions to address the impacts of climate change on our watershed. These actions include developing strategies to address changes in local hydrology and ecology, assisting communities to become more resilient, and helping people to live more sustainably and safely in the face of climate change."*

The NRWA's on-going effort to create a greenway corridor along our rivers through land preservation helps to mitigate the effects of flooding by keeping these lands, and associated wetlands, undeveloped and, therefore, better able to absorb excessive rainfall and prevent flooding. Working with federal, state, local, and private entities, the NRWA has encouraged conservation of forests, which helps with carbon sequestration. Our water quality monitoring program has collected information on temperature and other data in our rivers and streams for several decades and serves as an important basis for noting trends caused by a changing climate. The data are shared with the public, the Massachusetts Department of Environmental Protection, and the NH Department of Environmental Services; data are also utilized by the U.S. Environmental Protection Agency.

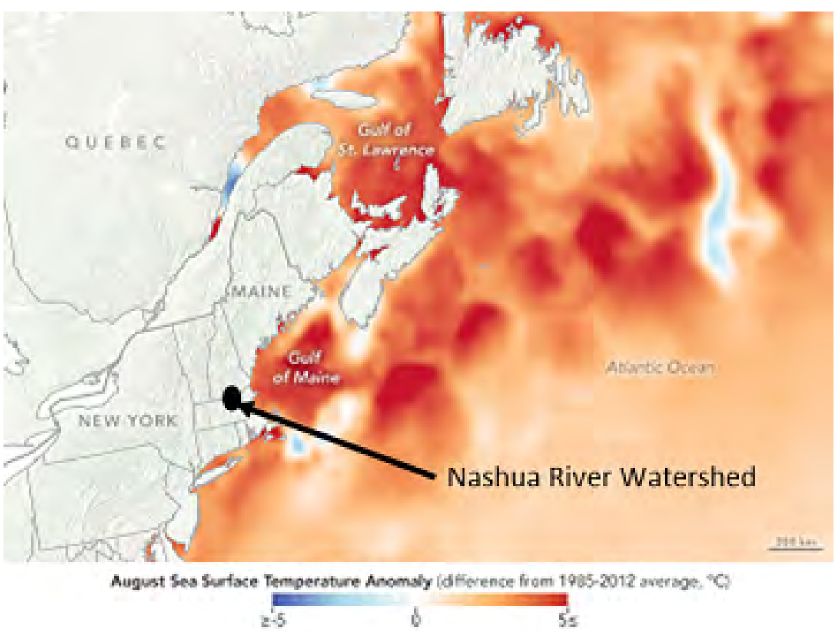
The NRWA works with municipalities on improving stormwater infrastructure, low impact development, and other best management practices that help them plan for development while protecting critical resources. Our environmental education programs in schools and for the general public have educated tens of thousands of children and adults on the value of wetlands and the importance of managing storm water and the hydrologic cycle at a watershed scale.

All in all, over the last fifty years, the NRWA's work to fulfill its mission has helped to mitigate the impacts of a changing climate, and our current work is continuing to do so.

What is a watershed? *A watershed is a geographic area of land in which all surface and ground water flows downhill to a common point, such as a river, stream, pond, lake, wetland, or estuary. "Healthy, resilient watersheds are the best insurance policy for a changing climate." (USDA, Forest Service, https://www.fs.fed.us/kidsclimatechange/products/water-climate-brochure.pdf)*

Climate Change in Our Region

The primary climatic impacts experienced in New England are the increase in the total amount of rainfall and rising temperatures. Notably, the National Weather Service reports that the frequency and intensity of strong rainfall events are increasing more in New England than anywhere else in the United States. Since most rainfall increases are occurring in the winter and early spring when the ground cannot absorb water, water is lost to runoff rather than recharging groundwater. As temperatures increase, we are experiencing a significant increase in the number of days over 90 degrees. In addition, the freeze-free period in New England is lengthening, and conversely the number of days of extreme cold is diminishing. These changes in rainfall events and intensity, and warming temperatures, are having a major impact on our ecology.



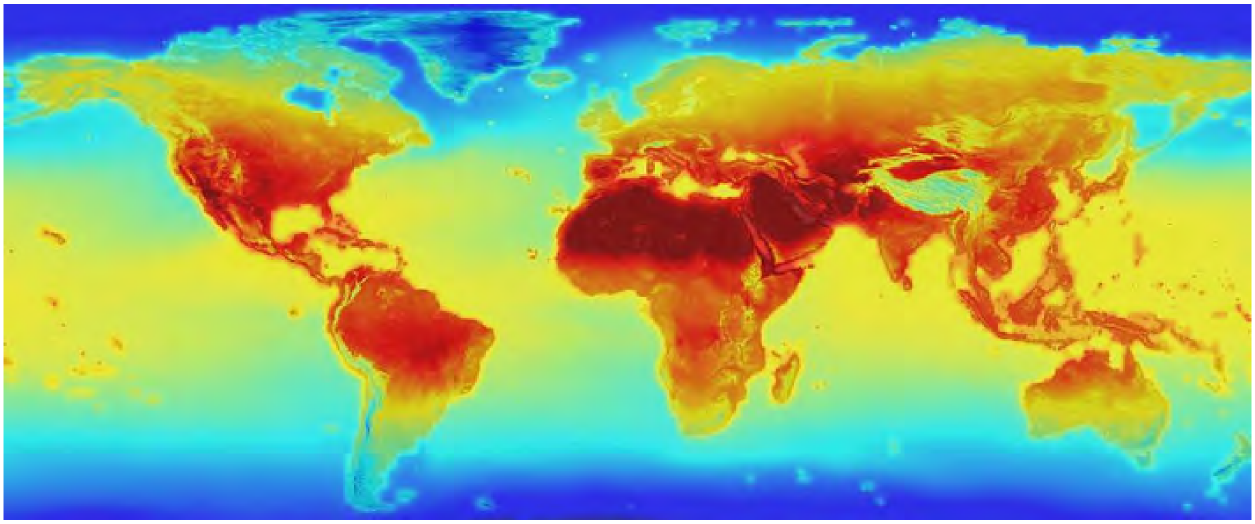
Warming Seas in the Gulf of Maine: *In the past three decades, the Gulf of Maine, just to our east, has warmed three times faster than the global average. Over the past 15 years, the basin has* *warmed at seven times the global average. The Gulf has warmed faster than 99 percent of the global ocean. (August 8, 2018. NASA Earth Observatory images by Lauren Dauphin, and sea surface temperature data from [Coral Reef Watch](). [https://climate.nasa.gov/news/2798/watery-heatwave-cooks-the-gulf-of-maine/]())*

Global Warming is Having Local Impacts

Here in Massachusetts and New Hampshire, an increase in the frequency and intensity of rainfall events will stress our existing infrastructure, which was not designed to withstand such challenges. Areas that have been developed or otherwise disturbed are vulnerable to flooding and damage. In addition, if the rate of warming is not slowed, our local climate is expected to resemble the current climate of New Jersey within the next 20 to 40 years, and the current climate of South Carolina within the next 50 to 70 years. In the process of undergoing these changes in such a short period, many of our native plants and animals, including birds and pollinators, are expected to become stressed and may no longer be able to survive in our climate. This will have major impacts on our region's agriculture, forests, wetlands, and landscape, and thus our overall quality of life.

Migrating State Climate: *Changes in average summer heat index—a measure of how hot it actually feels, given temperature and humidity—could strongly affect quality of life in the future for residents of the Northeast. Red arrows track what summers could feel like in Massachusetts over the course of the century under the higher-emissions scenario. Yellow arrows track what summers in Massachusetts could feel like under the lower-emissions scenario. (Frumhoff et al. 2007, Northeast Climate Impact Assessment/Union of Concerned Scientists)*

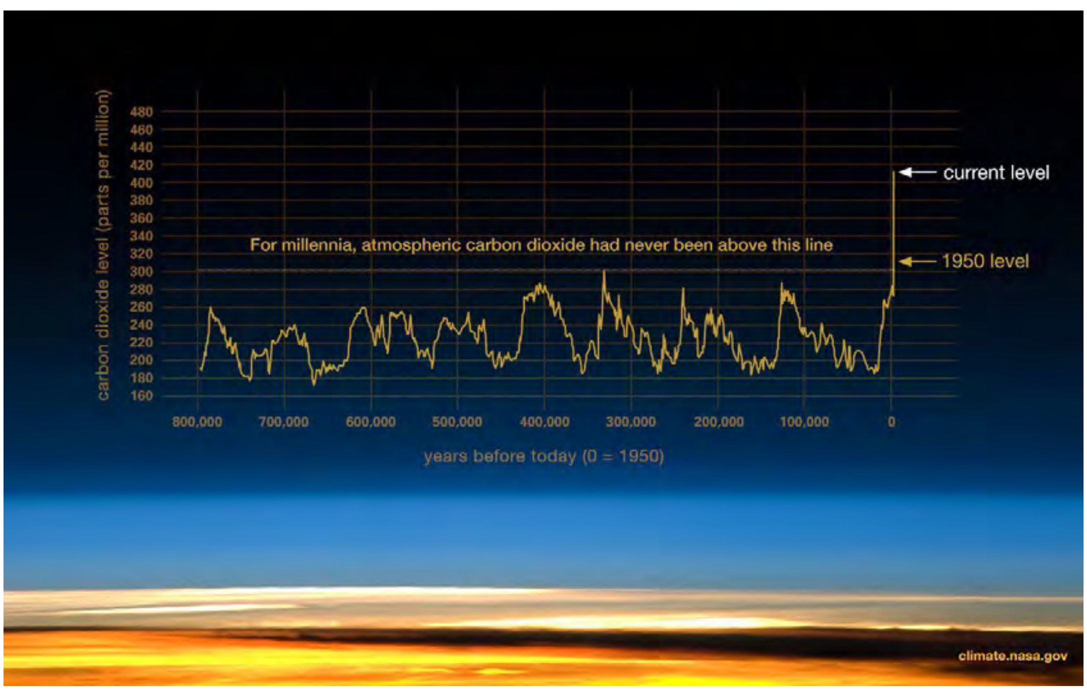
Climate Change Causes



The Science Behind Our Changing Climate

To gain an understanding of what is causing our climate to change, let us take a brief look at measurements that scientists such as those at NASA and the U.S. National Oceanographic and Atmospheric Administration (NOAA) have been tracking for many years.

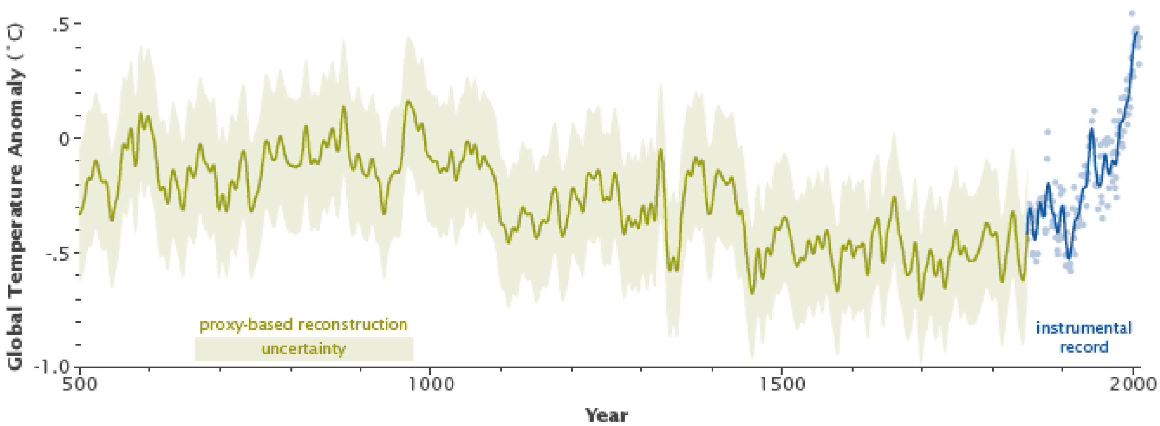
Scientists are in agreement that the global climate is rapidly warming and that the causes are rooted in human activity, predominantly combustion of fossil fuels and land use changes such as deforestation. Some of the clearest evidence that global climate change is occurring and is being caused by human activity comes from carbon dioxide (CO_2) levels in the atmosphere. The following graph shows atmospheric CO_2 levels over the past 800,000 years:



Historical levels of carbon dioxide. *This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO_2 has increased since the Industrial Revolution. (https://climate.nasa.gov/evidence/)*

It is evident that while atmospheric CO_2 levels do naturally fluctuate, today's levels are the highest in millennia. Carbon dioxide levels are much higher than they would otherwise be if humans were not burning so much fossil fuels (oil, gas, and coal), which give off CO_2 when they burn.

By studying hundreds of thousands of years of geological data, scientists have shown that temperatures increase when CO_2 levels increase, so the current spike in carbon dioxide is certain to result in a rapid additional increase in global temperature.



Historical temperature levels*. Temperature histories from paleoclimate data (green line) compared to the history based on modern instruments (blue line) suggest that global temperature is warmer now than it has been in the past 1,000 years, and possibly longer. (Graph adapted from https://earthobservatory.nasa.gov/features/GlobalWarming/page3.php)*

The paleoclimate record reveals that the current climatic warming is occurring much more rapidly than past warming events.

What is the Greenhouse Effect?

The greenhouse effect refers to the retention of the sun's warmth in the Earth's lower atmosphere by greenhouse gases. These gases (primarily carbon dioxide, methane, and nitrous oxide) act as a thermal blanket for the planet, warming the surface to what has been a life-supporting global average of 59 degrees Fahrenheit (15 degrees Celsius). The recent rapid increase in greenhouse gases has resulted in the atmosphere trapping more solar radiation and, in turn, raising the global temperature. There are three main sources of greenhouse gases:

- **Carbon in Fossil Fuels:** A major source of carbon in our atmosphere has been from the accumulation in the earth, over eons, of decayed organic matter from plants. Its longest-lasting deposits are coal, oil, and natural gas. Under natural conditions, these types of carbon slowly accumulated and remained stored in the Earth. However, over the past two centuries or so, humans have been extracting them and utilizing these "fossil fuels" for energy, by burning them for transportation, heating, and industrial purposes. Thus, carbon that took millions of years to be taken up from the atmosphere and to accumulate underground gets released back into the atmosphere in a short period of time. The rate of extraction and burning has increased over recent decades, adding to atmospheric CO_2 levels.

- **Plants and the Carbon Cycle:** Changes in land use, such as deforestation, have reduced the overall number of green plants on earth available to take up carbon dioxide from the atmosphere. Green plants absorb CO_2 through their leaves and convert it to energy-rich organic compounds in the process of photosynthesis. Trees, for example, use those compounds to form their woody stems and roots. Thus, as plants grow, carbon gets stored in them. When they die, that carbon gets decomposed by microorganisms and fungi, with the result that a significant fraction gets stored in the soil in the form of organic matter. A portion of that carbon gets released back into the atmosphere as CO_2, where it can then be taken up again by plants. This circular process is known as the carbon cycle. But the loss of forests worldwide (deforestation) to other uses such as mining, agriculture, urban and suburban sprawl, has led to fewer forested acres to sequester and store the ever-increasing amount of CO_2 in the atmosphere, with less stored in plant tissue or in the soil.

- **Methane Gas:** Methane is a very powerful greenhouse gas that is released to the atmosphere as a result of the natural fermentation of organic matter (for example from swamps). However, increasingly it is being emitted by ruminants (e.g., cattle, sheep, goats, and their relatives) as the world's population expands its need for food, from landfills, and from the extraction and leakage of natural gas from wells and pipelines. It has also been predicted and hypothesized that as temperatures rise, methane trapped by permafrost in northern boreal forests and methane trapped beneath the oceans will begin to be released into the atmosphere.

The vast majority of scientists agree that combustion of fossil fuels is the single largest driver of rising temperatures and climate change. If the release of CO_2 is not slowed, the costs to society of addressing its impacts will become staggering. The increasing availability of renewable forms of energy, such as solar, wind, and hydroelectric power, offers options for meeting energy needs. Fortunately, the cost of renewable energy can be competitive with gas and oil.

Banner graphic: https://www.nasa.gov/press-release/nasa-releases-detailed-global-climate-change-projections.

Climate Change References

Climate Central: https://www.climatecentral.org/gallery/graphics

Climate Change: How do we know? https://climate.nasa.gov/evidence/

Global Climate Change: Evidence and Causes: https://globalclimate.ucr.edu/resources.html#q2

How is today's warming different from the past? https://earthobservatory.nasa.gov/features/GlobalWarming/page3.php

U.S. Forest Carbon Storage, Carbon On Line Estimator (COLE): https://www.nrs.fs.fed.us/carbon/tools/#cole

Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. 2007. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Cambridge, MA: Union of Concerned Scientists (UCS)

Please check regional sources of information to stay abreast of the latest local, state, and federal programs and legislation concerning climate impacts, as they are frequently evolving.

Climate Change Impacts on Water in the Nashua River Watershed

Between 1958 and 2012, the Northeast saw more than a 70% increase in the amount of rainfall measured during heavy precipitation events—more than in any other region in the United States. Projections indicate continuing increases in precipitation. Rainfall events are increasing in both frequency and intensity, with most increases occurring in the winter and early spring when the ground cannot absorb water. This causes flooding and stresses the stormwater infrastructure. Another factor impacting the region's hydrology is the steadily rising temperatures. This is causing an increase in the temperature of water in our wetlands, streams, ponds, and rivers, which will have a significant impact on their ecological value.

Although the rivers and major streams in our watershed form a relatively simple hydrologic pattern, many of the smaller streams and wetlands that drain into those waterways are unusually complex. The last glacier deposited or sculpted many of the landforms found throughout the watershed, including drumlins and outwash features such as eskers and kames. As a result, natural drainage paths were blocked, which gave rise to the extensive wetlands, ponds, and meandering streams characteristic of this area. This hydrologic system has enriched the ecological value of the watershed. However, this system does not efficiently drain floodwaters, thereby making portions of the watershed at increased risk for flooding.

Major Impacts on Water

The major hydrological impacts of climate in the Nashua River watershed include the following:

Flooding

The increased frequency and intensity of storms is causing a corresponding increase in periodic major flooding as well as frequent minor flooding of small streams and wetlands. Since bridges, storm drains, and other stormwater infrastructures were designed for typical historic storms, larger more intense storms in the future may overwhelm them. If a stormwater structure becomes inadequate, increased flooding will take place upstream of the structure, and may also result in bridge failures and road wash-outs. Significant disruption of travel and risk to emergency vehicles and personnel may result. Increased flooding also causes increased property damage and general disruption.

Erosion/Sedimentation

The flooding and increased flow rates in rivers and streams will cause increased erosion of stream banks and scour of river-bottom sediments. Land areas with sloping topography or thin vegetative cover will also be subject to increased erosion. Streams into which runoff from sloping areas drain will see increases in sedimentation. Portions of rivers that are wide or deep will see increases in sedimentation. These alterations to fluvial geomorphology further affect flooding potential and aquatic habitat.

"Flash" Droughts

The overall increase in total yearly rainfall should result in a decrease in the frequency of long-term droughts, but this is offset by predicted significant summer periods with little or no rain. This lack of rain, combined with a significant increase in the number of days with very high temperatures, will cause relatively shorter but particularly intense periods of drought, called Flash Droughts. These intense periods can cause small streams and wetlands to rapidly dry up, resulting in disruption to some of the watershed's most critical and sensitive ecosystems, including systems that support endangered and vulnerable species. Flash droughts will also cause lakes to become stagnant more frequently and to develop algal blooms.

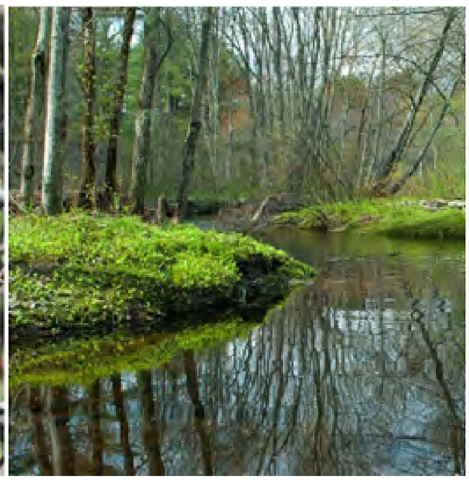
Warming Water Temperatures

Many aquatic species are particularly sensitive to changes in stream, pond, or lake temperatures. Waterways that currently support important coldwater fisheries, including species of trout, may lose these species entirely. Warming water temperatures and extended summer periods will cause increased frequency and intensity of algae blooms. The rate of reproduction for most species of algae increases proportionately to, in some cases geometrically, with increasing temperature. In addition, algae blooms will raise the pH level, lower dissolved oxygen, and decrease light penetration, which will adversely affect the aquatic habitat of lakes and streams. Changing the aquatic habitat may favor non-native species over native species, thereby altering the structure and function of aquatic communities, as well as increasing the stress on native species.

Water Quality

Multiple adverse impacts on water quality are anticipated due to climate change. Warming water temperatures may mean the loss of some coldwater fisheries in the watershed. Higher total rainfall and more severe storms may increase suspended solids and turbidity due to scouring of streambeds and erosion of their banks. More acid rain can be expected, lowering the pH of the water and increasing stress on aquatic life. Increased loadings from non-point source pollution, including pollution from more distant sources can be expected. This may include increased nutrients, pesticides, and bacteria from rural areas; metals, oil and grease from urban areas; and salt from highways. Older cities with combined sewer systems can expect more frequent overflows to the river bringing increased turbidity and bacteria. Lower summer flows and less dilution will make point sources of pollution more pronounced. The combination of warmer water temperatures and increased pollution will lower dissolved oxygen levels that are necessary to maintain aquatic life.

Climate Change Impacts on Ecology in the Nashua River Watershed


In the Nashua River watershed, geology, hydrology, and climate have combined in a unique way to create one of the most complex landscapes and some of the most diverse habitat anywhere. The diversity of our landscape begins with geology. This area contains remarkable concentrations of glacial landforms: extensive areas of eskers, kames and kettles; an impressive "swarm" of drumlins; broad ground moraines; and areas scraped bare by the glacier. In the middle of our watershed once stood Glacial Lake Nashua, more than thirty miles long, stretching from Boylston, Massachusetts to Nashua, New Hampshire, and bounded by walls of ice. Remnants of the lake are all around, ranging from lakebed deposits to hanging deltas sitting high above the current valley floor. This set of landforms left intricate and varied topography and soils.

This area also lies precisely at the transition between two forest biomes. One is the northern hardwood-hemlock-pine forests, which extend north to Canada. The other is the central deciduous-oak-hickory forests, which extend south to Georgia. Biomes are communities of plants that tend to exist together. At the transition of biomes, both sets of vegetation exist together. Complex combinations of the vegetation characteristic of each biome are found throughout the watershed.

An ecosystem thrives on diversity and interconnections between habitats. The more types of habitat, the greater the density and diversity of plants and animals. The river system, in particular, creates such interconnections.

The confluence of diverse habitat and interconnection has yielded unusual biodiversity, including major concentrations of rare and endangered species. Perhaps the best measure of our biodiversity is the presence of several rare or threatened species of turtles. Many of these turtles are wanderers, moving overland between different wetland areas. The complex distribution of wetlands and streams, combined with the varied uplands, provides critical habitat for these species.

Throughout the watershed there is also an unusual concentration of vernal pools, where many unique but vulnerable creatures, such as our salamanders, breed. Vernal pools and our woodland marshes give rise to springtime peepers.

In addition to many rare species, this landscape is home to coyote, fisher, and, increasingly, bobcat, moose, and bear. It also supports a myriad of birds, butterflies, and dragonflies. This remarkable diversity has led to three Areas of Critical Environmental Concern (ACEC), representing more than a quarter of all the ACEC lands in Massachusetts, being established within the watershed and the designation by the federal government of significant portions of the Nashua, Squannacook, and Nissitissit Rivers as Partnership Wild and Scenic Rivers.

Extensive impacts to the ecology of the watershed are being caused by numerous climate-related changes. These impacts will significantly diminish the biodiversity and richness of the watershed unless actions are taken to increase resiliency and to better allow species to adapt.

Major Impacts to Ecology

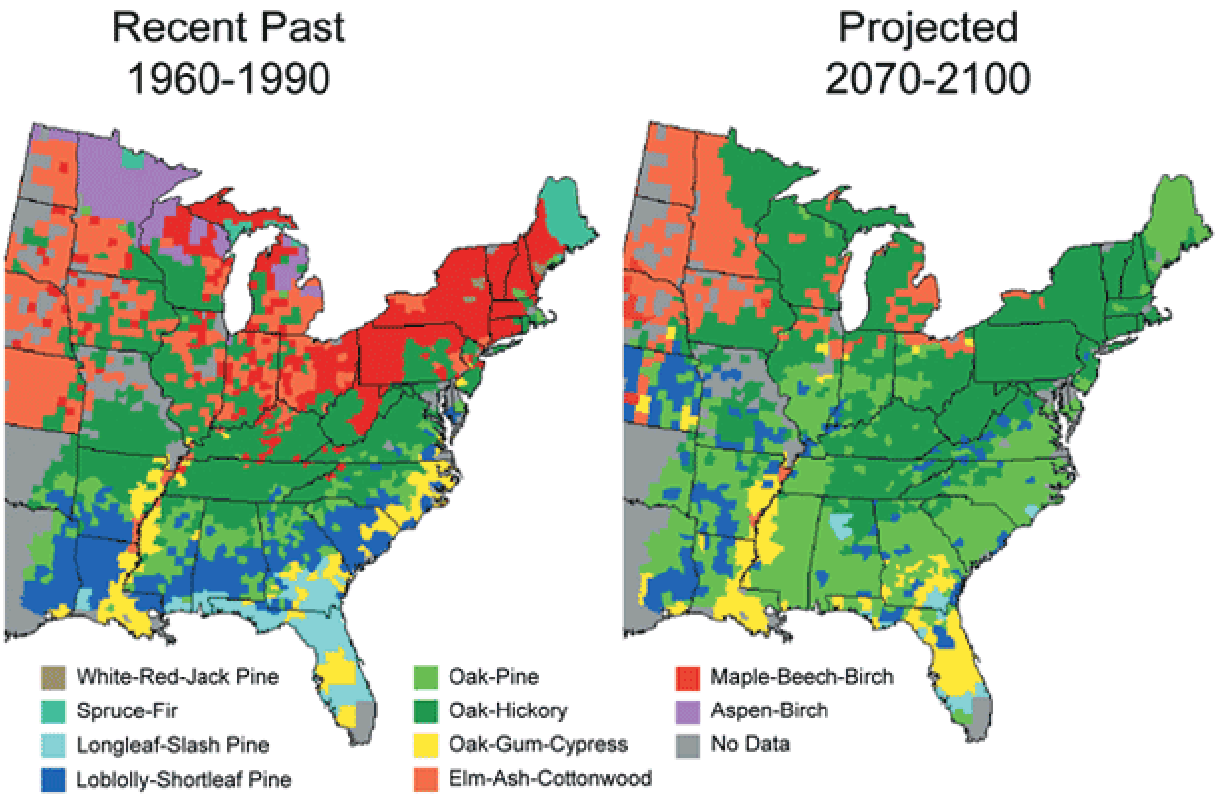
The major ecological impacts of climate in the Nashua River watershed include the following:

Changing Landscapes

One of the major consequences of regional warming is shifting of our forest biomes. The two major biomes that intersect in the watershed are "migrating" northward in response to warming temperatures. Within the next 30 to 50 years, conditions within our local landscape may become better suited to the more southerly forest biome, and this will cause a significant reduction in the biodiversity and richness of our landscape.

As the forest biome zones move northward, not all plants will shift together, and therefore plant communities will also change. Many local species of wildlife have adapted over long periods of time to these plant communities and may be reduced in numbers or disappear as the habitat changes.

Ecosystems are interconnected, synergistic, and complex. The web of life is vulnerable in ways that are unpredictable. The imprint of humanity, developed lands, and fragmented landscapes makes ecological adaptation difficult. Also, the rate of change is currently very rapid, further challenging adaptation.



Projected Changes in Forest Biomes due to Climate Change. *From 2009 National Climate Assessment "Global Climate Change Impacts in the United States."*

Invasives

Plants: Increased temperatures, especially less severe winters, will allow additional invasive (non-native) plant species to move into the watershed. As existing plant species become less competitive, invasives may be increasingly able to move in to replace them and take over areas. For example, some forests may be particularly vulnerable to increased invasions of Norway Maple and Buckthorn, which can outcompete native species. Over time, this can create monocultures with greatly reduced ecologic value. Another example is the increasing prevalence of Japanese Knotweed, a type of bamboo from Asia. It has become well established, especially in many disturbed locations along our rivers and streams and along roadsides, where it tends to form dense thickets and displace native plants.

Pests: Increased temperatures have led to the expansion of areas infested with new species of insects not previously in the watershed, some of which, such as the Elongated Scale and the Hemlock Wooly Adelgid, have caused extensive damage. As temperatures continue to rise, additional pests will invade, potentially causing the loss of key plant species.

Changing Seasons

The timing of seasons is shifting, affecting insects and the migrating and nesting birds that are dependent on them. The ecosystem of the watershed is complex, and the changing climate will have a detrimental impact on the flora and the fauna that is dependent upon it.

Declining Species

Insects: Significant declines in insect populations have been noted for many years. Although the focus has been on pollinator insects that are essential to many plant species, insects are an essential component of the entire ecosystem with many other species dependent on them.

Birds: A recent study, published in the journal *Science*, indicates that bird populations in the United States and Canada have declined by 29% over the past 50 years. This translates to a population loss of 2.9 billion birds. While there are many potential causes of the decline, such as land use changes and pesticide usage, climate change is involved. Changes to local habitat are certainly among the potential local causes.

General Wildlife: As temperatures warm and vegetation communities shift, habitat will decline and will not be adequate to support existing wildlife populations. Different wildlife species will seek ways to survive either by migrating to areas with adequate habitat or by adapting to the changes. The net result will be an overall decrease in the biological density.

Aquatic Habitats

Changing flow patterns will alter the suitability of streams as a habitat for aquatic life. This may include a decrease in the riffle-pool habitats preferred by many bottom-dwelling organisms that supply food for fish. Cobble-gravel stream bottoms may get clogged by increased siltation after scouring and erosion events. This may hinder spawning activities of fish. Changing sediment loads may alter the shape of channels. Together, these changes may decrease the quality and quantity of available habitat, inhibit reproduction and hinder the natural movement of aquatic organisms.

Adaptation-Migration Impediments

The interconnections among species and with landscape features are sometimes subtle but always powerful. The changing climate will disrupt the hydrologic and landscape systems in ways that will, in turn, disrupt the local and regional ecosystems.

Nature responds to change either by adapting to new conditions or through species migration. Some species, including some of our most vulnerable local species (such as those that require vernal pools or special habitat), do not have the ability to migrate and so must find ways to adapt if they are to survive.

Although the Earth has experienced major temperature swings and disruptions in the past, one of the major differences now is the rate of temperature change is too rapid to allow adaptation by some species. Another difference is the enormous number of barriers to natural migration due to human development. Major highways and heavily developed areas block movement, while fragmentation of the landscape prevents many species from moving to new areas where they can continue to survive.

Scouring by floods. *Old undersized and poorly sited culverts can become scoured by flooding from excessive rain events leading to the disruption of stream continuity as the culvert now sits above the stream level which prevents movement of fish and other aquatic species.*

Banner images at top (left to right): Indigo bunting, a neotropical migrant bird dependent on our watershed habitats during migration, photo by Nancy Lebedzinski; Nissitissit River, a valuable coldwater fishery with native trout populations, photo by Ken Hartlage; Bolton Flats Wildlife Management Area runs along the Nashua River in Lancaster, Bolton, and Harvard, and features specialized habitats like High-Terrace Floodplain Forest and Pitch Pine-Scrub Oak woods, photo by Chris Buelow.

Watershed Impact References

Water Impacts

Climate Impacts in the Northeast, incl. increases in rainfall: https://archive.epa.gov/epa/climate-impacts/climate-impacts-northeast.html

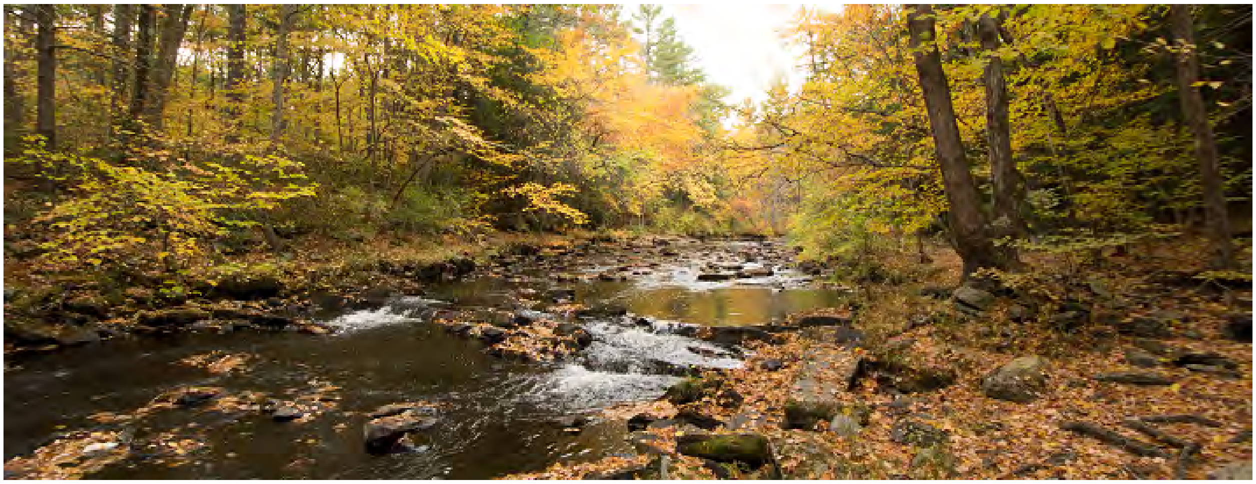
Ecology Impacts

2009 National Climate Assessment "Global Climate Change Impacts in the United States": https://nca2009.globalchange.gov/

Declining Species

https://www.birds.cornell.edu/home/wp-content/uploads/2019/09/DECLINE-OF-NORTH-AMERICAN-AVIFAUNA-SCIENCE-2019.pdf

Mitigating Impacts of Climate Change



Although far reaching and sometimes severe climate-related impacts in our watershed are increasing, many actions can be taken by individuals, municipalities, conservation groups, and businesses to mitigate the hydrologic and ecologic impacts of climate change. Such actions will make our environment more resilient, mitigate impacts, help to reduce overall climate change, and even improve the quality of our watershed for generations to come.

Primary strategies to mitigate hydrologic impacts include reducing stormwater flows and creating groundwater reserves to feed wetlands and small streams during drought periods. The primary strategies to address ecological issues include creating corridors for species migration and protecting important habitat areas.

Primary large-scale strategies to mitigate ecological impacts focus on ensuring resilient and connected areas as well as connections within and across the watershed to regional corridors that allow migration of wildlife and plants into and out of the watershed.

The Nashua, Squannacook, and Nissitissit Rivers, together with the other rivers and streams throughout the watershed, create connections for migration among numerous small protected areas. These separated but interconnected areas function in many ways as larger protected areas having ecological corridors. Since many of the most vulnerable species, such as vernal pool species, are not able to migrate, the protection of targeted areas for the preservation of those species is also critical. There are evolving adaptation strategies, such as assisted migration of more southern species being planted or moved further north along and above their current range, that continue to be investigated and researched.

The specific strategies outlined here range in scale from those that are within the scope of individuals and small landowners to those that require coordinated efforts by conservation groups, municipalities, and regional and state authorities. Many strategies simultaneously address both hydrologic and ecologic issues.

Mitigating Impacts Through Nature-Based Solutions

Nature has evolved in ways that buffer storms and adapt to change. Many of the most effective strategies to address the impacts of climate change are based on those natural systems. Many of the impacts we are facing are exacerbated by the ways we have changed the natural landscape and reduced the effectiveness of nature's tools. Impermeable surfaces, loss and disconnection of wetlands and floodplains, fragmentation of the landscape, barriers to the movement of wildlife, loss of forests and meadows, and many more human changes exacerbate the impacts of a warming climate. By actions such as increasing infiltration, slowing the flow of stormwater, reconnecting the landscape, conserving and managing our forests and meadows, and re-creating a more resilient environment, we can not only buffer impacts but also create an environment better adapted to the future.

Some Nature-Based Solutions also directly address climate change by sequestering and storing carbon in forests, meadows and wetlands. If we let forests mature, become old growth, and manage them for carbon storage and other ecosystem values and services (e.g. water supplies, biodiversity, forest products); if we plant meadows and adopt agricultural practices that store more carbon in the soil; and if we use the knowledge that science has provided, we can make a real difference to climate change in our watershed while creating a more ecologically viable and sustainable future.

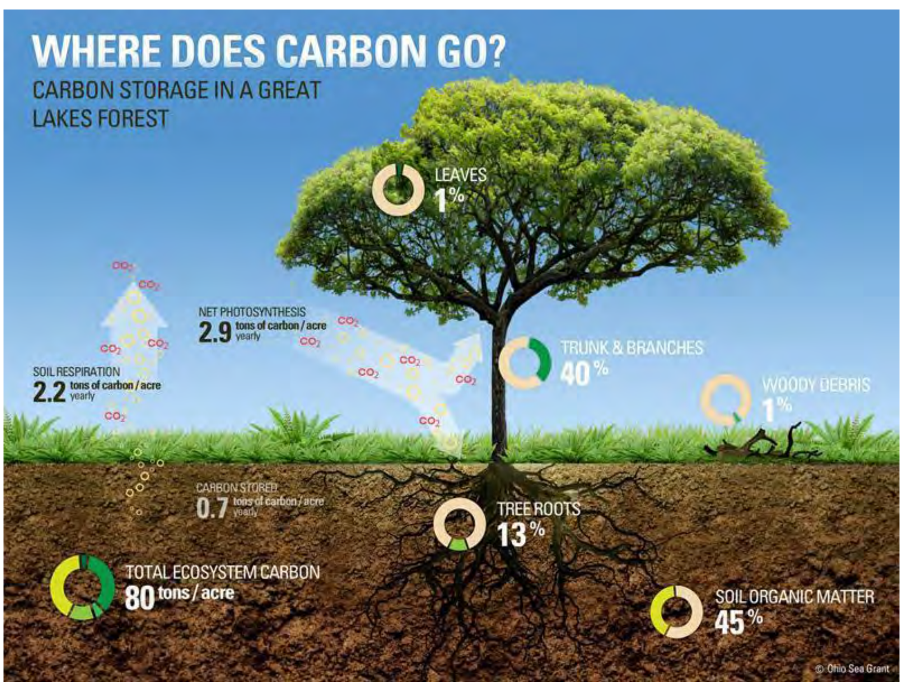
Many Nature-Based Solutions can work at different scales, from global programs to actions that individuals can take. Some create ecologic or hydrologic resilience while also removing atmospheric carbon and storing it not only in plant materials, but also in the soil, thereby reducing the overall impacts of climate change.

The United Nations Global Compact in the 2019 Climate Action Summit states:

> *"Nature-Based Solutions are a fundamental part of action for climate and biodiversity. Authoritative research indicates that Nature-Based Solutions can provide over one-third of the cost-effective climate mitigation needed ...They value harmony between people and nature, as well as ecological development and represent a holistic, people-centered response to climate change. They are effective, long-term, cost-efficient and globally scalable."*

Mitigating Impacts Through Carbon Sequestration

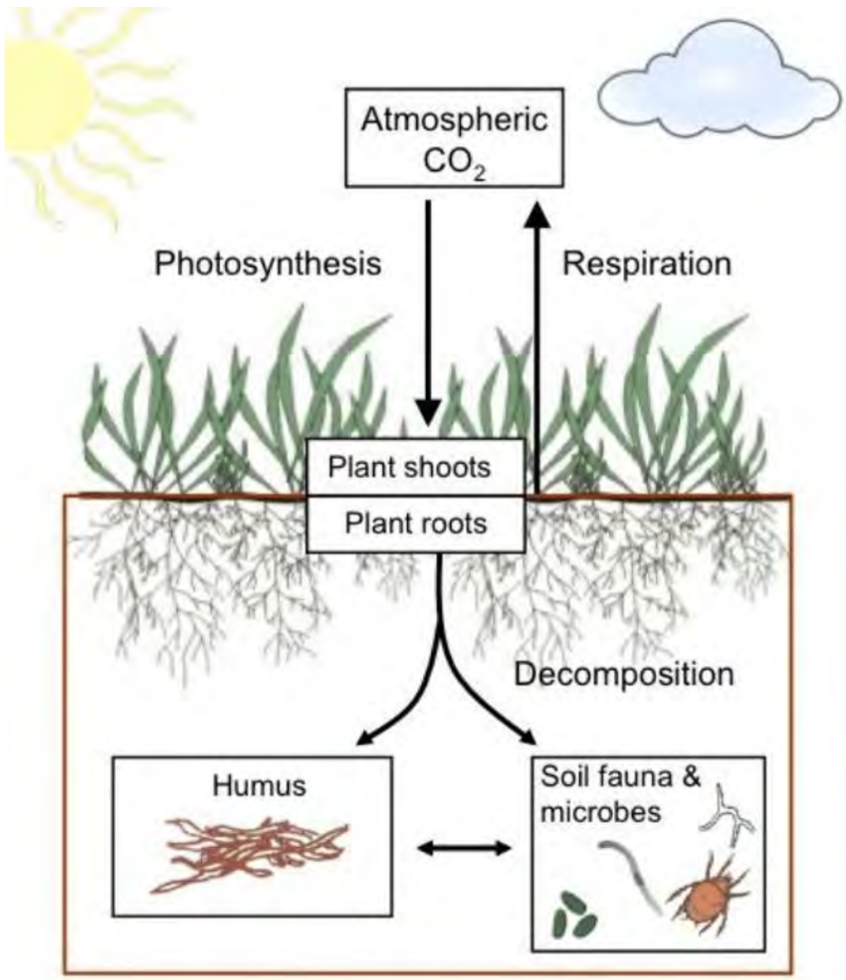
New England has one of the most extensive forested landscapes in the United States, storing a tremendous amount of carbon. By sequestering and storing carbon, forests can be one of the main ways we can mitigate against the adverse impacts of climate change, if we conserve and manage them well.



Where Does Carbon Go? *A forest's carbon pool, whether in the Great Lakes or the Northeast, is distributed with slightly more stored below ground in roots and the soil than aboveground in trunks, branches, and leaves. (Kramer et al. 2017)*

In addition to direct storage of carbon in trunks and roots of trees and other vegetation, natural systems can sequester large amounts of carbon in the soil. According to a 2017 study at Washington State University, the uppermost three feet of soil holds three times as much organic carbon as the total amount of carbon in the atmosphere. Studies indicate that, since the beginning of the industrial revolution, land use change and poor soil management have released more than a hundred billion tons of carbon from the soil, a major contribution to total atmospheric carbon.

Up to twenty percent of carbon fixed by photosynthesis in plants is exuded into the soil through roots. Fungi, including mycorrhiza, bacteria, and other organisms in healthy soil are essential to the process of transforming and storing carbon, mostly as organic matter, in the soil. Trees, shrubs, and meadow grasses can all be effective at sequestering and storing carbon in the soil.



Carbon balance in soil. *Carbon balance within the soil (brown box) is controlled by carbon inputs from photosynthesis and carbon losses by respiration. Decomposition of roots and root products by soil fauna and microbes produces humus, a long-lived store of soil organic carbon.*

Climate Impact Mitigation and Adaptation Overview References

Nature-Based Solutions

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Carbon Sequestration

U.S. Forest Carbon Storage, Carbon On Line Estimator (COLE): https://www.nrs.fs.fed.us/carbon/tools/#cole

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Soil and the Carbon Cycle (figure): https://serc.carleton.edu/eslabs/carbon/5a.html#:~:text=Soil%20Carbon%20Storage%3A%20Carbon%20balance,and%20carbon%20losses%20by%20respiration.&text=Humus%20is%20formed%20when%20soil,that%20reside%20in%20the%20soil.

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Mitigation and Adaptation Strategy: Conserve and Manage Forests

An important set of Nature-Based Solutions relates to forests. Forests absorb stormwater and slow runoff. They provide us with clean water, clean air, biodiversity, forest products, and recreational opportunities. They are a critical component of our ecosystem. Additionally, they remove (sequester) carbon from the atmosphere and store it (above and below ground). Massachusetts is currently 62% forest cover, the 8th most forested state in the US and the 3rd most densely populated state. However, forest cover in Massachusetts is decreasing and this means our environment's quality is being diminished and that carbon is being lost to the atmosphere.

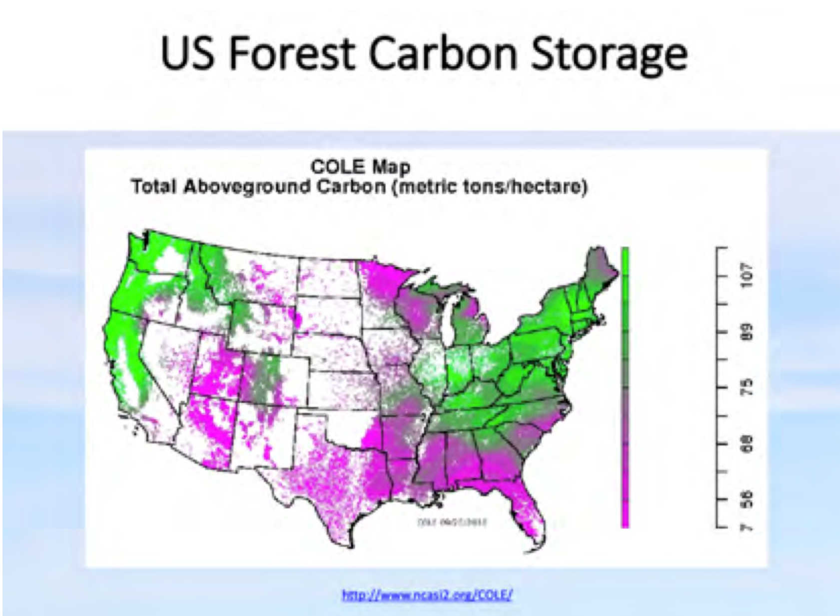


Image left: Above-ground storage of carbon. *The Northeast and Northwest have the highest above-and below-ground carbon sequestration in the United States.*

(https://www.nrs.fs.fed.us/carbon/tools/#cole)

Forest ownership in the watershed includes private landowners, land trusts, and local, state and federal governments. The many types of owners have a wide range of goals for their forested land, such as income generation, recreation, ecology, and protection of water supplies or other natural resources. From the perspective of climate change, independent of other goals, maximizing the amount of forested land and managing forests for carbon storage and biodiversity are critically important.

- The most important forest mitigation strategy is to stop the conversion of forest land to non-forest land uses and begin increasing forest cover. All forests sequester and store carbon, have significant ecological value, and provide numerous additional environmental benefits. Maximizing forest cover is critical to addressing the core causes and impacts of climate change.
- Non-managed, or minimally managed, forests generally provide the highest amount of carbon storage and highest ecological value. Older trees tend to provide the most carbon storage and forests with old-growth characteristics, such as a diversity of species, ages and size of trees, the presence of snags, large downed logs, and scattered canopy gaps provide especially valuable habitat for a wide range of animals. Although some younger forests may remove carbon from the atmosphere more rapidly than old-growth forests, the net effect of harvesting is a reduction in stored carbon.
- When landowner goals for forests include income or other objectives, managing the forests to also preserve and enhance some old growth characteristics can retain extra carbon storage and reduce ecological losses.
- Educating forest owners about management options is essential to ensure that the best solutions are utilized to meet owner needs and ensure carbon storage and biodiversity.
- Wildlands and Woodlands, a science-based conservation vision for the New England Landscape developed as a collaboration among forestry organizations and conservation groups in New England, sets a goal of permanently protecting a minimum of 70% of the total land in New England as forests to be sustainably managed for timber harvesting and other values, plus at least 7% conserved as farmland. Additionally, Wildlands and Woodlands recommends 10% of the permanently protected forests be conserved as wildlands to protect biodiversity and wilderness. While those goals may be low, they do express the right directions to be moving. The NRWA is a collaborator in the Wildlands and Woodlands Partnership.
- The Forest Legacy Program, a Federal program in which the NRWA has been a collaborator, has also played a significant role in conserving forests. Read more about NRWA's Forest Legacy projects.

An Example: Restoring Old Growth Characteristics

Numerous scientific studies point to the importance of forests in storing carbon. Old growth forests play a role as carbon sinks as they continue to accumulate carbon in their wood and their soils actively capture carbon. Forests with old growth characteristics also provide the highest level of landscape diversity and ecological value.

For managed forests, including smaller woodlots, such as the typical landowner is more likely to own and manage, the opportunity exists to restore old growth characteristics as a natural solution to climate change through modern forestry practices such as:

- leave "legacy" trees and very large trees 25+ inches diameter;
- leave large standing dead trees;
- leave large downed logs;
- allow for long-term accumulation of coarse woody material;
- support multi-aged trees and a variety of species;
- allow and create gaps in the canopy; and
- limit soil disturbance during forest management.

Educating owners of large and small forests that their trees contribute to climate resilience, that "legacy trees" are particularly important for their role in carbon storage, and about the ways that targeted forest management practices mitigate climate change is essential.

Table 1 Old-growth structural characteristics and corresponding management practices for promoting these characteristics.

Old-Growth Structural Characteristic	Management Practice
Increase the diversity of tree sizes and ages	Harvest single trees or small groups of trees, creating gaps up to 1/4 acre; repeat to create multi-aged stands
Increase the number of snags—large standing dead trees	Girdle (i.e., cut several rings of bark/cambium around the stem to deliberately kill the tree) selected medium- to large-sized trees, including cull trees
Increase number and volume of downed logs	Fell and leave on the ground selected medium- to large-sized trees, including cull trees, which can improve growth of residual trees
Provide for future snags and downed logs	Reserve permanent "legacy trees" within harvested areas (photo, pg. 8)
Increase number of large living trees	Thin woods by removing competing, low-quality trees adjacent to largest, most vigorous trees

Adapted from William Keeton (2005)

Table and image above adapted from UMass Amherst Outreach Extension's "Restoring Old Growth Characteristics" by Paul Catanzaro and Anthony D'Amato.

Mitigation and Adaptation Strategy: Protect and Enhance Floodplains, Wetlands and Small Streams

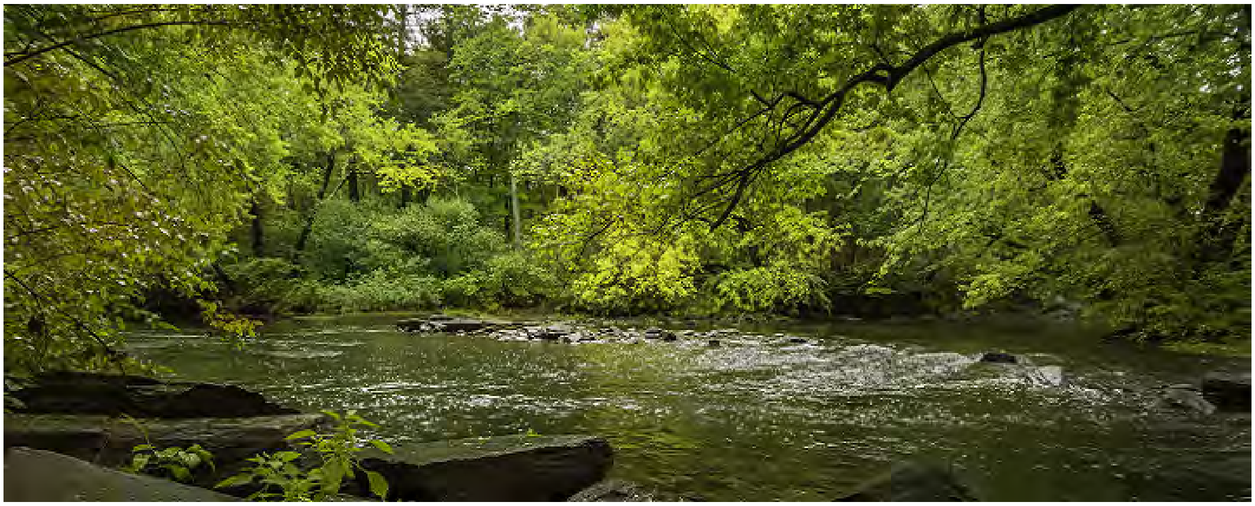
Floodplains are nature's system for reducing the severity of floods. Floodplains are also critical open space and wildlife habitat since they are typically part of greenways along river and stream systems. Altered seasonal water flows may threaten flood plain functionality, which can adversely impact biological and nutrient cycles, and also seed dispersal. In addition, it may favor non-native over native species. Where the connections between floodplains and rivers have been severed, as by development, efforts should be made to reconnect them.

Wetlands and small streams provide flood storage capacity. They are also vital parts of our ecosystem, especially for many locally endangered species. They purify water and slow runoff from storm events. Moreover, they are also effectively sequestering and storing carbon. When wetlands are lost or degraded, significant quantities of carbon can be released into the atmosphere.

As stated by A. M. Nahlik and M. S. Fennessy (2016): "Soil carbon is vital in regulating climate, water supplies and biodiversity—all essential contributions to the provision of ecosystem services. Wetlands contain a disproportionate amount of the earth's total soil carbon; holding between 20 and 30% of the estimated global soil carbon despite occupying 5-8% of its land surface. The anoxic conditions characteristic of wetland soils slow decomposition and lead to the accumulation of organic matter. As a result, wetlands can accumulate large carbon stores, making them an important sink for atmospheric carbon dioxide."

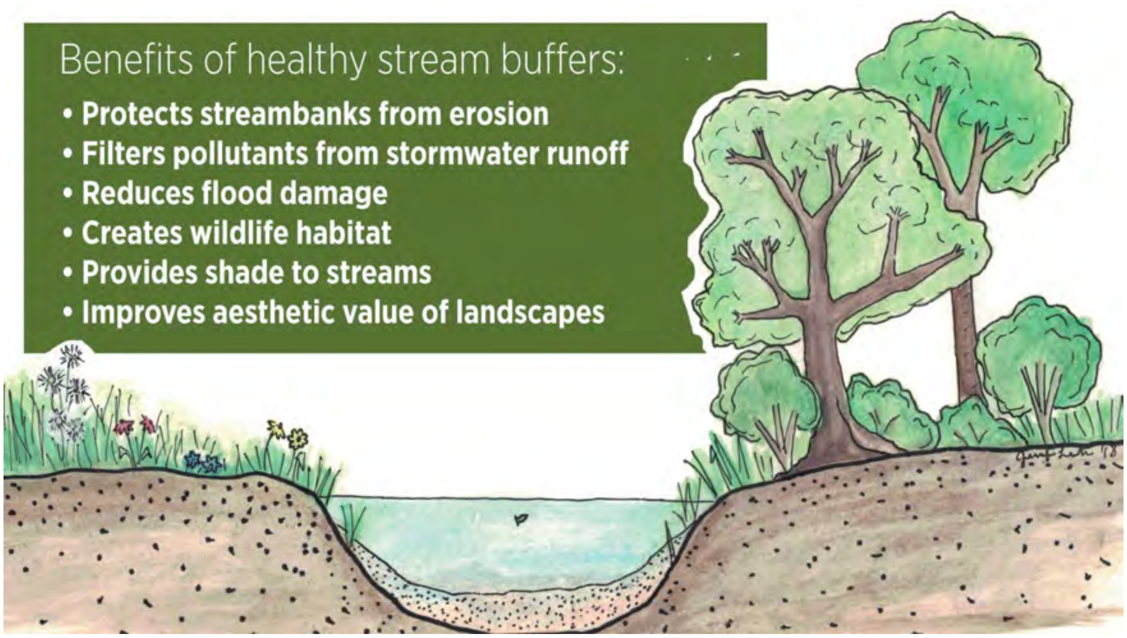
Ponds capture significant amounts of leaves and other organic debris. Similar to wetlands, anoxic conditions on the pond bottom slow decay and retain carbon. Ponds also temporarily store excess stormwater, reducing flows in streams and therefore down-gradient flooding.

Mitigation and Adaptation Strategy: Restore, Create and Protect Greenways and Aquatic Buffers



Aquatic buffers can clean runoff and provide a corridor for movement and migration by wildlife. Buffers can be enhanced with plantings that provide food and cover for movement. Buffers also help take up excess nutrients and salts that may otherwise degrade receiving waters. Aquatic buffers are typically the part of greenways that border the rivers or streams.

Greenways are critical corridors for the movement and migration of wildlife and vegetation and, where appropriate, can provide recreational opportunities.



Benefits of Healthy Stream Buffers. (*Graphic by Bluegrass Greensource. https://bggreensource.org/*)

Mitigation and Adaptation Strategy:
Infiltrate and Attenuate Stormwater Runoff


Addressing stormwater runoff can help to reduce flooding, buffer water temperature changes, increase seepage to cool river and stream temperatures, and protect habitat in wetlands, small streams, and floodplains. Strategies include:

- Create rain gardens, vegetated buffer strips, retention basins, and infiltration catch basins to facilitate stormwater infiltration that reduces runoff and increases groundwater reservoirs that feed wetlands and small streams in periods of drought. Such groundwater reserves also provide cool water to help sustain cold water species. Rain gardens and vegetated buffers infiltrate water and provide plantings that increase ecological value and sequester carbon.
- Maintain forested areas and other permeable surfaces to slow the rate at which stormwater can reach a stream, especially in headwater portions of watersheds, which can be an effective strategy in reducing downstream flooding. In addition, forested areas are effective in infiltrating stormwater.
- Reduce runoff from developed areas by increasing infiltration.
- Maintain shade to cool streams and water bodies, especially in warm summer months.
- Develop strategies for reducing water temperature by identifying and protecting locations where relatively large quantities of groundwater seep into streams. In addition, create strategies for reducing flash drought impacts in sub-watersheds that contribute to those seepage zones.
- Collect hydrologic data and refine models of watershed hydrology; evaluate and upgrade stormwater infrastructure to understand and predict storm water effects and risks and create a safer environment.
- Continue the NRWA water quality monitoring program. This activity has accumulated a large database of measurements of flows and water quality of the main river systems taken by NRWA volunteers. View the current NRWA River Report Card, or historic data. Combining

these data with data from USGS and the National Weather Service, as well as future measurements, will be invaluable in understanding changes to date and modeling future conditions.

- Evaluate the ability of existing infrastructure to accommodate predicted future flows. View story on NRWA's project to assess culverts for wildlife passage and climate resiliency,

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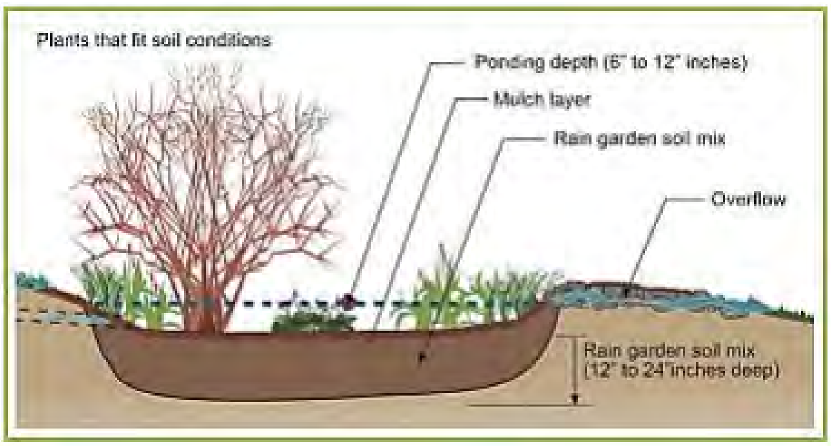
An Example: What is a Rain Garden?

A rain garden has a bowl shape to collect the rain that runs off from a roof, driveway, parking area or yard. This 6 to 9 inch deep basin fills with runoff and allows it to seep into the ground in a few hours. The rain garden plants and soils filter the stormwater and cleanse pollutants that could harm water quality.



Letting the runoff soak in, rather than go into the street, replaces the groundwater that keeps streams flowing during dry times. On hot summer days, rain gardens also cool runoff from dark pavement by putting it into the ground. A constant supply of cool, clean groundwater is essential to the health of stream and pond life.

Rain gardens are planted with flowers, shrubs, trees and grasses that are easy-to-maintain and thrive without fertilizers and pesticides. There is an array of colorful plants that can be obtained at garden centers and home improvement stores, which will provide food and habitat for wildlife.

Courtesy of the MA Watershed Coalition's Rain Garden Guide: http://www.commonwaters.org/images/stories/pdfs/raingardn_gde.pdf

Rain garden in fair weather (left) and after a rainstorm (right), photos from Massachusetts Watershed Coalition, www.commonwaters.org. View the Coalition's Rain Garden Guide.

Mitigation and Adaptation Strategy: Protect, Create, and Enhance Meadows, Gardens and Farms

Recent studies have documented significant declines in insect and bird population. Meadows provide food and habitat for many insects and birds, as well as other small animals. Meadow wildflowers and native grasses sequester significant amounts of carbon and provide infiltration of stormwater. Moreover, native grasses and wildflowers develop deep, extensive root systems. As these roots decay, organic matter in the soil builds up relatively quickly.

Image left: ***Big bluestem.*** *Big bluestem (Andropogon gerardii) is one of many deep-rooted prairie grasses in North America that can contribute to soil carbon sequestration.*

(https://www.flickr.com/photos/acryptozoo/21321111812 Licensed thru Creative Commons 2.0)

Properly managed gardens can sequester and store large quantities of carbon, especially if compost and organic waste are used as soil amendments. As pollinators decline in the environment, the need for natural pollinator plants increases. Leaving areas unmown and discouraging application of herbicides and pesticides along the margins of fields can provide more refuges for pollinators as well as other wildlife.

According to landscape ecologist Professor Robert Zomer (2017), more than a billion tons of atmospheric carbon could be sequestered and stored in the soil per year by improved agricultural practices alone. The strategies involve both preventing the loss of carbon and sequestering new carbon. Some of the management practices that reduce atmospheric carbon include the following:

- Adding organic amendments such as compost, manure, and crop residues to increase soil carbon and improve soil biology.
- Reducing or eliminating tillage to reduce carbon loss.
- Reducing erosion by contour plowing or terracing to reduce carbon loss.
- Using cover crops to reduce carbon loss and increase carbon input.
- Planting pollinator plants for insects and seed-bearing flowers and native grasses for birds.

Mitigation and Adaptation Strategy: Protect Interconnected, Resilient Ecological Reserves

- Develop comprehensive plans to protect important ecological areas within the watershed. Ecosystems are complex and vulnerable to damage by human activity and climate change.
- Connect and expand large conservation areas in order to allow plant and animal communities to migrate or adapt. Connections among protected areas expand their significance, especially when there are north-south orientations or areas with significant elevation change.
- Identify and protect optimum habitat for the endangered or vulnerable species within the watershed that have limited ability to migrate.
- Develop baseline documentation of existing conditions in order to understand and plan for the changes that are taking place within our watershed.
- Provide connectivity for wildlife to move through the landscapes. Many important wildlife species can move through developed areas that have cover and no barriers, significantly improving connectivity of reserves and allowing critical migration to take place.
- Road culverts can serve as barriers to aquatic and terrestrial species that would otherwise be able to move through the landscape. Doing an assessment of culverts in your community can reveal where they need to be replaced with more sustainable and ecologically friendly culverts. The Commonwealth of Massachusetts has a program that provides funding for such assessments and replacements.
- Identify and control invasives, the non-native plants that displace native plants or have the ability to create monocultures.

Image top: Celebration for the permanent protection of the Pepperell Springs property in Pepperell, MA, accomplished thru a broad partnership of state and local agencies, conservation groups, and individual efforts.

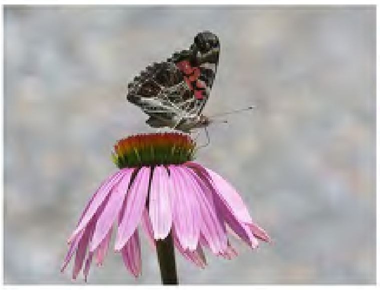
Mitigation and Adaptation Strategy: Establish Ecology-Based Municipal Open Space Plans

- Often municipal open space plans are oriented more toward recreational and visual values than ecological values. Critical ecology-based mitigation strategies are also needed. The concept of ecology-based municipal open space plans can be introduced and implemented.
- Massachusetts municipal officials can assure that their communities participate in the Massachusetts Municipal Vulnerability Preparedness Program, which provides grant funding for preparing and implementing mitigation strategies to address climate impacts.

Mitigation and Adaptation Strategy: Educate and Coordinate

- Many people associate climate change with increased storms and sea level rise, not the types of impacts that are taking place right now in our watershed. Educating the public about the changes that are taking place and the mitigation strategies that are available is therefore a critical, immediate need.
- Coordinate conservation plans among different conservation groups and among different towns. Municipalities and conservation groups can work across town boundaries on ecological strategies and habitat protection. By sharing plans, larger and more effective protected areas can be created.

Mitigation and Adaptation Strategy: Create Backyard Habitat



- Even small yards can become excellent habitat for insects and birds; and many yards support a range of wildlife. The National Wildlife Federation has a program to certify backyard habitats that can be valuable programs, especially for children.
- Use pollinator plants in gardens to support bees and other insects.
- Replace lawns with meadows: Wildflowers and native grasses provide excellent habitat for insects and birds. Converting lawns to meadows has the added benefit of creating attractive landscapes that reduce maintenance requirements.
- Remove Wildlife Barriers: maintain barrier-free landscapes that allow movement of wildlife through private lands.
- Plant Trees: Landowners, municipalities, and other private or public entities can work together to plant and maintain trees. Trees sequester and store carbon, moderate temperatures and provide critical habitat, and they enhance the visual landscape. If trees must be removed due to disease, aging, or other requirements, plant new trees. According to Eiseltova and coauthors (2012), a single shade tree can provide the cooling equivalent of many air conditioners running continuously. In Worcester, MA, after thousands of the shade trees infested with the Asian Longhorn Beetle had to be destroyed in 2008, a representative neighborhood city's summertime energy consumption increased by 37%, demonstrating the great value of shade trees in reducing the urban heat island effect.

An Example: Lawn to Meadow: Creating Biodiversity in Your Backyard

Imagine waking up to a choir of birds singing, bees buzzing, and butterflies fluttering about! Over the years, Pepperell resident Deb Fountain, turned her turf lawn into islands of native wildflowers, and even a meadow. "I started by planting a meadow and converting small patches around my yard to native plants adapted to my soil, and over the years, it gave me such pleasure, that I couldn't stop! Now I grow natives for friends, neighbors and our public grounds. I am always delighted to share what I have learned and often even a plant or two."

Give it a try. Start small. By reducing turf lawns with native wildflowers, hedgerows, trees, and swaths of meadow, you can eliminate the use of toxic pesticides and fertilizers that pollute our water, and you will be providing an essential habitat for wildlife, including for our most at-risk native pollinators. You'll love it and so will the birds!

Just getting started? Buy native plants at your local garden club plants sales; ask your public librarian for books on native plants for New England; or check out these garden and lawn online resources:

- Garden and Lawn Toolkit commissioned by the Lincoln Land Conservation Trust
- For Your Garden: Bring Home the Beauty of New England by the Native Plant Trust

Mitigation and Adaptation Strategy References

Protect and Manage Forests

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Recordings of a recent speaker series hosted by Climate Action Now of Massachusetts and Save Massachusetts Forests:

- Protecting Massachusetts Forests: Part 1 - How Massachusetts Forests Help Save the Climate, Dr. William R. Moomaw
- Protecting Massachusetts Forests: Part 2 - Our Massachusetts Forests: To Cut or Not to Cut, Michael Kellett and Dr. Bill Stubblefield, May 19, 2020
- Protecting Massachusetts Forests: Part 3. Bioenergy and Forests, Dr. Mary S. Booth, June 9, 2020
- Protecting Massachusetts Forests: Part 4. Forests and Brain Health: Emerging Research, Dr. Susan A. Masino, June 16, 2020

Burned: Are Trees the New Coal? Documentary film produced by Alan Dater and Lisa Merton of Marlborough, VT: http://burnedthemovie.com/

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Protect Interconnected, Resilient Ecological Reserves

https://www.mass.gov/service-details/replace-a-culvert

Establish Ecology-Based Municipal Open Space Plans

https://www.mass.gov/municipal-vulnerability-preparedness-mvp-program

Create Backyard Habitat

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Actions For Individuals and Landowners

Plant Meadows: Wildflowers and native grasses provide excellent habitat for insects and birds. Converting lawns to meadows has the added benefit of creating attractive landscapes that reduce maintenance requirements.

Plant and Manage Gardens for Habitat and Carbon Sequestration: Use pollinator plants in gardens to support bees and other insects. Add organic amendments such as compost, manure and crop residues to increase soil carbon and improve soil biology; reduce or eliminate tillage to reduce carbon loss.

Infiltrate Rainwater: Rain gardens, vegetated buffer strips, retention basins, and infiltration catch basins facilitate stormwater infiltration that reduces runoff and increases groundwater reservoirs feeding wetlands and small streams in periods of drought. Such groundwater reserves also provide cool water to help sustain cold water species. Rain gardens and vegetated buffers infiltrate water and provide plantings that increase ecological value and sequester carbon.

Control Invasives: As existing plant species become less well adapted to changing conditions, invasives may be increasingly able to move in to replace them and take over areas. Identify and control invasives, the non-native plants that displace native plants or have the ability to create monocultures.

Manage Forests for Habitat and Carbon Sequestration: Promote forests that have a diversity of tree species, ample tree regeneration of future-adapted species, vigorous trees of various sizes and ages, a variety of tree arrangements, and an appropriate amount of deadwood gives forests a complex structure and helps them withstand and recover from stressors. These practices also improve soil health and increase soil carbon sequestration. When forests need to be harvested, careful adherence to excellent forestry practices, such as those utilizing alternative, less intensive forest management systems and those utilizing Continuous Cover Forestry (CCF) can reduce the loss of carbon and maintain ecologically healthy forests.

Consider Personal Lifestyle Changes

Download NRWA's Climate Impact Action List for Individuals and Landowners (PDF).

An Example: Eating Less Meat Benefits Our Climate

Reducetarianism is the practice of eating less meat. The concept is appealing because not everyone is able or willing to follow a completely vegetarian diet. Reducetarians improve their health, save the lives of animals, and help mitigate climate change. Here are some reasons to consider adopting this practice in your life:

- Every minute, the land equivalent of 7 football fields is cleared to make room for animal agriculture.
- Cows produce 150 billion gallons of methane (a powerful greenhouse gas) per day.
- Transitioning to more plant-based diets could reduce the global mortality rate by 6-10%.
- Producing one pound of beef requires over 1,800 gallons of water.

Courtesy of the Reducetarian Foundation: http://www.reducetarian.org

Actions for Conservation Groups

Educate people about issues and mitigation strategies: Many people associate climate change with increased storms and sea level rise, not the types of impacts that are taking place right now in the Nashua River watershed. Educating the public about the changes that are taking place and the mitigation strategies that are available is therefore a critical, immediate need.

Determine Opportunities to create Ecological Reserves and Connections: Develop comprehensive plans to protect important ecological areas within the watershed. Ecosystems are complex and vulnerable to damage by human activity and climate change. Connect and expand large conservation areas in order to allow plant and animal communities to migrate or adapt. Connections among protected areas expand their significance.

Protect and Manage Forests for habitat and sequestration: Promote forests that have a diversity of tree species, ample tree regeneration of future-adapted species, vigorous trees of various sizes and ages, a variety of tree arrangements, and an appropriate amount of deadwood to give forests a complex structure and helps them withstand and recover from stressors. These practices also improve soil health and increase soil carbon sequestration. When forests need to be harvested, careful adherence to excellent forestry practices, such as those utilizing alternative, less intensive forest management systems and those utilizing Continuous Cover Forestry (CCF) can reduce the loss of carbon and maintain ecologically healthy forests.

Coordinate Land Protection and Management with conservation groups and towns: Municipalities and conservation groups can work across town boundaries on ecological strategies and habitat protection. By sharing plans, larger and more effective protected areas can be created.

Prepare Baseline Documentation of Ecologic Resources: Develop baseline documentation of existing conditions in order to understand and plan for the changes that are taking place within our watershed.

Download NRWA's Climate Impact Action List for Conservation Groups (PDF).

Actions for Municipalities

Evaluate Storm-related Infrastructure and upgrade as needed: Evaluate the ability of existing infrastructure to accommodate predicted future flows. Contact NRWA to obtain data and for assistance with evaluations.

Establish Ecology-Based Municipal Open Space Plans: Often municipal open space plans are oriented more toward recreational and visual values than ecological values. Critical ecology-based mitigation strategies are also needed. The concept of ecology-based municipal open space plans can be introduced and implemented.

Require Infiltration Catch Basins, Rain Gardens, and Stormwater Retention: Rain gardens, vegetated buffer strips, retention basins, and infiltration catch basins facilitate stormwater infiltration that reduces runoff and increases groundwater reservoirs that feed wetlands and small streams in periods of drought. Such groundwater reserves also provide cool water to help sustain cold water species. Rain gardens and vegetated buffers infiltrate water and provide plantings that increase ecological value and sequester carbon.

Join the Municipal Vulnerability Program (MVP): Massachusetts municipal officials can assure that their communities participate in the Massachusetts Municipal Vulnerability Preparedness Program, which provides grant funding for preparing and implementing mitigation strategies to address climate impacts.

Manage Town-owned Forests for habitat and carbon sequestration and storage: Manage forests for: a diversity of tree species, ample tree regeneration of future-adapted species, vigorous trees of various sizes and ages, a variety of tree arrangements, and an appropriate amount of deadwood to give forests a complex structure and help them withstand and recover from stressors (i.e. – increased rainfall, flooding, drought conditions during the growing season, invasive plants – trees – insects – invertebrates – diseases).

Protect Ecologically Valuable Properties: Develop comprehensive plans to conserve and protect important ecological areas within the watershed. Ecosystems are complex and vulnerable to damage by human activity and climate change. Connect and expand large conservation areas in order to allow plant and animal communities to migrate or adapt. Connections among protected areas expand their significance.

Download NRWA's Climate Impact Action List for Municipalities (PDF).

Actions for Businesses

Create Permeable Surfaces including Rain Gardens: Permeable pavements, rain gardens, vegetated buffer strips, retention basins, and infiltration catch basins facilitate stormwater infiltration that reduces runoff and increases groundwater reservoirs that feed wetlands and small streams in periods of drought. Such groundwater reserves also provide cool water to help sustain cold water species. Rain gardens and vegetated buffers infiltrate water and provide plantings that increase ecological value and sequester carbon.

Landscape with Native Grasses, Pollinator Plants, and Trees: Trees sequester and store carbon, moderate temperatures and provide critical habitat, and they enhance the visual landscape. If trees must be removed due to disease, aging, or other requirements, plant new trees.

Educate Employees about Local Climate Impacts and Mitigation Opportunities: Encourage employees to look at NRWA Climate Impact website and to take appropriate actions.

Set Goals to Become a More Climate Resilient and Sustainable Business: Take a look at your business and see if there are ways to reduce your water and energy usage, improve your recycling to reduce waste, or prepare a plan to protect your business from a climate disaster, like flooding. View the Devens Climate Action Toolkit for Businesses, from the Devens Enterprise Commission, for many ideas on how your business can become more resilient and help your community become more sustainable.

Download NRWA's Climate Impact Action List for Businesses (PDF).

NRWA Climate Change Glossary

The following terms are defined as they are used on the Nashua River Watershed Association's website.

Adaptation

Adjustments that societies or ecosystems make to limit the negative effects of climate change or to take advantage of opportunities provided by a changing climate (EPA definition).

Aquatic Buffers

Undeveloped area along a shoreline, wetland, or stream that protects the water body, filters runoff, and provides a corridor for movement and migration by wildlife.

Biodiversity

The variety of living species on Earth, including plants, animals, bacteria, and fungi. Scientists have estimated that there are around 8.7 million species of plants and animals in existence (National Geographic definition).

Biomes

Communities of flora and fauna that tend to exist together, such as the northern hardwood-hemlock-pine forests and central deciduous-oak-hickory forests found in the Nashua River watershed.

Carbon Cycle

The process in which carbon atoms continually travel from the atmosphere to the Earth and then back into the atmosphere (NOAA definition).

Carbon Footprint

The total amount of greenhouse gases that are emitted into the atmosphere each year by a person, family, building, organization, or company.

Carbon Sequestration

Processes by which trees and plants absorb carbon dioxide, release oxygen, and store carbon.

Climate Change

A significant change in the measures of climate lasting for an extended period of time. Climate change includes major changes in temperature, precipitation, or wind patterns, among others, that occur over several decades or longer.

Climate Impact

A negative effect on a natural system due to climate change.

Conservation

The protection, preservation, management, or restoration of natural environments and the ecological communities that inhabit them (USDA definition).

Corridor

Connectivity through relatively narrow, linear strips of land or water. Upland strips normally contain cover.

Deforestation

Human-driven and natural loss of trees, which affects wildlife, ecosystems, weather patterns, and climate.

Ecology

The study of the relationships between living organisms, including humans, and their physical environment.

"Flash" Drought

Short but severe drought conditions due to extraordinary heat and dryness, often caused by climate change.

Fluvial Geomorphology

The study of the interactions between the physical shapes of rivers, their water and sediment transport processes, and the landforms they create.

Fossil Fuels

Decayed organic matter from plants that accumulated in the earth over eons and is extracted primarily in the form of coal, oil or natural gas for use as energy for transportation, heating, and industrial purposes.

Greenhouse Effect

Retention of the sun's warmth in the Earth's lower atmosphere by greenhouse gases, primarily water vapor, carbon dioxide, methane, nitrous oxide and fluorinated compounds.

Greenway

A corridor of undeveloped land preserved for recreational use or environmental protection, often along a river. Naturally vegetated greenways may protect river corridors and serve as aquatic buffers.

Groundwater

Water that exists underground in saturated zones beneath the land surface. The upper surface of the saturated zone is called the water table (USGS definition).

Habitat

Place where an organism makes its home. A habitat meets all the environmental conditions an organism needs to survive, including shelter, water, food, and space (National Geographic definition).

Habitat Fragmentation

Division of large, contiguous, landscapes into smaller, unconnected areas. Fragmentation can be caused by construction of roads, homes, subdivisions, commercial and industrial activities, and other human development and can negatively impact wildlife.

Hydrology

The branch of science concerned with the properties of the earth's water, and especially its movement in relation to land.

Infiltration

The process by which water on the ground surface enters the soil. If the rate of precipitation exceeds the rate of infiltration, runoff will usually occur unless there is some physical barrier.

Invasive Species

Plants, animals, and other living organisms that are non-native (or alien) to the ecosystem and can negatively alter the environment, such as by displacing native plants or creating monocultures.

Landscape Connectivity

The degree to which a landscape facilitates or impedes movement for animals and plants.

Landscape Permeability

Developed landscapes that retain adequate natural areas to provide habitat or allow migration of wildlife and plants.

Low Impact Development

Systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration, or use of stormwater in order to protect water quality and associated aquatic habitat (EPA definition).

Meadow

An open habitat, or field, vegetated by grass, herbs and other non-woody plants. Meadows provide habitat for birds and wildlife, help to infiltrate water, protect against drought, and sequester carbon.

Mitigation

Human intervention to reduce the impact on the climate system including strategies to reduce greenhouse gas sources and emissions and enhance greenhouse gas sinks.

Municipal Vulnerability Preparedness Program (MVP)

Technical assistance available in Massachusetts for towns and cities to complete climate change vulnerability assessments, develop action-oriented resiliency plans, and implement top-priority climate change resilience projects.

Nature-Based Climate Solutions

Protecting or managing natural systems to mitigate climate impacts. Some Nature-Based Climate Solutions directly combat climate change by sequestering and storing carbon.

Non-Point Source Pollution

Non-point source pollution includes contaminants from surface runoff, groundwater discharge, sediment leaching, and atmospheric deposition. Pollution from many diffuse sources, such as fertilizers, oil and grease, road salt, and animal waste. These can be carried by rainfall or snowmelt runoff into waterways where they have harmful effects on drinking water supplies, recreation, fisheries and wildlife (EPA definition).

Paleoclimatology

The study of ancient climates, prior to the widespread availability of instrumental records, using records of climate conditions preserved in tree rings, locked in the skeletons of tropical coral reefs, sealed in glaciers and ice caps, and buried in laminated sediments from lakes and the ocean (NOAA definition).

Permeable Surface

Surfaces that let water pass through into the soil below. Unlike asphalt and concrete, permeable materials allow natural infiltration and slow the runoff of rainwater.

Pollinators

Anything that helps carry pollen from the male to female parts of flowers. Plants that are not self-pollinating depend on wind, water, birds, bees, butterflies, beetles, bats, and other small mammals for fertilization and the production of fruits, seeds, and young plants.

Pollinator Plants

Flowering plants that provide nectar or pollen for a wide range of pollinating insects. Planting a pollinator garden supports the health of pollinators such as honey bees, native bees, and monarch butterflies.

Rain Garden

A vegetated landscape depression that collects rainwater from a roof, driveway, parking area, or street and allows it to soak into the ground. Benefits of planting rain gardens include slowing the flow of runoff, filtering out pollutants, and providing food and shelter for wildlife.

Renewable Energy

Energy resources that are often considered naturally replenishing such as hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action.

Reserve

A large resilient or resistant, protected area where climate-induced changes occur in a manner that allows plant and animal communities to migrate or adapt.

Resilience

A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment (EPA Definition).

Resistance

The ability of an ecosystem or population to persist and remain relatively stable in response to climate change or other stress. Landscapes that are resistant are particularly important for species that require specific habitat or have little ability to migrate, such as vernal pool species.

Restoration

Actions to reverse the current climate change trends and to restore the Earth to a healthy climate for humanity's well-being.

Sedimentation

In rivers, eroded or discharged organic and inorganic material transported by water that settles out as the water flow slows.

Stormwater

Runoff generated from rain and snowmelt events that flows over land or impervious surfaces, such as paved streets, parking lots, and building rooftops, and does not soak into the ground (EPA definition). It often carries contaminants, such as sediment, heavy metals, organic molecules including oil & grease and pesticides, nutrients such as nitrogen and phosphorus, and pathogens.

Stormwater Infrastructure

Traditional "gray" infrastructure refers to curbs, gutters, drains, piping, and collection systems that collect and convey stormwater into a series of piping that ultimately discharges untreated stormwater into a local water body. "Green" stormwater infrastructure is designed to mimic nature and capture rainwater where it falls, reducing the volume of pollutants, such as sediment, nitrogen and phosphorus, entering our waterways (EPA definitions).

Sustainable Development

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (UN definition).

Sustainability

A state in which the demands placed on the environment can be met without reducing its capacity to allow all people to live well, now and in the future.

Vernal Pool

An isolated wetland that is a shallow pool that fills in the spring and dries up annually or every few years. They supply essential breeding habitat for several species of animals, particularly amphibians, because they lack a fish population that would otherwise prey on them.

Watershed

An area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel (USGS definition).

Wetlands

Areas where water covers the soil, or is present either at or near the surface of the soil, all year or for varying periods of time during the year, including during the growing season (EPA definition).