



Wood-Pawcatuck Watershed

Flood Resiliency Management Plan

prepared by FUSS & O'NEILL

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1 Introduction

This watershed management plan provides recommendations to protect and enhance the flood resiliency of communities in the 300-acre Wood-Pawcatuck watershed and improve river and stream ecosystems, including water quality and habitat. This introductory section describes: 1) the flooding and water quality issues in the Wood-Pawcatuck watershed, 2) the purpose and benefits of developing a comprehensive watershed-based plan and a multi-benefit, ecosystem-based approach to flood resiliency, and 3) the overall organization of this document.

> Watershed Management
>
> A **watershed** is the land area that drains to a common outlet such as a river, stream, lake, or bay. Watersheds ignore political boundaries. **Watershed planning** is a process that identifies ways to protect and restore the water quality and other natural resources in a watershed. The outcome of the watershed planning process is documented in a **watershed management plan**.

1.1 The Wood-Pawcatuck Watershed

The Pawcatuck River and its major tributary, the Wood River, are located in southwestern Rhode Island and portions of southeastern Connecticut (Figure 1-1). The lower Pawcatuck River forms the border between Rhode Island and Connecticut and flows into the eastern end of Long Island Sound at Little Narragansett Bay. The area of land that drains to the Pawcatuck and Wood Rivers – commonly referred to as the "Wood-Pawcatuck watershed" – is approximately 300 square miles and includes numerous tributaries (Queen, Usquepaug, Chickasheen, Chipuxet, Ashaway, Beaver, Shunock, and Green Falls Rivers) and portions of 14 communities. The Wood-Pawcatuck is the most rural and least developed major watershed in Rhode Island, with a majority of the development focused in the southern part of the watershed in Westerly, Rhode Island and Stonington, Connecticut as well as small towns and villages along the Pawcatuck and its tributaries.

> Flood Resiliency
>
> The term "resiliency" or "resilience" has many definitions. In general, it is the ability to become strong, healthy, or successful again after something bad happens – the ability to spring back into action. In the context of flooding, resiliency refers to a community's ability to plan for, respond to, and recover from floods. It includes measures taken to reduce the vulnerability of communities to damages from flooding and to support long-term recovery after an extreme flood (EPA, 2014).

1.2 Flooding in the Wood-Pawcatuck

Riverine flooding and drainage-related flooding in developed areas are relatively common in the Wood-Pawcatuck watershed. The watershed communities have suffered extensive flooding and flood-related damages, with the most extreme flooding on record having occurred in the March and April floods of 2010 (Figure 1-2). The incredible amount of precipitation (over 16 inches) that fell in February and March 2010, along with saturated soils, high water tables, lack of leaf cover and limited pervious surfaces all contributed to the worst flooding ever experienced along the Pawcatuck River and many other areas of Rhode Island (RIEMA, 2011).

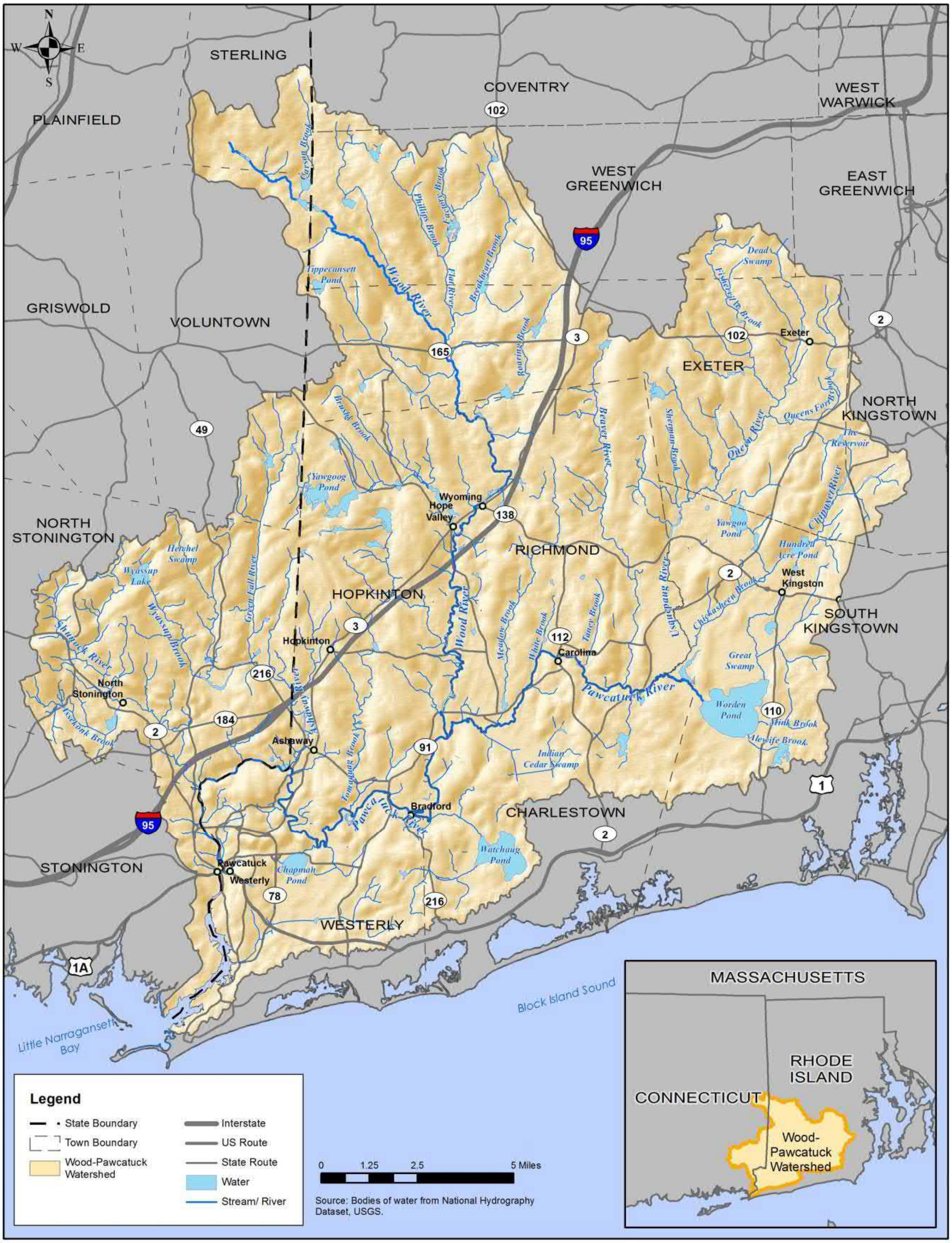


Figure 1-1. Wood-Pawcatuck watershed.

Communities that were most severely affected by the 2010 flooding include Westerly, Stonington, Charlestown, Hopkinton, Richmond, and Exeter. Flood damages consisted of flooding and washout of roadways, damages to bridges and culverts, damages to and failure of dams, flooding of properties and structures, erosion and sediment deposition in watercourses and wetlands, and sediment and pollutant loads carried downstream to in-stream impoundments and ultimately Little Narragansett Bay.

Figure 1-2. Flooding in the Wood-Pawcatuck watershed during March and April 2010. Aerial photo of flooding in Westerly, RI (top left). Route 91 underwater in Westerly can barely be seen crossing wetlands east of Chapman's Pond. Flooding in the Friendship Street area of Westerly, RI (top right). Flooding at the Potter Hill Dam and fish ladder, Ashaway, RI (bottom left). Flooding along Beaver River at Hillsdale Road (bottom right).

Types of Flooding in the Watershed

Riverine flooding is the most common type of flooding in the Wood-Pawcatuck watershed. Riverine flooding occurs when rivers or streams overflow their banks and flow into the adjacent floodplain. The recurrence interval of a flood is defined as the average time interval, in years, expected to take place between the occurrence of a flood of a particular magnitude to an equal or larger flood. Flood magnitude increases with increasing recurrence interval (RIEMA, 2014). Hazards associated with riverine flooding include both flood inundation of developed areas (roads, homes, businesses, etc.) and riverine erosion, including erosional and depositional processes. Riverine erosion can affect structures located outside, as well as inside the regulatory floodplain, and elevating structures above the 100-year base flood elevation may not provide adequate protection from erosion damages (ASFPM Riverine Erosion Hazards Working Group, 2016).

Urban drainage flooding is also common in the more urbanized areas of the watershed as a result of outdated and undersized storm drainage systems. Urbanization contributes to flooding by increasing impermeable surfaces, increasing the speed of drainage collection, and reducing the carrying capacity of the land, all of which can overwhelm storm drainage collection systems. High groundwater levels and poor soils, which are common in highly developed areas, can exacerbate urban drainage flooding (RIEMA, 2014).

Dam failure or breach can also result in sudden downstream flooding (i.e., flash flooding). Dam failures can result from natural or human-induced events, or some combination of the two. Failures due to natural events such as prolonged periods of rainfall and flooding can result in overtopping, which is the most common cause of dam failure. Overtopping occurs when a dam's spillway capacity is exceeded and portions of the dam, which are not designed to convey flow, begin to pass water, erode away and ultimately fail. Other causes of dam failure include design flaws, foundation failure, internal soil erosion, inadequate maintenance or operational failure. Complete failure of a dam can release a high-velocity wall of debris-laden water that rushes downstream, damaging or destroying everything in its path (Town of Charlestown Natural Hazard Mitigation Committee, 2016). The Blue Pond Dam in Hopkinton experienced a significant breach during the 2010 flood. Flooding and damage to roads was experienced along the inundation area downstream of the dam. Alton Pond Dam, the next downstream dam, was overtopped but did not fail (Hopkinton Hazard Mitigation Committee, 2011).

Coastal flooding is typically a result of storm surge and wind-driven waves caused by hurricanes, nor'easters, and other large coastal storms. Storm surges may push sea water up coastal rivers and inlets, blocking the downstream flow of inland runoff (RIEMA, 2014). In the Wood-Pawcatuck watershed, coastal flooding is limited to the estuarine portion of the Pawcatuck River.

Factors Contributing to Flooding in the Watershed

Several factors contribute to flooding in the watershed. Historical development in the watershed has resulted in filling of wetlands, floodplains, and floodways, which has reduced natural flood storage and placed development in flood-prone areas. Many of the streams in the watershed, as is common in New England, have also been physically modified (i.e., moved, straightened, hardened), which can increase riverine erosion hazards in certain areas. Development of the landscape with roads, parking lots, and buildings – impervious surfaces that prevent rainfall from infiltrating into the ground naturally – has increased the amount of storm runoff. Stormwater drainage infrastructure in developed areas also conveys runoff quickly to rivers and streams. Undersized bridges and culverts have also contributed to flooding and erosion. Dams within the watershed create flood hazards by backing up water during major floods and by releasing very large quantities of flow, sediment, and debris in the event of a sudden failure.

History of Flooding in the Watershed

Flood events have caused significant damage in the Wood-Pawcatuck watershed over the years. Some of the more notable historic floods in the region include:

- November 1927: Based on historical information obtained for the USGS gaging stations on the Wood River at Hope Valley and on the Pawcatuck River at Westerly, the worst flood since 1886 occurred in November 1927, which was caused by a tropical storm.

- March 1968: Prior to the 2010 floods, the March 1968 flood constituted the record flood for the State of Rhode Island. The March 1968 flood resulted from heavy rainfall that followed a period of sustained snowmelt which had caused stream flows to be much above normal.

- June 1982: A torrential storm on June 5-6, 1982, produced as much as 8 inches of rain and caused Statewide flooding. The Pawcatuck and Pawtuxet Rivers were among the hardest hit in the region.

- March 2010: Rhode Island (and southeastern Connecticut) experienced the worst flooding in its recorded history on a number of the State's largest rivers, including, but not limited to the Pawtuxet, Pawcatuck and Woonasquatucket. The incredible amount of precipitation in February and March 2010, along with saturated soils, high water tables, lack of leaf cover and limited pervious surfaces all contributed to the disastrous flooding during March.

- Hurricane Sandy (2012): Hurricane Sandy caused significant coastal damage in southern New England, including Little Narraganset Bay and coastal areas south of the watershed.

Table 1-1 summarizes significant rainfall and flooding events in Washington County since the early 1990s, according to information compiled by the National Climatic Data Center (Town of Charlestown Natural Hazard Mitigation Committee, 2016). Figure 1-3 shows flood flow hydrographs for selected USGS stream gaging stations in the Wood-Pawcatuck watershed, including recent and historical floods.

Table 1-1. Significant rainfall and flooding events in Washington, County, Rhode Island.

Date	Rainfall (inches)	Comments
April 1, 1993	Flash Flood	Pawcatuck River flooding onto Driftwood Drive
September 18, 1996	2”-3.5”	Early season coastal storm
December 7, 1996	2”	No damage reported
January 10, 1997	Coastal Flood	A new moon in combination with strong SE winds resulted in a 2’-4’ storm tidal surge in Narragansett Bay.
August 29, 1997	2.5”-5”	Extensive flooding along Route 1
November 1, 1997	2”- 3”	No damage reported
February 18, 1998	2”-3.5”	Flooding in poor drainage areas
March 8, 1998	2”-3”	Flooding in poor drainage areas and flood prone property
April 1, 1998	2”	No damage reported
June 13, 1998	6”-8”	Numerous small streams flooded their banks
May 23, 1999	3.15”	No damage reported
September 10, 1999	2”-5”	No property damage reported
September 16, 1999	2”-5”	Several trees downed, no flood damage reported
March 29, 2003	2”-3”	Flooding in poor drainage areas
October 15, 2005	2.5”-4.5”	Heavy rain caused flooding across the region and forced some roads to close as a result.
October 28, 2006	2”-4”	Rainfall produced significant urban flooding and caused some minor flooding of rivers and streams.
March 2, 2007	2”-3”	Snow quickly changed to heavy rain and caused widespread urban and small stream flooding.

Table 1-1. Significant rainfall and flooding events in Washington, County, Rhode Island.

Date	Rainfall (inches)	Comments
April 16, 2007	3”-5”	Slow moving coastal storm produced heavy rain and gusty winds, minor to moderate coastal flooding.
March 8, 2008	2”-3”	Heavy rain coinciding with snowmelt caused some river flooding. Along the coast high astronomical tides combined with rough seas and storm surge to produce minor coastal flooding.
August 22, 2009	2”-4”	Tropical depression caused heavy rain and high surf in the area. Several driveways on Charlestown Beach Road were flooded with ocean waters.
March 14, 2010	3”-6”	Heavy rain caused flooding of small steams, urban and poor drainage areas. Strong winds associated with the storm also downed trees, limbs and wires.
March 29, 2010	5”-10”	The Pawcatuck River set a record of nearly 15 ½’ and overflowed its banks in Charlestown closing Route 91 and Shannock Road. Numerous roads and basements were flooded. The entire state was impacted by this event and a Presidential Disaster Declaration was made. It is estimated that there were over $26 million in damages.
August 10, 2012	Wind Damage	Southerly winds drew tropical moisture over the area, resulting in very heavy rain in showers and thunderstorms that developed. In addition, strong winds in the upper levels and 30-40 knots of deep layer shear resulted in wind damage with the strongest of these storms.
June 7, 2013	3”-6”	Three to six inches of rain fell across Washington County. In Charlestown, Route 1, Route 112, Old Coach Road, and Klondike Road all were flooded.
March 30, 2014	2”-5”	Anywhere from two to five inches of rain fell across southern New England with the highest amounts falling along the south coast of RI and MA. This resulted in flash flooding across much of this area.
July 15, 2015	Flood/Flash Flood	Showers and thunderstorms developed across the area as a result of an upper level disturbance and a cold front. A couple of these slow moving storms resulted in flooding or flash flooding.
July 28, 2015	Damaging Winds/Heavy Rains	A strong upper level disturbance sparked showers and thunderstorms across much of southern New England. A few of these storms became severe, producing damaging winds. Others produced heavy rain that resulted in flooding.

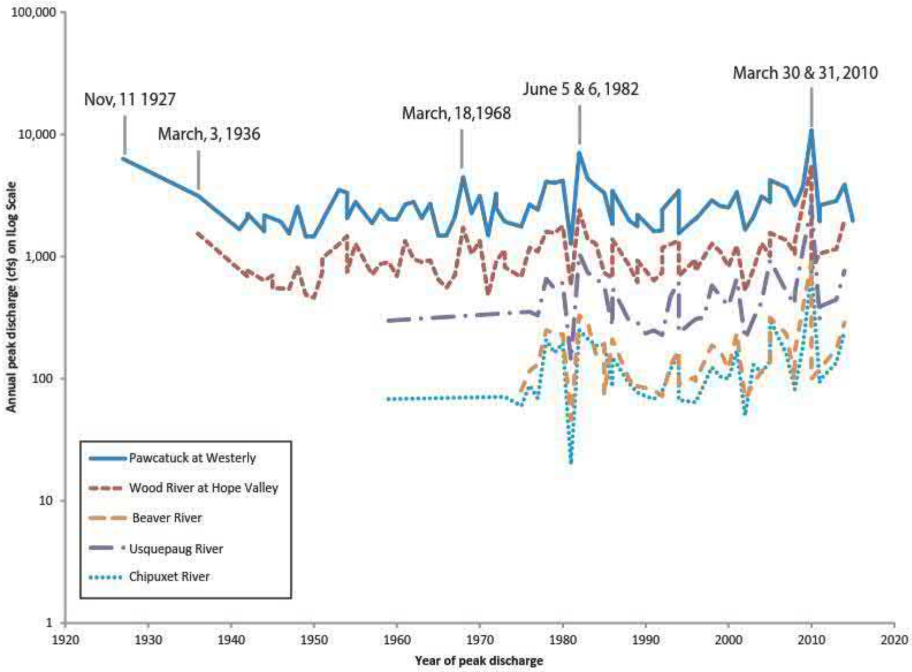


Figure 1-3. Plot of annual peak discharge at several USGS stream gages in the Wood-Pawcatuck watershed (Field, 2015).

Flood events of a magnitude which are expected to be equaled or exceeded once on the average during any 10-, 50-, 100-, or 500-year period (recurrence interval) are used by federal and state agencies and local communities for implementing floodplain management programs and for flood insurance rates. These events, commonly termed the 10-, 50-, 100-, and 500-year floods, have a 10-, 2-, 1-, and 0.2-percent chance, respectively, of being equaled or exceeded during any year. Although the recurrence interval represents the long term average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year (FEMA, Revised 2013). For example, a 100-year flood is not a flood that occurs every 100 years. In fact, the 100-year flood has a 26-percent chance of occurring during a typical 30-year mortgage (RIEMA, 2014).

Table 1-2 summarizes peak flow estimates for the Pawcatuck River at Westerly and Wood River Junction for various recurrence intervals. USGS estimates that most gaged locations in the Wood-Pawcatuck watershed experienced 500-year return interval peak flows during the 2010 flood (Zarriello, Ahearn, & Levin, 2012).

Table 1-2. Estimated magnitude of flood flows for selected Annual Exceedance Probabilities (AEP) at selected stream gages on the Pawcatuck River.

		Peak Flow Estimate (cfs)	
AEP (%)	Return Interval (years)	Pawcatuck River at Westerly, RI (01118500)	Pawcatuck River at Wood River Junction, RI (01117500)
20	5	3,300	1,030
10	10	4,080	1,280
4	25	5,230	1,660
2	50	6,220	1,990
1	100	7,340	2,370
0.5	200	8,610	2,790
0.2	500	10,600	3,440

Future Flooding and Climate Change

Both mean and extreme precipitation in the region has increased during the last century, with the highest number of extreme events occurring over the last decade. Continued increases in frequency and intensity of extreme precipitation events are projected (Runkle, et al., 2017). According to the National Climate Assessment, "the Northeast has experienced a greater increase in extreme precipitation over the past few decades than any other region in the United States; between 1958 and 2010, the Northeast saw a 74% percent increase in the amount of precipitation falling in very heavy events" (Melillo, Richmond, T.C., & Yohe, G.W., 2014). Rainfall in New England is expected to continue to increase due to climate change, which is expected to increase the risk of river-related flooding in the future. Bridges, roads and dams will be more susceptible to flood damage because of more severe storms and heavy rainfall.

Sea level has risen more than 9 inches since 1930 at Newport, RI, faster than the global average. A recent assessment by the National Oceanic and Atmospheric Administration projects a possible worst-case sea level rise scenario for Rhode Island of 9-10 feet by 2100 (National Oceanic and Atmospheric Administration, 2017), which is significantly higher than previous projections of sea level rise in the region, which have generally ranged from 1 to 4 feet by 2100 (Runkle, et al., 2017). Increases in sea level will likely increase coastal flooding and erosion during winter storms (nor'easters) and hurricanes, threatening coastal infrastructure and populations.

Rainfall in New England is expected to continue to increase due to climate change, which is expected to increase the risk of river-related flooding in the Wood-Pawcatuck watershed. Rising sea levels are expected to directly impact the Pawcatuck River estuary but could also lead to development pressure in the watershed as populations retreat inland from a receding shoreline.

Given this trend, the communities in the Wood-Pawcatuck watershed face an increasing risk of flooding and storm-related damages as large storms and floods become more common. In addition to climate change, some parts of the watershed are susceptible to future development pressure that, if not appropriately controlled, could increase floodplain encroachments, reduce the natural water-absorbing capacity of the land, increase impervious surfaces and stormwater runoff, and worsen flooding impacts. Future development pressure in inland areas could also be accelerated by rising sea levels along the coast. This could put significant pressure on the real estate market and lead to new development in the Wood-Pawcatuck watershed as populations retreat inland from a receding shoreline in response to rising sea levels.

Flood Zones

Flood zones are defined by the Federal Emergency Management Agency (FEMA) as the area below the high water level that occurs during a flood of a specified recurrence interval. Special Flood Hazard Areas (SFHA) are defined on FEMA Flood Insurance Rate Maps (FIRM) as the area that will be inundated by the flood event having a 1-percent chance of being equaled or exceeded in any given year. The 1-percent annual chance flood is also referred to as the base flood or 100-year flood. Moderate flood hazard areas, also shown on the FIRM, are the areas between the limits of the base flood and the 0.2-percent-annual-chance (or 500-year) flood. Figure 1-4 depicts Special Flood Hazard Areas in the Wood-Pawcatuck watershed.

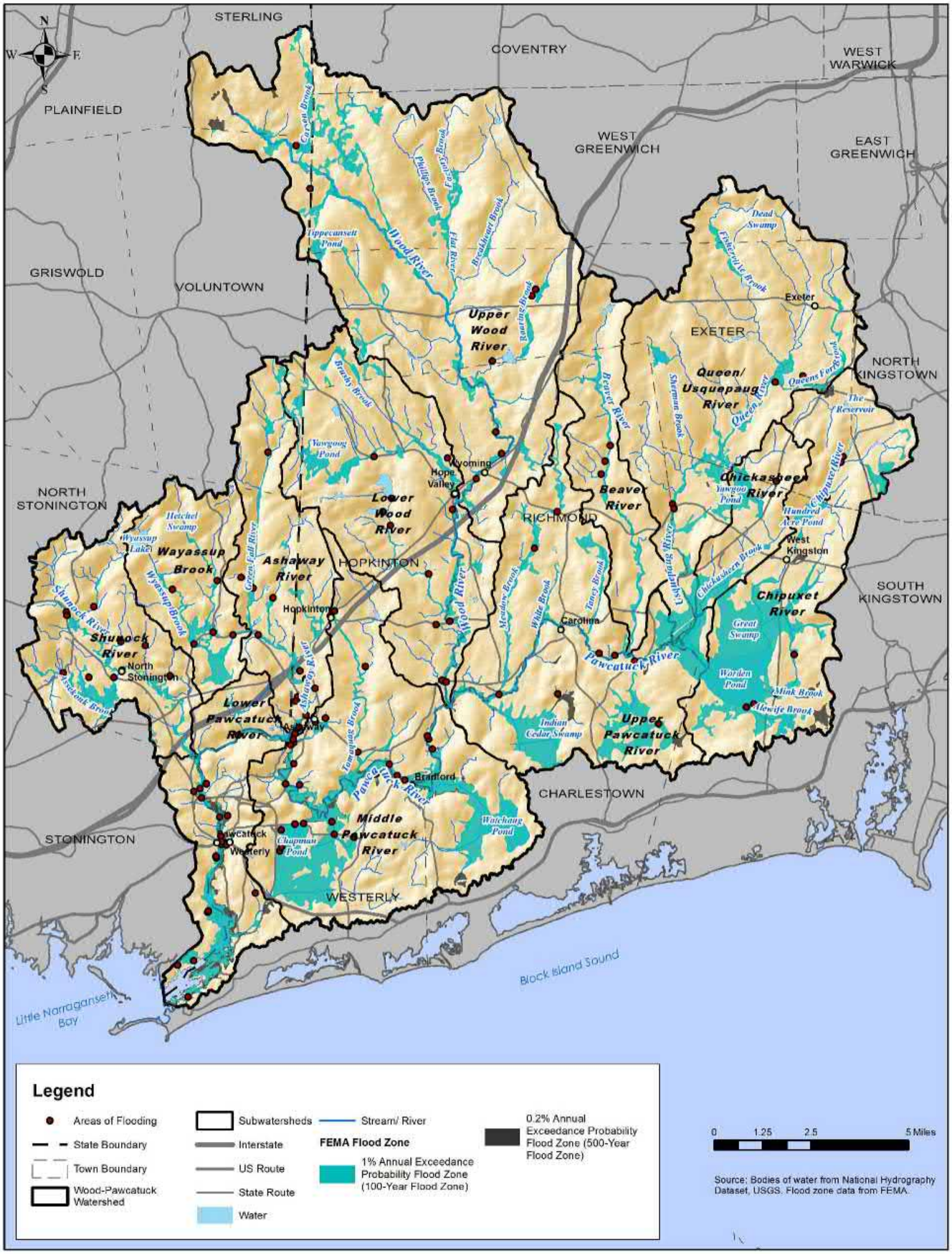


Figure 1-4. Special Flood Hazard Areas and areas of flooding in the Wood-Pawcatuck watershed.

FEMA is working with the U.S. Geological Survey (USGS) and other federal, state, and local partners to identify flood risk and help reduce that risk through the Risk Mapping, Assessment and Planning (Risk MAP) program. Risk MAP is designed to help increase the purchase of flood insurance and increase the public's awareness of flood prone structures and potential mitigation measures (RIEMA, 2014). FEMA and USGS are nearing completion of a Risk MAP project for major portions of the Wood-Pawcatuck watershed including the Chipuxet, Queen-Usquepaug, Beaver, Wood, Ashaway, Shunock, and Pawcatuck Rivers. The project will result in updated flood mapping for the watershed, which will support community-based flood mitigation planning efforts. Updated flood mapping for the watershed is expected to be released in 2017.

The Baseline Assessment report in Appendix A contains a tabular summary of documented areas of flooding in the Wood-Pawcatuck watershed obtained from FEMA Flood Insurance Studies, local hazard mitigation plans and municipal comprehensive plans, input from the Project Steering Committee and municipal staff. The documented flooding locations include both individual sites such as specific road-stream crossings, bridges, streets, etc., as well as more generalized areas of flooding such as entire neighborhoods or stream reaches. These documented flooding locations are shown on the flood hazard map in Figure 1-4.

Existing Flood Mitigation and Resiliency Programs

National Flood Insurance Program (NFIP)

The National Flood Insurance Program (NFIP), established by Congress in 1968, provides flood insurance to property owners in participating communities. This program is a direct agreement between the federal government and the local community that flood insurance will be available to residents in exchange for the community's compliance with minimum floodplain management requirements such as the adoption of a floodplain management or flood damage prevention ordinance. In order for property owners to purchase flood insurance through the NFIP, their community must be in good participant standing in the NFIP. Communities participating in the NFIP must (RIEMA, 2014):

- Adopt the FIRMs as an overlay regulatory district or through another enforceable measure
- Require that all new construction or substantial improvement to existing structures in the SFHA will be compliant with the construction standards of the NFIP and State building code, which is implemented at the local level by municipal building officials
- Require additional design techniques to minimize flood damage for structures being built in high hazard areas, such as floodways or velocity zones.

All of the watershed communities and the Narragansett Indian Tribal Nation are members of the NFIP and are in good standing. For most of the watershed communities, floodplain and flood management requirements are incorporated into municipal zoning and subdivision regulations.

Community Rating System (CRS)

The Community Rating System (CRS) is a voluntary program that recognizes and encourages a community's efforts that exceed the NFIP minimum requirements for floodplain management. The CRS program emphasizes the reduction of flood losses, facilitating accurate insurance rating, and promoting the awareness of flood insurance. By participating in the CRS program, communities can earn a discount for flood insurance premiums based upon the activities that reduce the risk of flooding within the community. Currently, four (4) communities in the Wood-Pawcatuck watershed – Charlestown, North Kingstown, Westerly, and Stonington – participate in the CRS program, receiving discounts for flood insurance premiums of between 5% and 15% (RIEMA, 2016; Community Rating System (CRS), 2016).

Flood Mitigation Funding Programs

FEMA, the U.S. Department of Housing and Urban Development, and the U.S. Department of Transportation are the primary federal funding agencies for flood mitigation projects. The FEMA Hazard Mitigation Assistance Program provides funding through the Flood Mitigation Assistance (FMA), Hazard Mitigation Grant Program (HMGP), Pre-Disaster Mitigation (PDM), and Public Assistance grant programs. HUD provides flexible grants to help cities, counties, and States recover from Presidentially- declared disasters, especially in low-income areas, through the Community Development Block Grant – Disaster Recovery Funding (CDBG-DR) program. The U.S. Army Corps of Engineers (USACE) also builds and repairs major flood control projects such as dams and levees, sometimes requiring a state or local match for the investment (USEPA, 2014). Other sources of funding are becoming available for flood resiliency projects that benefit natural systems, including the RIDEM Narragansett Bay and Watershed Restoration Fund. Section 6 identifies potential funding sources for implementation of the recommendations in this plan.

1.3 Other Issues Facing the Watershed

Flooding is not the only water-related issue facing the Wood-Pawcatuck watershed. Water quality, habitat, and species diversity have also been affected by floodplain development, stream corridor modifications, and impervious cover. The Wood-Pawcatuck has some of the highest quality surface water, groundwater, and ecological resources in the State of Rhode Island given the high percentage of undeveloped and forested land in the watershed. However, surface water quality has been degraded in the more developed portions of the watershed, including the lower part of the Pawcatuck River and Little Narragansett Bay, in other developed areas along the main stem of the Pawcatuck and its major tributaries, and near the headwaters in South Kingstown. Excessive quantities of nutrients, sediment, and indicator bacteria from various point and nonpoint pollutant sources, including urban and agricultural stormwater runoff, are among the causes of water quality problems in the watershed. The impacts of commercial turf farms and other significant surface water users on streamflow and aquatic habitat is an ongoing concern in the watershed. In addition to contributing to flood hazards, undersized road stream crossings (i.e., culverts and bridges) and dams in the watershed are also potential obstacles to aquatic organism passage, preventing fish and other wildlife from using certain portions of the river system and isolating some populations.

1.4 Why Develop a Watershed-Based Management Plan?

A watershed plan provides a framework to help groups within a watershed work across municipal boundaries to address flooding and protect and restore water resources throughout the watershed.

Watershed-based planning is an effective approach for addressing flooding and water quality. The Wood-Pawcatuck Watershed Association (WPWA) and its project partners, including the watershed municipalities, the Rhode Island Department of Environmental Management (RIDEM), the Connecticut Department of Energy and Environmental Protection

(CTDEEP), and other groups, recognize the need to increase flood resiliency and protect and restore water quality and ecological conditions of the Wood-Pawcatuck using a watershed-based approach. This can be accomplished by developing and implementing a comprehensive watershed management plan.

Project Objectives

The objectives of this project are to:

1. Assess the vulnerability of the watershed to the growing risks from flooding and riverine erosion,
2. Develop a comprehensive, watershed-based management plan that will identify prioritized actions to protect and enhance the resiliency of the watershed communities to future flooding and improve river and stream ecosystems, including water quality and habitat.

Plan Goals and Outcomes

The primary goals and expected outcomes of the watershed management plan include:

This plan is intended to help local decision-makers think more strategically about utilizing natural systems to provide more effective strategies that will reduce flooding, while also benefitting the watershed ecosystem.

- Protect and enhance the resiliency of the watershed communities to future flood damages.
- Strengthen and restore natural ecosystems, including water quality, species and habitat, while increasing flood resiliency.
- Help the watershed communities (local and state governments and private land owners) prepare for and mitigate the impacts of future severe storms.
- Protect critical community infrastructure and the ability of communities to deliver vital municipal services.
- Protect and enhance fish and wildlife species and habitats.
- Maintain and improve the viability of agricultural and forested land.
- Help communities understand watershed and riverine processes so that better land use and infrastructure investments can be made.
- Strengthen local land use policies and regulations to enhance flood resilience.
- Improve the quality of life and economic viability of the watershed communities.
- Facilitate capacity-building and engage the watershed municipalities and other stakeholder groups in the watershed planning process and future plan implementation.
- Promote collaboration across municipal boundaries, bringing the watershed communities and groups together to cooperate around shared issues of concern and objectives without compromising their “home rule” principles.
- Better position the watershed communities for future grant funding from State and Federal sources.

1.5 A Multi-Benefit Approach to Flood Resiliency

Flooding places risks on community infrastructure, public safety and welfare, and can have impacts to ecosystems. Natural systems such as wetlands, floodplains, forests and other vegetated open spaces are natural filters that can absorb rain and floodwaters and mitigate flooding, while also benefiting water quantity and quality for communities and sustaining a healthy ecosystem.

A key objective of this project is to promote flood resiliency measures that consider both infrastructure (e.g., roads, bridges, culverts, buildings) and natural system solutions (e.g., conservation, restoration of habitat including riparian corridors, wetlands, and forests). This plan is intended to help local decision-makers think more strategically about ways to utilize natural systems to provide more effective strategies to reduce flooding, while also benefitting the watershed ecosystem. The protection and restoration of natural resources in the watershed will reduce flood potential while protecting water quality and ecological health.

1.6 Organization of this Document

This watershed plan document is organized as follows:

- Section 1 – Introduction describes the flooding and water quality issues in the Wood-Pawcatuck watershed, the purpose and benefits of developing a watershed-based plan and a multi-benefit approach to flood resiliency, and how this plan is organized.

- Section 2 – Plan Development Process describes the process used in developing the watershed management plan, including the project partners and funding, Project Steering Committee, technical assessments, and public participation and outreach process.

- Section 3 – Watershed Overview summarizes the key physical, land use, and ecological characteristics of the Wood-Pawcatuck watershed.

- Section 4 – Management Recommendations describes the Plan's specific recommendations and implementation actions for a range of management measures.

- Section 5 – Funding Sources identifies potential state and federal funding sources to augment municipal funding for implementing the plan recommendations.

- Section 6 – References contains a list of references cited in this document.

- Appendices – the Plan appendices include Town-specific summaries, maps of plan recommendations by subwatershed, and links to technical reports documenting the technical assessments that serve as the basis for the plan recommendations.

2 Plan Development Process

2.1 Project Partners and Funding

In 2014, the Wood-Pawcatuck Watershed Association (WPWA) received a grant from the National Fish and Wildlife Foundation Hurricane Sandy Coastal Resiliency Competitive Grant Program to develop a flood resiliency management plan for the Wood-Pawcatuck watershed. Fuss & O'Neill, Inc. was retained by WPWA to lead the development of the watershed management plan. Key project partners include the watershed municipalities, the Rhode Island Department of Environmental Management (RIDEM), the Connecticut Department of Energy and Environmental Protection (CTDEEP), and other governmental agencies, stakeholder groups, and interested citizens.

> *Funding for this project was provided by a grant from the National Fish and Wildlife Foundation Hurricane Sandy Coastal Resiliency Competitive Grant Program.*

The plan development process consisted of review of existing information, watershed technical assessments including field data collection and analysis, public participation and outreach, and input from a project steering committee. The plan builds upon recent and ongoing flood hazard mitigation efforts in the watershed by state and federal agencies, including:

- A recently-completed multi-year flood risk management feasibility study for the lower Pawcatuck River in response to the 2010 flooding, conducted by the U.S. Army Corps of Engineers (USACE) (Pawcatuck Flood Risk Management Feasibility Study).
- A joint effort by the U.S. Geological Survey (USGS) and Federal Emergency Management Agency (FEMA) to update flood hazard mapping for large portions of the Wood-Pawcatuck watershed (Risk Mapping, Assessment and Planning program).
- Municipal flood management programs implemented by the watershed communities under the National Flood Insurance Program and Community Rating System.
- Wild & Scenic River Study for the Wood-Pawcatuck watershed.

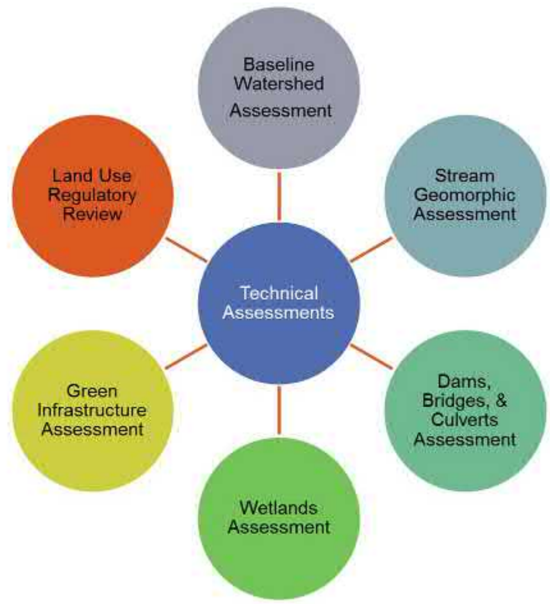
This flood resiliency management plan has also been developed in conjunction with RIDEM and CTDEEP and will serve as a companion to a separate "water quality" watershed-based plan that is being developed by RIDEM for the Wood-Pawcatuck watershed. Both plans will better position the watershed communities for funding under Section 319 of the Clean Water Act and improve the chances for funding through other State and Federal sources.

2.2 Project Steering Committee

A Project Steering Committee was formed to guide the plan development. The Steering Committee consisted of representatives from the watershed municipalities most affected by flooding (Hopkinton, Richmond, Charlestown, Westerly, and Stonington, although all of the watershed communities were invited to participate), government agencies including RIDEM, CTDEEP, USGS, and USACE, and others who live and work within the watershed.

Members of the Project Steering Committee attended workshop meetings and provided review comments on draft deliverables. The watershed plan reflects the combined efforts of WPWA, the watershed municipalities, government agencies, other stakeholders, and the Fuss & O'Neill project team. Members of the Project Steering Committee and other individuals involved in the plan development process are listed in the Acknowledgements section at the beginning of this document.

2.3 Technical Assessments



A series of technical assessments were conducted for the Wood-Pawcatuck watershed to inform and guide the management plan recommendations. The assessments involved review of historic information and studies, screening-level evaluations using available GIS data to prioritize field efforts, and field data collection and analysis. Field data collection and use of secondary data followed the methods outlined in an approved Quality Assurance Project Plan (QAPP) developed for this project. The methods and results of the technical assessments are documented in separate technical memoranda. Electronic versions of the technical memoranda can be accessed at the links provided in the plan appendices.

- Baseline Watershed Assessment: A baseline assessment of the watershed was prepared to document the watershed's physical, land use, and ecological characteristics. The baseline assessment, combined with the other watershed technical evaluations described below, informed the management plan recommendations and serves as a background reference document to support future implementation activities within the watershed.

- Stream Geomorphic Assessment: A watershed-wide fluvial geomorphic assessment was performed to identify the geomorphic classification of the rivers and streams in the watershed. The assessment included detailed analysis of approximately 40 miles of rivers and streams in the watershed, focusing on known areas of flooding and erosion and areas of the river corridors with potential for future development. Based on the results of the geomorphic assessment, river corridor planning recommendations were developed to identify restoration projects that could reduce flood hazards and downstream sediment loading and improve aquatic habitat.

- Dams, Bridges, and Culverts Assessment: An assessment was performed of the hydraulic structures in the watershed (i.e., culverts and bridges), including an assessment of their hydraulic capacity under current and future (i.e., climate change) conditions, flooding impact potential, geomorphic vulnerability, and aquatic organism passage. Structures were prioritized for upgrade or replacement based on the assessment findings. This task also includes an assessment of the dams in the watershed for potential removal, repair or modification to reduce flood risk due to dam failure, potential re-purposing to increase flood storage, and to enhance fish passage and aquatic habitat.

- Wetlands Assessment: A watershed-wide wetlands assessment was conducted to evaluate potential wetland protection, enhancement, and restoration opportunities in the Wood Pawcatuck watershed to enhance flood resiliency, habitat, and water quality.

- Green Infrastructure Assessment: A green infrastructure assessment was performed for the Wood-Pawcatuck watershed. The assessment identified opportunities for site-specific green stormwater infrastructure retrofits that would increase flood resiliency by reducing runoff volumes and peak flows and improve or protect water quality by reducing pollutant loads to receiving waters. The assessment identified approximately 30-site-specific project concepts in the watershed.

- Land Use Policy and Regulatory Review: A review was conducted of the existing land use policies, plans, and regulations of the municipalities in the Wood-Pawcatuck watershed relative to flood management, stormwater management, and related issues. The objective of the review is to recommend new or modified land use policies and/or regulations that could be implemented by the watershed municipalities to enhance flood resiliency in the Wood-Pawcatuck watershed.

2.4 Public Participation and Outreach

Public participation and outreach was conducted as part of the watershed planning process to increase public understanding of issues affecting the watershed, to encourage participation in the development of the watershed plan, and to build support for implementation of the plan. The following public outreach activities occurred during the watershed planning process.

Project Steering Committee Meetings

A series of meetings were held with the Project Steering Committee and other invited stakeholders to discuss issues of concern in the watershed and to identify watershed planning goals and objectives. Steering committee meetings were held at WPWA headquarters in Hope Valley, Rhode Island on the following dates:

- March 26, 2015
- May 21, 2015
- November 19, 2015
- April 14, 2016.

Documents from these meeting are provided in Appendix B.

Watershed Survey

A survey was conducted to obtain early feedback from the Project Steering Committee and other stakeholders regarding the top concerns and issues in the Wood-Pawcatuck watershed and the desired outcomes of the watershed planning process. The survey was completed on-line using Survey Monkey and by filling out paper forms in some cases. The survey results are provided in Appendix C of this plan.

Although survey responses varied, the most common issues and concerns regarding the Wood-Pawcatuck watershed were:

1. River-related flooding
2. Drainage-related flooding
3. Clean water/water quality

4. Stormwater management
5. Groundwater/drinking water
6. Dams – safety/fish passage

The most common desired outcomes of the Wood-Pawcatuck watershed flood resiliency planning process were:

1. Flood protection/mitigation
2. Protection of groundwater drinking supplies
3. Increased use of sustainable land use practices for future development
4. Improved fish passage/dam removal
5. Provisions for infrastructure inspection/repair
6. Prioritized list of specific actions

Community Meetings

Two community meetings were held in October 2016 for municipal staff and the public. The first meeting was held on October 13, 2016 at the Richmond Volunteer Fire Station in Richmond, Rhode Island. A second meeting was held on October 20, 2016 at the Westerly Library in Westerly, Rhode Island. The objectives of the meetings were to present a summary of the study findings and preliminary recommendations, and to obtain feedback from the watershed communities to help shape the watershed management plan. Meeting agenda, notes, and presentation materials are provided in Appendix D.

3 Watershed Overview

This section summarizes the physical, land use, and ecological characteristics of the Wood-Pawcatuck watershed. More detailed information on the watershed is available in the Baseline Assessment report (Fuss & O'Neill, 2016e) in Appendix A.

3.1 Watershed Description

The Wood and Pawcatuck Rivers are situated in southwestern Rhode Island and southeastern Connecticut. The area of land that drains to the Wood and Pawcatuck Rivers – commonly referred to as the "Wood-Pawcatuck watershed" – encompasses just over 300 square miles, or one quarter the size of Rhode Island. The watershed resides in all or portions of ten towns in Rhode Island and four towns in Connecticut (Table 3-1). The towns of Hopkinton, Richmond, Exeter, Westerly, North Stonington, Charlestown, West Greenwich and South Kingstown account for just over 92% of the total watershed area.

Table 3-1. Towns located within the Wood-Pawcatuck watershed.

Town	State	Area of Town within Watershed (mi^2)	% Area of Town within Watershed	% of Watershed Area
Charlestown	RI	24.9	66.3	8.3
Coventry	RI	0.9	1.4	0.3
East Greenwich	RI	0.1	0.6	0.0
Exeter	RI	53.4	91.4	17.7
Hopkinton	RI	44.1	100.0	14.6
North Kingstown	RI	3.2	7.3	1.1
Richmond	RI	40.8	100.0	13.5
South Kingstown	RI	27.9	46.4	9.3
Westerly	RI	23.2	77.1	7.7
West Greenwich	RI	26.2	51.1	8.7
North Stonington	CT	38.4	69.8	12.7
Sterling	CT	6.0	22.0	2.0
Stonington	CT	4.4	11.4	1.5
Voluntown	CT	8.2	20.5	2.7

More than 83,000 people live in the Wood-Pawcatuck watershed. The main population centers are in Westerly, Rhode Island and Pawcatuck, Connecticut along the estuary portion of the Pawcatuck River, and in South Kingstown, Rhode Island on the eastern side of the watershed. Most of the watershed consists of a predominantly rural wooded landscape amongst a series of towns that developed as mill villages along the Pawcatuck River and its tributaries. The Pawcatuck River is approximately 38 miles long and the Wood River is roughly 27 miles long, with approximately 490 miles of mapped rivers and streams in the watershed. The major rivers and streams generally flow from northeast to southwest. The subwatersheds that correspond to the major tributaries of the Wood-Pawcatuck are shown in Figure 3-1 and summarized in Table 3-2.

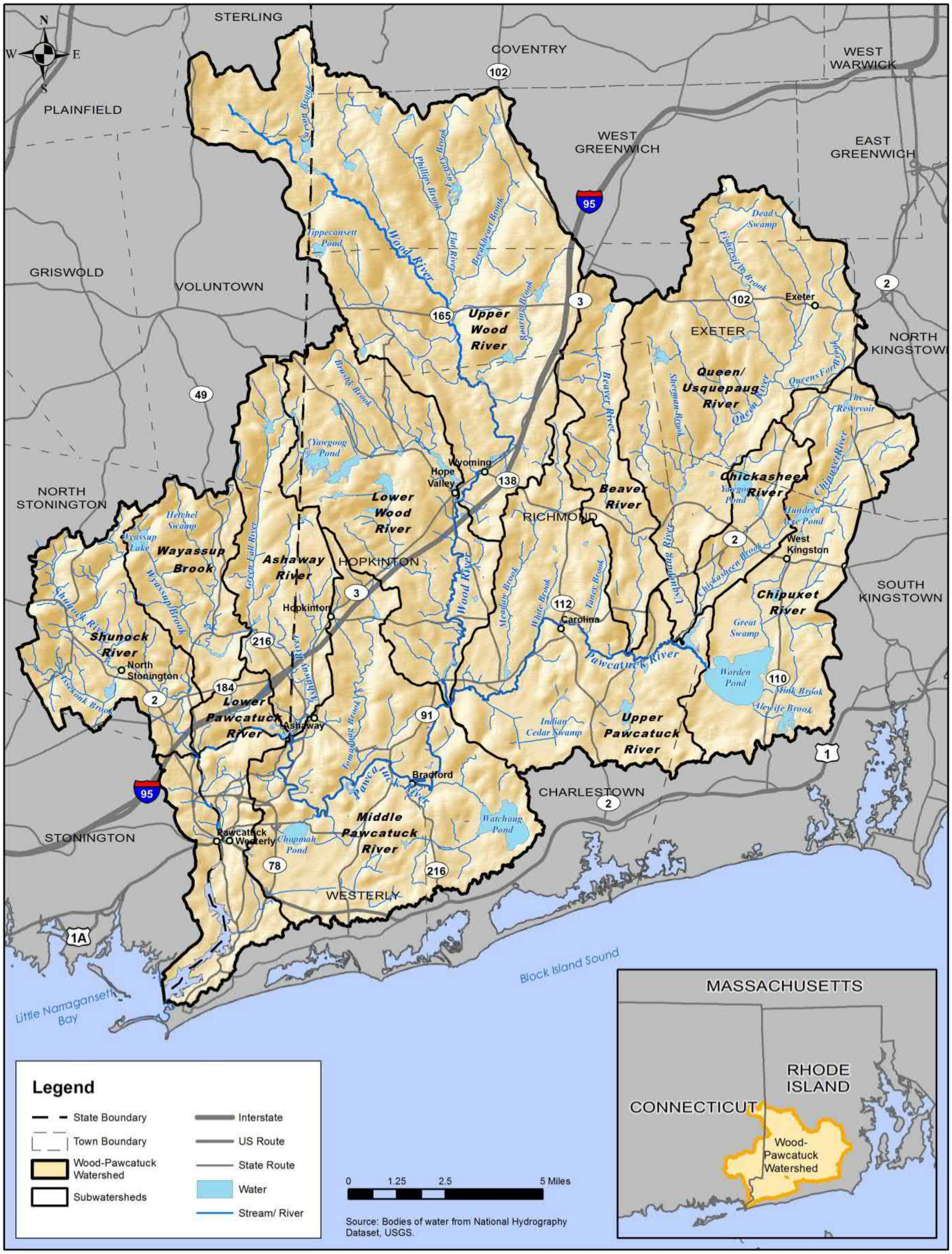


Figure 3-1. Major subwatersheds of the Wood-Pawcatuck.

Table 3-2. Subwatersheds in the Wood-Pawcatuck watershed.

Subwatershed Name	Area (mi^2)	Length of Mapped Streams (Miles)
Upper Wood River	61.0	82.71
Lower Wood River	28.6	53.349
Upper and Middle Pawcatuck River	71.0	100.58
Lower Pawcatuck River	15.8	27.06
Shunock River	16.6	46.21
Wyassup Brook	11.5	19.77
Ashaway River	16.4	34.44
Queen-Usquepaug River	37.1	62.23
Beaver River	12.4	18.53
Chickasheen Brook	6.6	11.59
Chipuxet River	25.7	33.50
Total	303	490

- Wood River: The headwaters of the Wood River begin in a swamp near Porter Pond in Sterling, Connecticut. From there, it flows southeast to Hazard Pond, where the river crosses into Rhode Island. From the state line, it flows southeast over Stepstone Falls, then south through Beach Pond State Park where it receives the Flat River. (The upper Wood River is also known locally as the Falls River.) After receiving the Flat River, the Wood continues south through the Arcadia Management Area and into the towns of Richmond and Hopkinton, where it flows through the villages of Wyoming and Hope Valley. The river continues south through Hopkinton where it converges with the Pawcatuck River at the village of Alton. The Wood River serves as the border between Richmond and Hopkinton. Almost 90% of the Wood River watershed is undeveloped, with much of this land protected as part of the Arcadia Management Area. The Wood River and its tributaries are notable for their high biodiversity, pristine water quality, cold water fisheries, and significant recreational value.

- Green Fall/Ashaway River and Wyassup Brook: The Green Fall River originates at a swamp south of Rockville Road in Voluntown, Connecticut. The river then flows south to Green Fall Pond and continues south through North Stonington and into Hopkinton, Rhode Island where the river joins with Parmenter Brook near Route 216 to form the Ashaway River. The Ashaway River flows south parallel to Laurel Street through a residential area before it empties into the Pawcatuck River along the Connecticut border. Wyassup Lake located in North Stonington, Connecticut drains southeast into Wyassup Brook, which flows into the Green Fall/Ashaway Rivers and eventually the Pawcatuck River. The overall watershed covers approximately 28 square miles, with the majority of the watershed located in Connecticut. The watershed is largely undeveloped (84%), with Pachaug State Forest comprising a large portion of the upper watershed. Developed uses (including residential and commercial uses) occupy approximately 5%, agricultural land uses occupy 7%, and wetlands and other surface waters occupy 4% (RIDEM, 2011).

- Shunock River: The headwaters of the Shunock begin in the northern portion of North Stonington, Connecticut. The river flows in a southeasterly directly through the center of North Stonington and crosses Route 184, Interstate 95, and Route 49 before emptying into the Pawcatuck River just north of the Stonington-North Stonington town line. Assekonk Brook is a tributary of the Shunock River. The Shunock River watershed, which historically supported a thriving mill industry in the 19th century, is approximately 63% forested, 15% urban area, 12% agriculture, and 10% water (CTDEEP, 2012).

- Beaver River: The Beaver River watershed is an approximately 12.4 square mile area of land situated east of the Queen-Usquepaug River watershed. The river begins at James Pond in Exeter. From there, it flows roughly due south for approximately 11 miles through Exeter and Richmond to its mouth at the Pawcatuck River near the village of Shannock. There are several dams along the Beaver River, and the river crosses major roads including New London Turnpike and Route 138. The northern and middle portions of the watershed are primarily forested, while the lower watershed contains a larger percentage of agricultural land use including some turf farms.

- Queen-Usquepaug River: The approximately 37 square mile Queen-Usquepaug River watershed is situated in the northwest portion of the Wood-Pawcatuck basin between the Beaver River and Chickasheen/Chipuxet watersheds. The Queen River originates at Dead Swamp in West Greenwich, Rhode Island and flows approximately 11 miles due south through Exeter and into South Kingstown where it converges with Glen Rock Brook to become the Usquepaug River just upstream of the village of Usquepaug. The Usquepaug River flows into Glen Rock Reservoir, then south through Usquepaug and eventually empties into the Pawcatuck River. There are a few large and a number of smaller impoundments in the watershed, and approximately 90-95% of the watershed is forested. The remainder of the basin is agricultural, recreational (golf courses), commercial, and medium-to-low-density residential land. The Queen-Usquepaug also has a wide and relatively undisturbed riparian corridor, and a fair amount of land has been preserved by Rhode Island Audubon Society, The Nature Conservancy, and private landowners (Armstrong & Parker, G.W., 2003).

- Chickasheen Brook: The Chickasheen Brook watershed is located in Exeter and South Kingstown, Rhode Island. The headwaters of Chickasheen Brook originate in Maple Swamp near a residential area east of Route 2. The brook flows west under Route 2 and enters Arrow Swamp. The brook flows southwesterly through Arrow Swamp, then through a culvert under the Miskiania Trail, before continuing southerly to the inflow of Yawgoo Pond at the border with South Kingstown. Chickasheen Brook then leaves Yawgoo Pond and flows southeast where it joins with Mud Brook and eventually Barber Pond. The brook eventually joins the Usquepaug River, which flows to the upper reaches of the Pawcatuck River. The watershed is largely undeveloped (over 80%), with residential and commercial uses comprising less than 10% of the land area (RIDEM, 2011). Agricultural land uses (primarily turf farms) are also present in the watershed.

- Chipuxet River: The Chipuxet River watershed comprises approximately 26 square miles within Exeter, North Kingstown, and South Kingstown, Rhode Island. The Chipuxet River flows approximately 13 miles, paralleling the Amtrak train line through Slocum, crossing Route 138 near Plains Road/Route 110, passing through the Great Swamp, before entering Worden Pond. Groundwater in the watershed, namely the Chipuxet Aquifer, is a source of drinking water for the University of Rhode Island (URI) and the Kingston Water District. There is also a significant water demand from turf farms in the watershed. Consequently, the Chipuxet River (and to a lesser extent, Chickasheen Brook) is considered a “stressed” basin for streamflow, with water demands sufficient to dry up the Chipuxet River at times (Audubon Society of Rhode Island).

- Pawcatuck River: The Pawcatuck River begins as the outflow from Worden Pond in South Kingstown, Rhode Island and flows southwest through Richmond, Charleston, Hopkinton, and Westerly, Rhode Island, before forming the border between Westerly, Rhode Island and North

Stonington, Connecticut. For the purposes of this assessment, the Pawcatuck River is separated into three segments and associated watershed areas:

- Upper Pawcatuck River: The Upper Pawcatuck River forms the border between Charlestown and Richmond between Worden Pond and its confluence with the Wood River. Major tributaries to this segment include the Usquepaug River, Beaver River, Taney Brook, White Brook, and Meadow Brook. The Upper Pawcatuck flows through Great Swamp as it leaves Worden Pond and continues flowing west through the villages of Kenyon, Shannock, Carolina, and Alton.

- Middle Pawcatuck River: The Middle Pawcatuck River segment begins at the confluence with the Wood River and flows south-southwest through primarily forested and wetland areas, crossing the Amtrak rail line several times, through the village of Bradford along the Hopkinton-Westerly town border, and ending at the confluence of the Ashaway River. Tomaquaug Brook is the major tributary to this segment of the Pawcatuck River.

- Lower Pawcatuck River: The Lower Pawcatuck River is defined as the portion of the river downstream of the Ashaway River, as the Pawcatuck forms the border between Rhode Island and Connecticut. The river flows southwest from Potter Hill in semi-circle towards downtown Westerly, Rhode Island and Pawcatuck, Connecticut. As the River travels downstream of Route 78, the watershed becomes more urbanized and developed (RIDEM, 2011). The estuarine portion of the river begins at the Route 1 crossing and extends south to Little Narragansett Bay. The Shunock River and several smaller tributaries that drain more urbanized portions of Westerly and Stonington flow into this lower segment of the Pawcatuck River.

3.2 Land Use and Development

Land Use

Approximately 60% of the Wood-Pawcatuck watershed consists of deciduous, evergreen, or mixed forest (Figure 3-2). Wetlands and open water account for 20% of the watershed. Developed land uses make up approximately 20% of the watershed. The Rhode Island portion of the watershed gained an estimated 614 acres of urban land and lost an estimated 662 acres of forest land from 2001 to 2011. All of the major subwatersheds in the Wood-Pawcatuck experienced an increase in urban land and all except the Ashaway River subwatershed experienced a loss in forest acres (Narragansett Bay Estuary Program, 2016). The watershed population is expected to grow by 4% by 2020.

Population growth and development in the watershed has the potential to increase impervious surfaces and runoff quantity, degrade water quality through increased pollutant loads, and exacerbate flood hazards by allowing development in flood-prone areas.

Impervious Cover

Impervious surfaces prevent precipitation from naturally soaking into the ground, resulting in a variety of hydrologic changes in a watershed. Impervious cover is a measure of the amount of impervious surfaces covering the landscape and is a useful indicator of ecological conditions in a watershed. Impervious surfaces account for less than

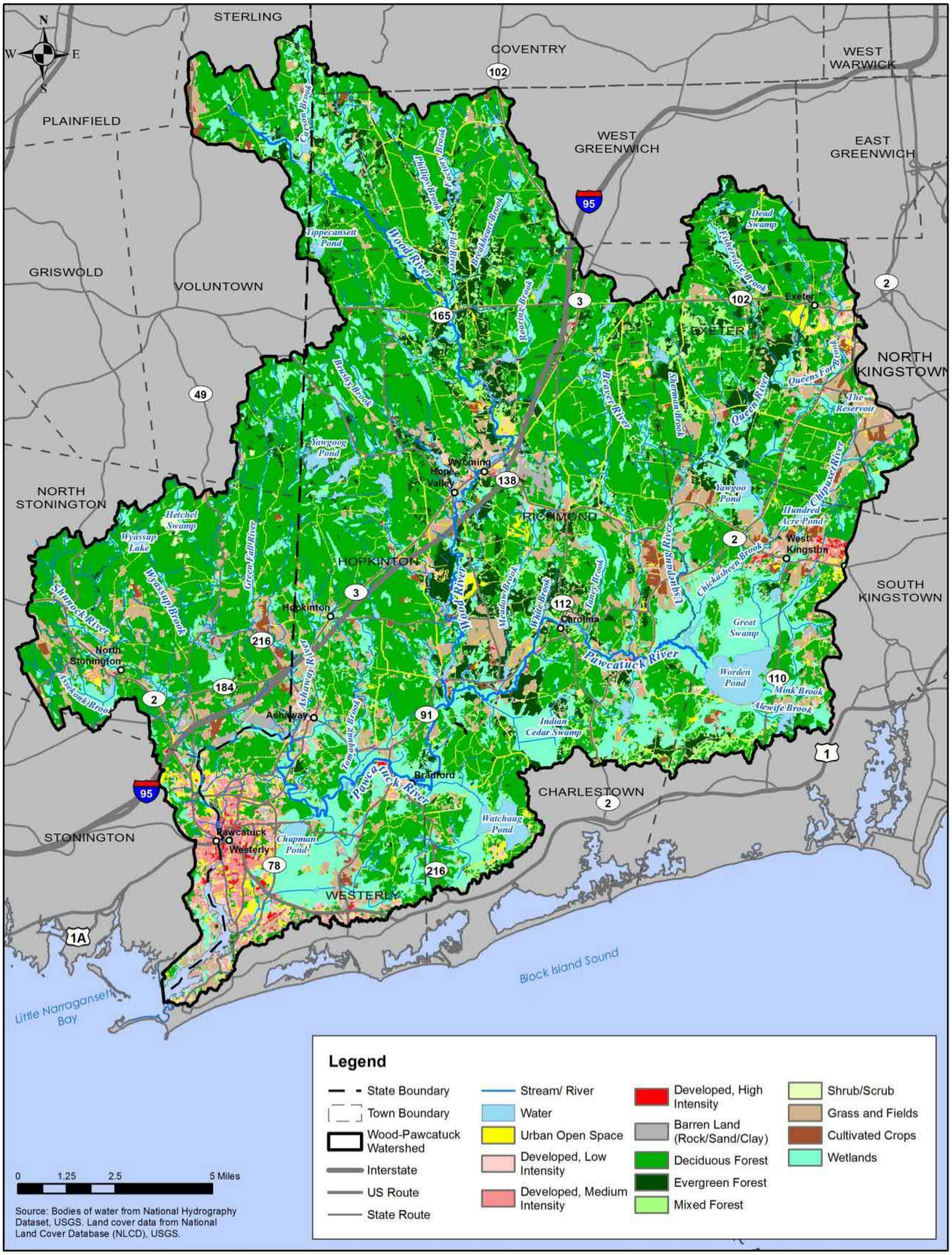


Figure 3-2. Land cover in the Wood-Pawcatuck watershed.

5% of the land area in most of the Wood-Pawcatuck subwatersheds, with the exception of the Lower Pawcatuck River subwatershed where impervious cover exceeds 20% (Figure 3-3). In terms of the watershed communities, Westerly, North Kingstown, and East Greenwich, Rhode Island and Stonington, Connecticut have the highest percentage of impervious cover (10-20%) in the watershed.

Open Space

Open space lands consists of undeveloped land characterized by natural features such as forests, riparian zones, and vegetated areas, as well as developed land including agricultural lands, recreational lands (e.g., parks, golf courses, and playing fields), and other developed open space areas.

Open space protection provides the permanent preservation of lands in a watershed by limiting development and impervious coverage, preserving the integrity of floodplains and other lands critical to flood mitigation, preserving natural pollutant attenuation characteristics, and supporting other planning objectives such as farmland preservation, community preservation, and passive recreation. Open space planning aimed at acquiring or protecting vulnerable land in river corridors and floodplains can be an effective approach for enhancing flood resiliency and protecting water quality.

Nearly 60,000 acres of land in the Wood-Pawcatuck watershed are already protected as open space or conservation land, which is a primary reason for the watershed's high-quality natural resources. Figure 3-4 shows the location and type of protected open space in the Wood-Pawcatuck watershed. These areas are comprised primarily of state and municipally-owned wildlife management areas and preserves, along with cemeteries, golf courses and recreational fields.

3.3 Physical Characteristics

Geology and Soils

Glaciers formed the topography of the Wood-Pawcatuck watershed roughly 16,000-17,000 years ago leaving behind a landscape of low rolling hills with associated valleys that trend north to south with a slight east to west component. The surficial geology of the watershed is characterized by deposits of glacial till overlaying areas of crystalline bedrock (Bent, et al., 2011; Breault, et al., 2009). The most distinct geologic feature within the watershed is the Charlestown moraine, which makes up the southern boundary of the watershed. The Charlestown moraine is a glacial deposit that represents the long-term recessional position of the retreating glacier (Schafer, 1965). As the glacier retreated, the moraine effectively dammed the formerly southerly draining rivers in the area and directed the flow to the southwest (Masterson, Sorenson, Stone, Moran, & Hougham, 2007). The glacial deposits underlying the watershed have contributed to a legacy of fairly well draining soils throughout the Wood-Pawcatuck.

The glacial deposits underlying the watershed have contributed to a legacy of fairly well draining soils throughout the Wood-Pawcatuck watershed.

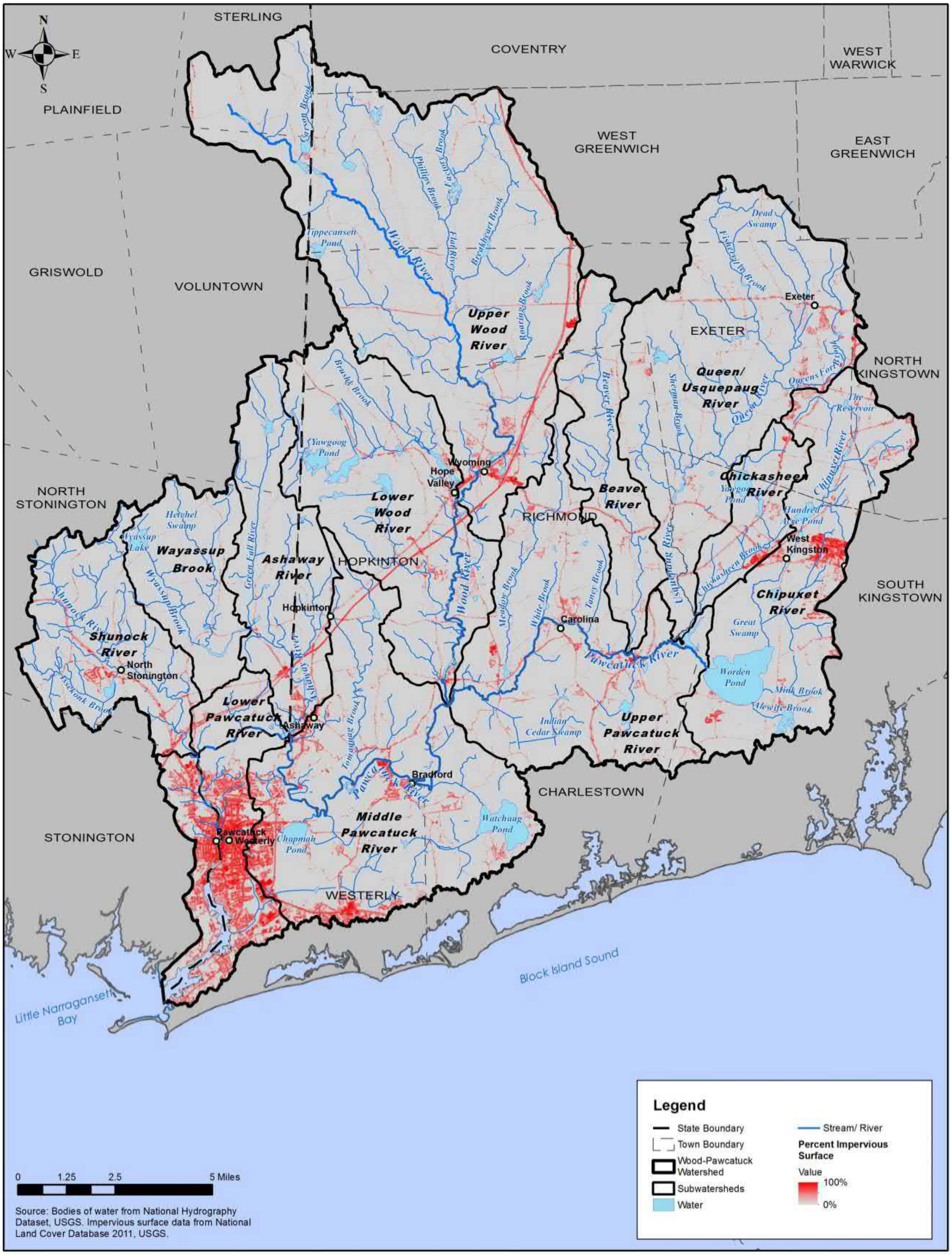


Figure 3-3. Percent impervious cover within the Wood-Pawcatuck watershed.

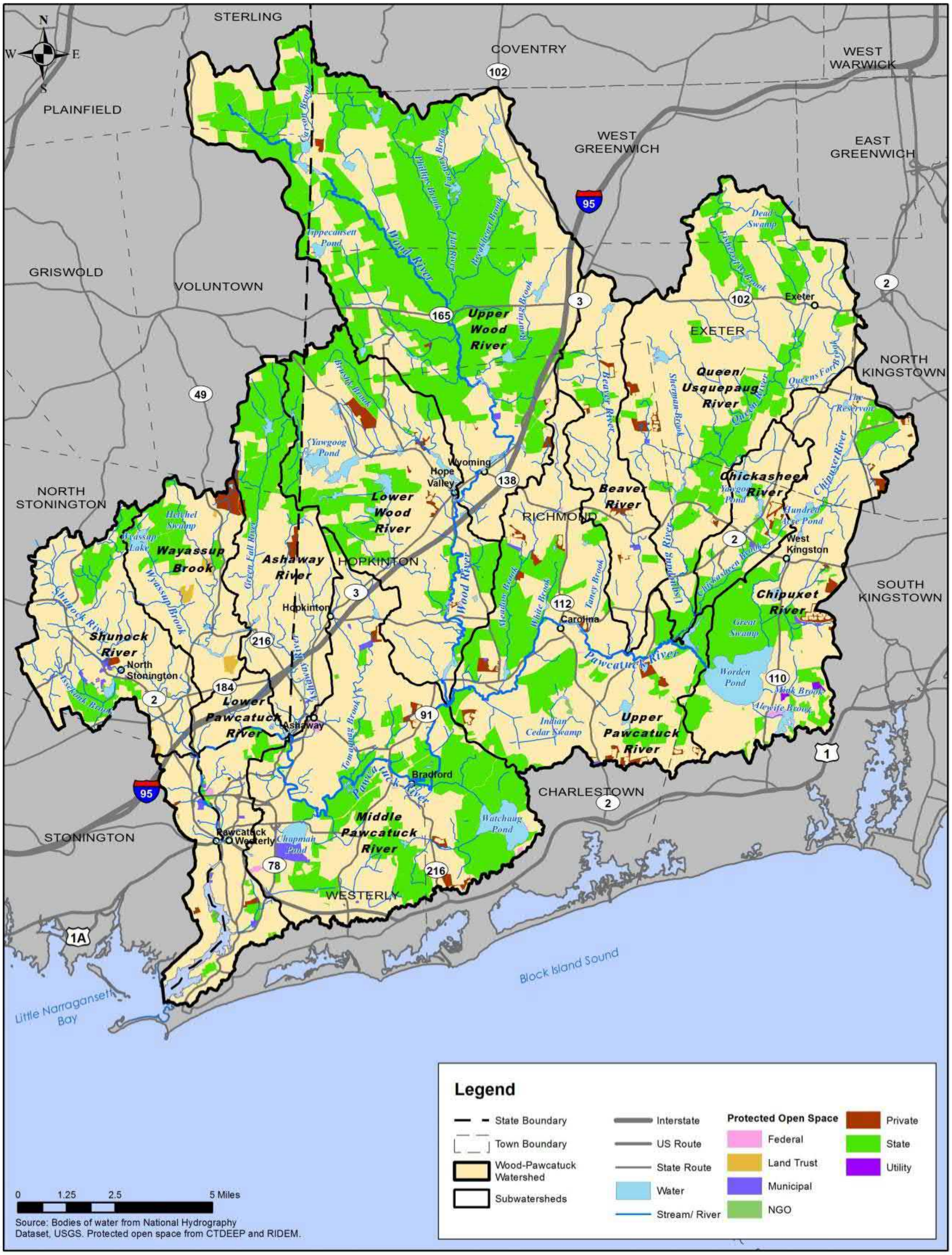


Figure 3-4. Areas of protected open space within the Wood-Pawcatuck watershed.

Hydrology

A portion of the precipitation that falls in the Wood-Pawcatuck watershed eventually reaches surface waters (rivers, streams, lakes, and ponds) and groundwater. Approximately 50% of the average annual precipitation in the watershed leaves the basin as streamflow near the mouth of the river in Westerly. The remaining 50% of the precipitation leaves the basin by a combination of evaporation, plant transpiration, and water withdrawals/transfers out of the basin (Breault, et al., 2009).

Based on streamflow data collected by the U.S. Geological Survey from 2000-2013, mean annual streamflow (ft^3/s or "cfs") varies significantly across the watershed. When normalized by drainage area, mean annual streamflow yield ($ft^3/s/mi^2$ or "csm") is relatively consistent, ranging from 2.1-2.5 csm.

> *Groundwater serves as the sole source of drinking water for more than 60,000 residents in the Wood-Pawcatuck watershed.*

Significant groundwater resources underlie large portions of the Wood-Pawcatuck watershed. Groundwater serves as the sole source of drinking water for more than 60,000 residents (designated an EPA Sole Source Aquifer) and supplements water supplies outside of the watershed. In addition to public water supply, water resources in the basin are also used for irrigation, particularly by the large number of turf farms in the watershed. In the Wood-Pawcatuck, drinking water is supplied solely from groundwater sources and irrigation is primarily withdrawn from surface water sources.

3.4 Ecological Resources

The Wood-Pawcatuck watershed has a high degree of species and habitat diversity, with some of the most pristine and undisturbed natural resources in all of southern New England. Preservation of these unspoiled natural areas (i.e., existing "green infrastructure") has helped to maintain excellent water quality, a variety of high-quality habitat types, and natural flood resiliency in much of the watershed (National Park Service, 2013) (Pawcatuck Watershed Partnership, 1999).

Forests

The Wood-Pawcatuck watershed is characterized by large tracts of deciduous forest and is noted for having the largest, most undisturbed forest lands remaining between Boston and New York City (National Park Service, 2013). The forest landscape is home to many unique habitats and rare species that exist in the watershed. Figure 3-2 shows the existing land cover in the Wood-Pawcatuck watershed. Nearly 60% of the watershed consists of deciduous, evergreen, or mixed forests.

Wetlands

Wetlands are lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. Wetlands are critical to protect water quality, to provide wildlife habitat, to mitigate flooding, to recharge groundwater, and to provide other important natural functions.

Wetlands comprise nearly 18%, or over 34,000 acres, of the Wood-Pawcatuck watershed (Figure 3-5). The watershed is dominated by forested wetlands (approximately 71% of the wetlands in the Rhode Island portion of the watershed). Shrub swamps make up the next largest category of wetlands at just over 10% of the total acreage of wetlands in the watershed (Miller & Golet, 2000).

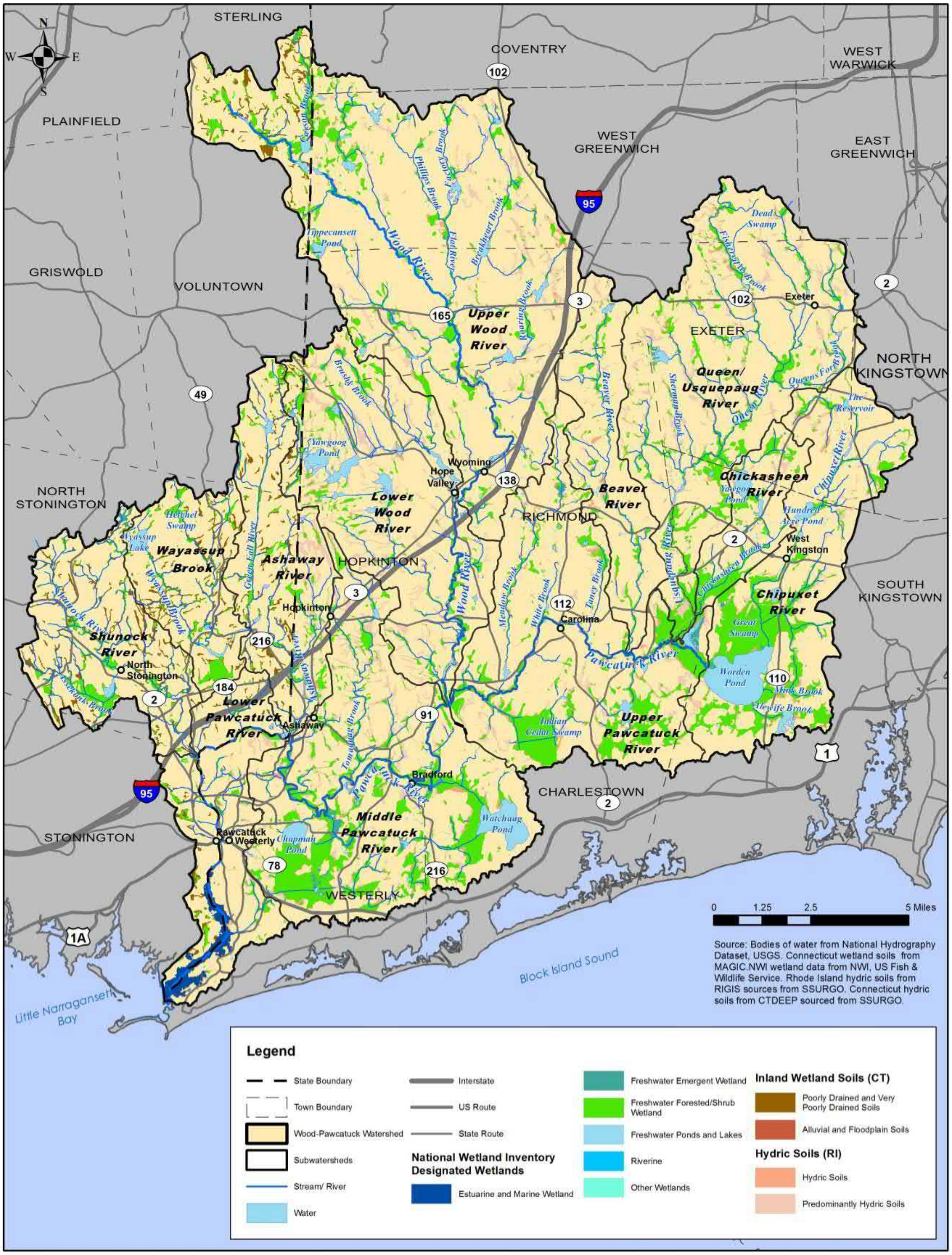


Figure 3-5. Wetland resources in the Wood-Pawcatuck watershed.

Fisheries

> *46% of the Wood-Pawcatuck watershed provides areas that support brook trout, which is the most significant habitats for brook trout within the entire Narragansett Bay study area (Narragansett Bay Estuary Program, 2016).*

Historically, coastal watersheds in southern New England, including the Wood-Pawcatuck system, contained thriving populations of anadromous fish species (species that migrate from sea to freshwater to spawn). Most of the anadromous runs in Rhode Island were destroyed in the 1800s when many rivers were dammed for industrial uses. Dams within the Wood-Pawcatuck watershed, in addition to serving as physical barriers to fish migration, alter environmental conditions that affect fish species composition by increasing suitable warm water habitat and competition from warm water fish species that may result in reduced growth and survival of cold water species such as brook trout (Wood-Pawcatuck Watershed Association, 2004a; Wood-Pawcatuck Watershed Association, 2004b; Wood-Pawcatuck Watershed Association, 2005).The numerous culverts and bridges in the watershed also restrict or limit passage for fish and other aquatic organisms.

The Pawcatuck River has been targeted for fisheries restoration efforts over the last few decades, focusing on anadromous species such as American shad and river herring (which include alewife and blueback herring). Many of the tributaries to the Pawcatuck River have water quality that supports cold water fish species. Opening up the full length of the mainstem of the Pawcatuck River would support fisheries restoration efforts throughout the rest of the watershed.

> *Many of the tributaries to the Pawcatuck River have water quality that supports cold water fish species. Opening up the full length of the mainstem of the Pawcatuck River would support fisheries restoration efforts throughout the rest of the watershed.*

Several fish passage projects have been completed in recent years including removal of Lower Shannock Falls Dam and White Rock Dam, and construction of fish passage structures at Kenyon Mills Dam and Horseshoe Falls Dam, in addition to the older existing fishways at Potter Hill Dam and Bradford Dam, which have had mixed success. The Nature Conservancy is pursuing fish passage restoration at Bradford Dam through the construction of a nature-like fishway. The USGS gaging station in Richmond is passable to some fish species but needs to be retrofitted to pass species such as river herring.

In the Connecticut portion of the watershed, the Shunock River and Green Fall River have the greatest fisheries restoration potential. The recent removal of White Rock Dam potentially opens up the Shunock River to river herring and other resident species from the lower Pawcatuck. Fishways or dam removal would need to be considered for several of the dams on the Shunock to allow access to the upstream portions of the Shunock subwatershed. Several dams on the Ashaway River currently block access to the Green Fall River (the Green Fall River becomes the Ashaway River at the Rhode Island state line). The dams along the Ashaway River would need fishways or removal to restore connectivity in the lower portion of the Green Fall River subwatershed, which may have supported historic runs of river herring (Gephard, 2015).

3.5 Water Quality

Water quality is a primary indicator of the ecological health of a river system and its ability to support specific uses such as drinking water supply, recreation, habitat, and industrial uses. Water quality is also inherently linked to the activities that take place in a watershed. Water quality in the Wood-Pawcatuck watershed is monitored by the Wood-Pawcatuck Watershed Association (WPWA), working closely with the University of Rhode Island's Watershed Watch program, other local partners, and volunteers. Water quality in the Wood-Pawcatuck watershed is monitored on a regular basis by RIDEM and CTDEEP to support designated use assessments.

Surface water and groundwater quality in the Wood-Pawcatuck is generally excellent due to the large amount of forested and natural lands in the watershed. "Impaired" waterbodies (waterbodies that do not meet water quality standards for certain uses) are more prevalent in the developed, downstream portions of the watershed, including the estuarine section of the Pawcatuck River and Little Narragansett Bay. Figure 3-6 is a map of the impaired waters in the Wood-Pawcatuck watershed, according to the latest integrated water quality reports for Rhode Island and Connecticut (RIDEM, 2015; CTDEEP, 2014). The Baseline Assessment report in Appendix A provides additional information on the impairments.

Most of the listed inland rivers and streams are impaired for recreation or fish and wildlife habitat, while the tidal portion of the Pawcatuck River is not supporting for contact recreation, shellfish and aquatic life. Stormwater runoff and nonpoint source pollution are the primary causes of many of these impairments. Pathogens are the most common pollutant contributing to impairments in the Wood-Pawcatuck watershed. Additional pollutants contributing to impairments include nutrients (specifically phosphorus), non-native aquatic plants, and heavy metals such as cadmium and mercury.

Overall, there are 32 stream segments listed as impaired, covering over 156 miles of streams in the Rhode Island portion of the watershed and 7 additional segments listed as impaired for at least one designated use covering another 12 miles of streams in Connecticut. Twenty three ponds are listed as impaired for at least one designated use. One pond is listed as impaired in Connecticut, for both recreation and fish consumption. The Pawcatuck River estuary is broken into five segments, three in Rhode Island and two in Connecticut. All but one of the Connecticut segments is listed for failing to meet its designated uses for at least one pollutant; insufficient data exists for one unlisted section of the estuary.

A TMDL is a pollution budget that specifies how much of a specific pollutant that a waterbody can receive without exceeding water quality standards. The TMDL process maps a course for states, municipalities, private landowners, and other stakeholders to follow to ultimately restore impaired waters. The following TMDLs have been developed and approved for impaired waterbodies in the Wood-Pawcatuck watershed:

- Rhode Island Statewide TMDL for Bacteria Impaired Waters (RIDEM, 2011): The State of Rhode Island has a TMDL addressing bacterial pollution across the state, including many rivers and streams in the Wood-Pawcatuck watershed. In 2014, the TMDL was updated to include 5 additional impaired stream segments in the Wood-Pawcatuck (RIDEM, 2014).

- Rhode Island Pawcatuck River and Little Narragansett Bay Waters Bacteria TMDL (RIDEM, 2010): In 2010, RIDEM developed a TMDL for the bacteria-impaired waters of the estuarine portion of the Pawcatuck River and Little Narragansett Bay.

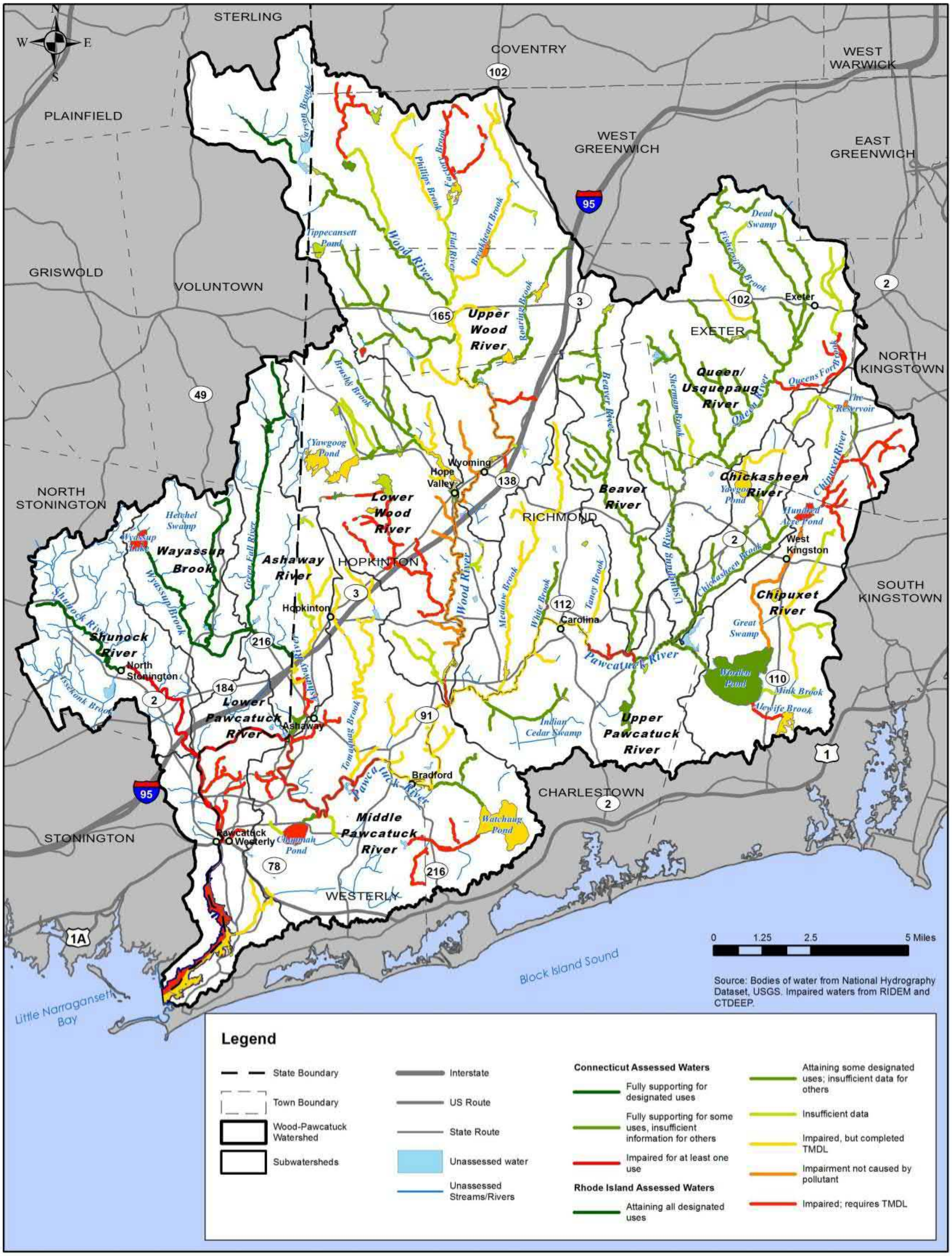


Figure 3-6. Impaired waterbodies in the Wood-Pawcatuck watershed.

- Total Phosphorus TMDL for Chickasheen Brook, Barber Pond, and Yawgoo Pond (RIDEM, 2004): RIDEM developed a TMDL for the nutrient-related impairments in Chickasheen Brook, Barber Pond, and Yawgoo Pond.

- Connecticut Statewide Bacteria TMDL (CTDEEP, 2012): Connecticut also has a statewide TMDL for bacteria. The TMDL includes the impaired segments of the Shunock and Pawcatuck Rivers.

- Connecticut Pawcatuck River Watershed Bacteria TMDL (CTDEEP, 2014): In 2014, CTDEEP developed a bacteria TMDL specifically for the Connecticut portion of the Pawcatuck River, which builds on information contained in the 2012 statewide bacterial TMDL.

The TMDL documents address in detail the sources and causes of the impairments, required pollutant load reductions for these waterbodies to meet water quality standards and support certain uses, and recommended management actions to help achieve the necessary load reductions.

4 Management Recommendations

This section describes recommended actions to meet the watershed management goals of this study. The recommendations include watershed-wide and targeted actions:

- Watershed-wide Recommendations are recommendations that can be implemented throughout the Wood-Pawcatuck watershed. These basic measures can be implemented in most areas and communities within the watershed and are intended to increase community resiliency and enhance habitat and water quality. The flooding and water quality/habitat benefits of these measures are primarily long-term and cumulative in nature resulting from strengthened land use policy, land conservation, runoff reduction, pollution prevention and source controls, and improved stormwater management.

- Targeted Recommendations include site-specific projects and/or actions intended to address issues within specific stream reaches, stream corridors, upland areas, or subwatersheds, rather than watershed-wide. Targeted recommendations also include actions to address common types of problems that are identified at representative locations throughout the watershed, but where additional field assessments or evaluations are required to develop more detailed site-specific recommendations. Targeted recommendations can have both short and long-term benefits.

Due to the large size of the Wood-Pawcatuck watershed and the planning-level scope of this study, additional field assessments, modeling, and/or feasibility evaluations are recommended to further refine certain plan recommendations and potential site-specific restoration projects.

The plan recommendations are also classified according to their timeframe for implementation. Recommendations include ongoing, short-term, mid-term, and long-term actions:

- Ongoing Actions are actions that occur annually or more frequently such as routine water quality monitoring, fundraising, and education and outreach.

- Short-Term Actions are initial actions to be accomplished within the first two years of plan implementation. These actions have the potential to demonstrate immediate progress and success and/or help establish the framework for implementing subsequent plan recommendations.

- Mid-Term Actions involve continued programmatic and operational measures, delivery of educational and outreach materials, and construction of larger retrofit and/or restoration projects between two and five years after plan adoption.

- Long-Term Actions consist of continued implementation of watershed projects, as well as an evaluation of progress, accounting of successes and lessons learned, and an update of the watershed management plan. Long-term actions are intended to be completed between 5 and 10 years or longer after plan adoption. The feasibility of long-term actions, many of which involve significant infrastructure improvements, depends upon the availability of sustainable funding programs and mechanisms.

The remainder of this section describes the recommended actions presented in this watershed management plan. The recommendations are categorized as follows:

1. Dams and Impoundments
2. Culverts and Bridges
3. Floodplains and River Corridors
4. Wetlands
5. Stormwater

Recommendations relative to education and outreach are included within the above categories since watershed stewardship is a critical aspect of many of the plan recommendations. Although the plan's primary focus is on flood resiliency for inland areas, considerations for the estuarine portion of the watershed (i.e., the tidal portion of the lower Pawcatuck River) are also provided, where appropriate, to address coastal resiliency.

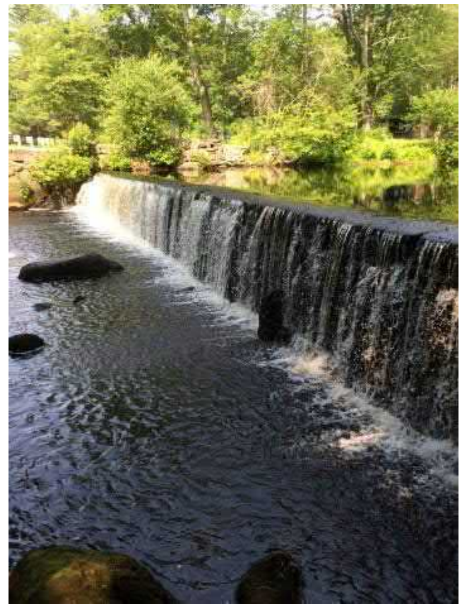
The following sections include a goal statement, a brief description of the issue, and a description of recommended actions including a proposed timeframe and key partners for implementing the recommendations. Locations of proposed site-specific projects or actions are shown on the subwatershed maps located in Appendix E. Planning-level cost estimates are provided for some site-specific plan recommendations, while relative costs or typical unit costs are presented for other recommendations. Recommendation summaries tailored to each watershed community are provided in Appendix F to help guide municipal policy, planning and project implementation.

Implementation Strategy – Making Use of Limited Funds

Recognizing that limited funding is available to implement the plan recommendations, communities should initially focus on implementing the "low-hanging fruit" – land use policy/regulatory recommendations. Well-informed municipal land use policies and regulations can help communities become more resilient to flooding by preserving the significant undeveloped land in the watershed, siting development in locations less vulnerable to flooding, and promoting designs that reduce runoff and are less likely to be damaged in a flood.

In terms of structural restoration measures, communities and project proponents should focus limited resources and funding on implementing priority dam management recommendations (dam repair and removal), upgrading priority road stream crossings, and conserving and restoring natural floodplain functions. These types of projects will have more immediate and tangible flood resiliency benefits by removing floodplain encroachments, upgrading vulnerable infrastructure, and discouraging future development in flood-prone areas. Wetland restoration and stormwater retrofits are more expensive and generally less cost-effective and should be integrated into other planned restoration projects or capital improvements.

4.1 Dams and Impoundments



Reduce the flood risk posed by dams in the watershed, and restore the connectivity of streams for fish and other aquatic organism passage.

The Issue

There are over 160 documented dams in the Wood-Pawcatuck watershed (Figure 4-1). Many of these are relatively small dams built to power small industry mills of the 17th and 18th centuries, are no longer used for their original purpose, and are in poor or deteriorating condition. Many of the remaining dams in the watershed and their associated impoundments provide recreational opportunities, aquatic and wildlife habitat, and water supply. Some of the dams in the watershed – and their associated lakes or ponds – also provide historic and cultural values. None of the dams in the watershed were originally constructed for flood control purposes and most support run-of-river impoundments that are small in size relative to their drainage area. Many dams in the watershed provide only limited, if any, flood control benefit.

Assessment of Existing Dams in the Wood-Pawcatuck Watershed

An assessment of the existing dams in the Wood-Pawcatuck watershed was conducted to evaluate flood risk potential in the event of failure and to identify management recommendations (i.e., dam removal, repair or modification) to increase flood resiliency as well as improve aquatic habitat, river continuity, and fish passage. The assessment involved file reviews and limited visual condition assessments of approximately 70 dams in the watershed. A range of potential management options were considered for each dam including removal, repair, fish passage structures, and repurposing for flood control. The assessment is documented in a separate report entitled *Dams, Bridges and Culverts Assessment Technical Memorandum* (Fuss & O'Neill, 2016b) (see **Appendix G**).

The dams in the Wood-Pawcatuck watershed pose upstream flood hazards by backing up water during floods. Dams also present a hazard to downstream areas in the event of a breach or failure, which can result from aging infrastructure, insufficient maintenance and changes in upstream flow regimes. Dam failure can release large quantities of flow, sediment (sometimes contaminated), and debris and is therefore a threat to property, ecosystems, and public safety. Dams have also fragmented the riverine systems in the watershed, preventing the movement of fish and other aquatic life to feed, spawn, or migrate past the dams.

The Blue Pond Dam in Hopkinton experienced a significant breach during the 2010 flood. Flooding and damage to roads was experienced along the inundation area downstream of the dam.

The impoundments created by dams can also affect water quality. In general, increased retention time of water behind dams causes physical, thermal, and chemical changes to take place both in the impounded and downstream waters. Small dams on low order streams (i.e., smaller headwater streams) can result in elevated water temperatures for miles downstream of

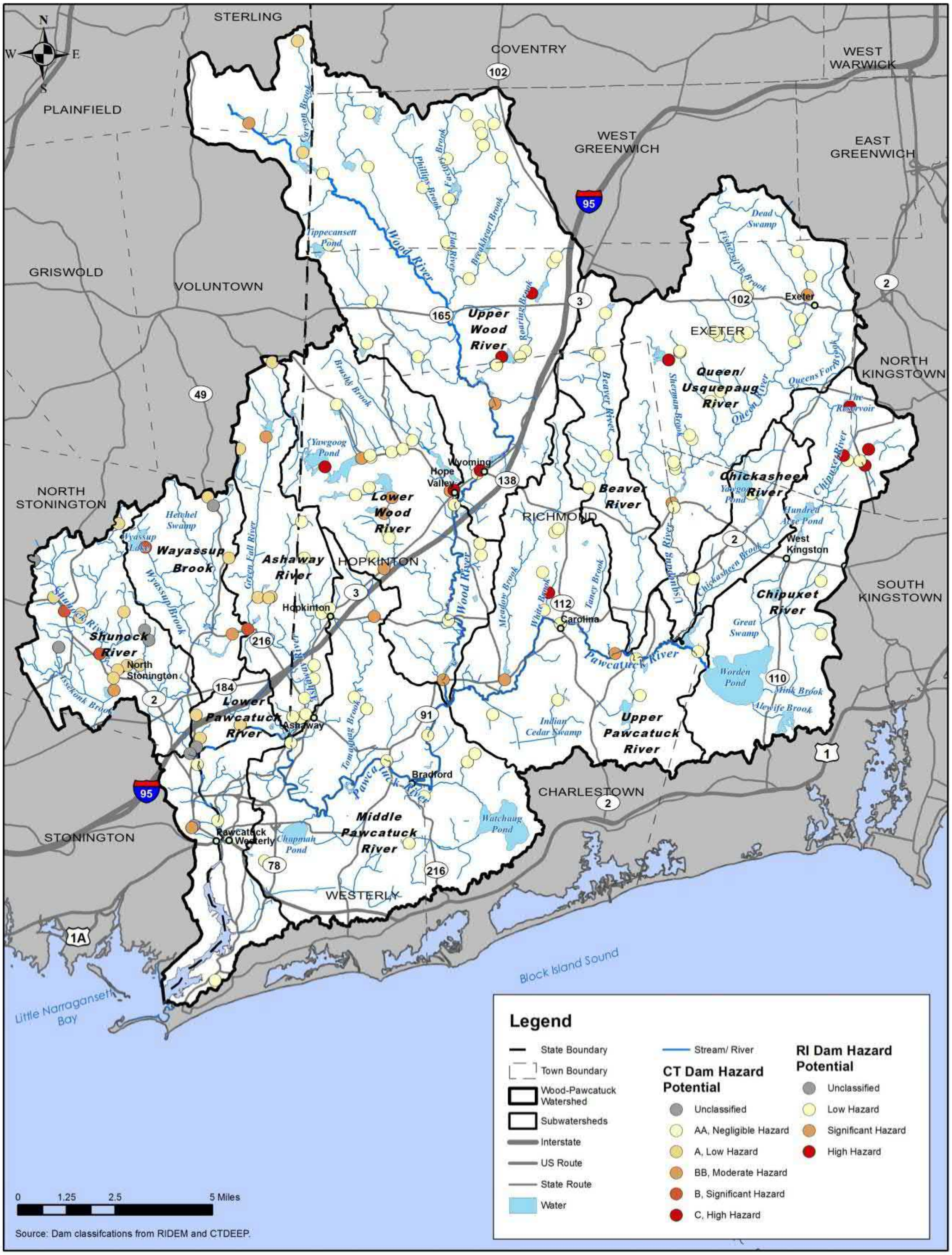


Figure 4-1. Dams and associated hazard classifications in the Wood-Pawcatuck watershed.

the dam, which can impact sensitive cold water fisheries habitat (Wood-Pawcatuck Watershed Association, 2004a). Excess inputs of nutrients from stormwater, nonpoint source runoff, and nutrient-rich sediments can lead to the growth of algae and nuisance aquatic vegetation in impoundments created by dams.

Reservoirs with dams in lower order, headwater streams, with relatively large hydraulic residence time, have also been shown to provide nitrogen removal benefits in downstream waters, serving to reduce nitrogen loads to sensitive estuaries such as Little Narragansett Bay (Gold, Addy, Morrison, & Simpson, 2016). The nitrogen removal benefit of reservoirs decreases as the ratio of watershed area to reservoir area increases (i.e., as you move downstream on main stem rivers), thereby decreasing retention time in the reservoir. The aquatic passage benefits of dam removal tend to decrease in headwater areas, so aquatic passage goals do not tend to conflict with nitrogen removal objectives. The tradeoff is more commonly between maintaining a headwater dam for nitrogen removal and removing the dam to eliminate a safety risk from potential dam failure. The nitrogen removal benefits of any single dam/reservoir tend to diminish for estuaries with large watersheds, such as the Wood-Pawcatuck watershed (Gold, Addy, Morrison, & Simpson, 2016).

Dam Management Alternatives

Dam Removal – nationwide and in New England, many communities and dam owners have begun to remove dams, particularly those that have not been maintained, are in disrepair, and no longer serve their original purpose. Dam removal eliminates flood risk due to failure or breach, potentially reduces flood risk in upstream areas, meets aquatic organism passage objectives, and eliminates significant liability and costly maintenance for dam owners (see text box on the following page for a discussion of the benefits of dam removal).

The Pawcatuck River has been targeted for fisheries restoration efforts over the last few decades, focusing on anadromous species. Several dams on the lower Pawcatuck River have been removed, including the dam at Lower Shannock Falls in 2010 and White Rock Dam in 2015 (see text box on the following page). In addition to fisheries restoration, removal of these two dams has reduced flood elevations upstream of the dams and reduced flood risk to downstream properties, roads, and bridges from potential dam failure.

Aquatic Organism Passage Structures – this alternative involves construction of an engineered structure at a dam to provide for Aquatic Organism Passage (AOP), including fishways such as fish ladders and nature-like rock ramps and bypass channels. This option is designed to provide enhanced stream continuity if dam removal is not feasible, although it does not provide the other benefits of dam removal including enhanced flood resiliency and public safety or elimination of owner liability and maintenance.

A rock ramp fishway and Denil fish ladder were installed at Kenyon Mills Dam and Horseshoe Falls Dam, respectively. Potter Hill Dam and Bradford Dam have existing Denil fishways, although the U.S. Fish and Wildlife Service has identified issues associated with fish passage effectiveness at these dams (Sojkowski, Morales, J., & Orvis, C., 2014). The Nature Conservancy is pursuing fish passage restoration at Bradford Dam through the construction of a nature-like fishway, which is scheduled to begin construction during the summer of 2017 and be completed by early 2018.

Repair – the repair alternative includes repair of structural components of a dam to address existing deficiencies that threaten the structural integrity of the dam, thereby reducing the potential for failure or breach during a large storm event. The dam repair alternative alone does not eliminate the risk of failure nor does it improve aquatic organism passage. In some cases, the repair option, potentially combined with provision of aquatic organism passage, may be the only viable alternative if removal is not feasible. The dam repair alternative involves the up-front cost of the repairs and a long-term financial commitment to inspect and maintain the dam following the initial repairs. It also assumes that the current owner has the willingness, ability, and financial resources to adequately maintain the dam.

The Benefits of Dam Removal

While some dams in the Wood-Pawcatuck watershed provide important societal benefits such as recreation, irrigation, infrastructure support, open water habitat, or cultural/historical value, many of the dams no longer serve the function for which they were constructed, pose a public safety risk, negatively affect the environment, are a liability to their owners, and require expensive ongoing maintenance. Dam removal, where feasible, can provide the following benefits:

Flood Resiliency and Public Safety

- Prevent damage to human life and property resulting from dam failure
- Reduce backwater flood hazards upstream of dammed impoundments

Environmental

- Restore natural river flow and sediment and debris transport
- Remove barriers to fish migration and passage of other aquatic organisms and wildlife
- Improve water quality

Economic

- Eliminate liability to dam owners
- Eliminate costly ongoing maintenance and repairs needed to meet current dam safety standards

Community

- Enhance fishing and recreational boating opportunities in a restored river
- Riverfront revitalization opportunities
- Improve or enhance aesthetics

White Rock Dam Removal

White Rock Dam was removed from the lower Pawcatuck River in 2015, improving flow conditions for migratory fisheries, reducing flood elevations upstream of the dam, improving river connectivity for other aquatic species and recreational boaters, and reducing flood risk to downstream properties, roads, and bridges from potential dam failure.

Repurposing – repurposing involves modification of an existing dam to provide increased storage during floods. For example, repurposing could include modification of the low-level outlet structure to significantly reduce the impoundment size and normal pool elevation, allowing the river or stream to flow freely, under normal conditions (i.e., a dry impoundment), but allowing the impoundment to fill up and store floodwaters during larger storms. Given the low-gradient nature of the Wood-Pawcatuck system, none of the dams were originally constructed for flood control purposes and most of the existing impoundments provide limited flood storage. Repurposing also assumes that the current owner has the willingness, ability, and financial resources to adequately maintain the dam. The U.S. Army Corps of Engineers evaluated the feasibility of repurposing Potter Hill Dam, but found that conversion of the dam/impoundment for flood control would not provide measurable flood risk reduction benefit given the size of the impoundment and its location within the watershed.

Recommended Actions

Table 4-1 contains recommendations relative to dams and associated impoundments in the Wood-Pawcatuck watershed.

Table 4-1. Recommendations for dams and impoundments.

	Action	Lead Entity	Timeframe	Estimated Cost	Possible Funding Sources
1.	Incorporate priority dam management recommendations identified in this study into local hazard mitigation planning documents.	Watershed Municipalities	1-2 years	$	Municipal funds
2.	Conduct site-specific feasibility studies to further evaluate the potential for dam removal, as well as other management options.	WPWA, TNC, Watershed Municipalities, Dam Owners	2-5 years	$$$ to $$$$	Cost-share grants (NOAA, CRMC, USFWS, NFWF), municipal funds
3.	Obtain funding for and implement dam removal projects, where determined technically feasible and acceptable by the community.	WPWA, TNC, Watershed Municipalities, Dam Owners	2-10 years	$$$$$	Cost-share grants (RIDEM-BWRF, NOAA, CRMC, USFWS, NFWF), municipal funds

$ = $0 to $5,000 $$ = $5,000 to $10,000 $$$ = $10,000 to $50,000 $$$$ = $50,000 to $100,000
$$$$$ = Greater than $100,000

1. *Incorporate priority dam management recommendations identified in this study into local hazard mitigation planning documents.*

   Communities with FEMA-approved hazard mitigation plans are eligible to apply for Hazard Mitigation Grant Program funding from FEMA for measures identified in their plans. Identified dam management recommendations need to be identified in these plans before floods occur. Priority dam removal and repair recommendations identified in this watershed management plan and the accompanying *Dams, Bridges and Culverts Assessment Technical Memorandum* in Appendix G, particularly high- and medium-priority recommendations, should be included in the hazard mitigation plans of the watershed communities.

2. Conduct site-specific feasibility studies to further evaluate the potential for dam removal, as well as other management options.

The dams assessment described in the *Dams, Bridges and Culverts Assessment Technical Memorandum* (Appendix G) consisted of an initial screening-level assessment to evaluate and guide the development of management recommendations for each dam, with the goal of improving flood resiliency and aquatic habitat, river continuity, and fish passage. The assessment considered a number of site-specific factors including hazard classification, condition, flood storage potential, hydraulic capacity, current uses of the impoundments, cost-effectiveness, ease of permitting, the owner's ability to maintain the dam, land area available for aquatic organism passage structures, planned and ongoing dam removal and repair projects, and other potential benefits and impacts. Preliminary screening-level management recommendations were developed for each dam, and each recommendations was classified as high-, intermediate-, or low-priority. Table 4-2 lists high- and medium-priority dam management recommendations by subwatershed and stream. A complete list of all of the assessed dams in the Wood-Pawcatuck is provided in the technical memorandum in Appendix G.

The screening-level recommendations are preliminary in nature and require more detailed, site-specific evaluation to adequately assess various management alternatives, potential flood resiliency and ecological benefits, and potential impacts. Detailed feasibility studies are required to support selection of a preferred alternative, as well as future planning, design, permitting, and funding requests for implementation of specific dam management recommendations.

Dam Removal Feasibility Study

The feasibility of removing a dam is dictated by many factors including current uses of the impoundment, cooperation of the owner, potential impacts to existing wetlands and habitat, and management of potentially contaminated sediments. A feasibility study is needed to inform the decision about how to manage a dam, including the feasibility of dam removal as well as other options. The feasibility study provides concept-level plans and quantitative information on environmental and engineering feasibility to make final decisions on the project approach and funding needs. A feasibility study should include the following elements, at a minimum:

- Background data and information gathering
- Determine current uses and legal rights associated with dam and impoundment
- Assess land ownership around the impoundment and dam
- Conduct site visit and planning meeting with project proponent, dam owner, local, state, and federal agencies
- Survey - topographic, dam, bathymetry, and property boundary – and base mapping
- Wetland resource delineation
- Habitat assessment, listed species
- Hydrologic and hydraulic analysis
- Scour analysis
- Aquatic organism passage analysis
- Recreational and cultural assessment
- Archaeological reconnaissance survey
- Channel and riparian restoration plan
- Sediment characterization (quantity and quality of sediment in impoundment) and sediment management plan
- Preliminary structure removal plan
- Alternatives evaluation
- Preliminary/conceptual design drawings
- Preliminary opinion of cost
- Identification of required permits
- Report or technical memorandum

The Wood-Pawcatuck Watershed Association, working with dam owners including the watershed municipalities, state agencies, and private dam owners, as well as The Nature Conservancy and other organizations, should secure initial funding for and conduct feasibility studies to further evaluate the potential for dam removal, as well as other management options, for specific priority dams identified in this management plan.

When considering the costs and benefits of dam removal, the environmental services that could be restored should be included in any benefit-cost analysis. In addition, the benefit-cost analysis of dam repair should include the lost environmental services, life-cycle operation and maintenance cost, capital reinvestment costs, and the cost of ultimately decommissioning the dam.

3. *Obtain funding for and implement dam removal projects, where determined technically feasible and acceptable by the community.*

Upon completion of the feasibility study, the project proponent should proceed with the following steps where dam removal is determined to be technically feasible and acceptable by the community:

- Fundraising – Develop a fundraising strategy and a list of potential grant sources, gather letters of support, and apply for funding (see funding sources listed in Section 6 of this plan).
- Community Outreach – Meet with abutters and stakeholders to review alternatives and seek to obtain local support for a preferred alternative.
- Pre-Permitting Meetings – Meet with local, state, and federal officials and regulators to clarify and confirm regulatory review requirements and any additional information requirements needed by the agencies.
- Engineering Design - Develop engineering design plans (modification or dam removal and stream restoration), project specifications, and Engineer's Cost Estimate for construction.
- Permitting – prepare and file regulatory permit applications, attend public hearings, and address public and agency comments and permitting considerations.
- Construction – Hire contractors, drawdown impoundment, address impoundment sediments as necessary, remove dam structure, restore stream channel, and revegetate impoundment.
- Post-Removal Monitoring – conduct monitoring of restoration area and habitat following construction.

The cost to remove a dam is highly site-specific and can range from tens of thousands of dollars up to several million dollars depending on a variety of factors including the size of the dam, management of potentially contaminated sediments, and the aerial extent of the upstream restoration. Most dam removal projects generally range from $100,000 to $1 million in total costs. Total project costs for removal of Lower Shannock Falls Dam in 2011 and White Rock Dam in 2015 were $825,000 and $950,000, respectively, including design, permitting, and construction.

Table 4-2. High- and medium-priority dam management recommendations.

Subwatershed	Stream Name	Dam Name (Town)	Hazard Class	Owner	Description	Recommendation	Priority
Ashaway River	Ashaway River	Ashaway Line Pond Dam (Hopkinton, RI)	Low	Ashaway Line & Twine Mfg. Co.	The impoundment is currently used for fire suppression, although the owner is not opposed to removal. The downstream watercourse is open to fish passage, and the dam is deteriorating. Removal should be considered.	Consider Removal	High
	Ashaway River	Ashaway Mill Pond Dam (Hopkinton, RI)	Low	Ashaway Line & Twine Mfg. Co.	This dam is part of the RIDOT bridge supporting High Street (Route 216). The impoundment does not appear to support any active uses. The dam is deteriorating. Removal should be considered in conjunction with Ashaway Line Pond Dam removal.	Consider Removal	High
	Ashaway River	Bethel Pond Dam (Hopkinton, RI)	Low	Bermuda Realty, Inc.	The impoundment does not appear to support any active uses and the dam is not being maintained. Removal should be considered in conjunction with removal of Ashaway Line Pond Dam and Ashaway Mill Pond Dam.	Consider Removal	High
Beaver River	Beaver River	DeCoppett Pond Dam (Richmond, RI)	Low	RIDEM	The dam is located on the Beaver River, which is one of the most valued cold water streams in RI and has a known population of Brook Trout. The impoundment does not appear to support any active uses and the dam is deteriorating. Removal should be considered.	Consider Removal	High
	Beaver River	Tug Hollow Pond Dam (Richmond, RI)	Low	Helen Buchanan	The impoundment does not appear to support any active uses. Removal would improve water quality and connectivity on the Beaver River, which is one of the most valued cold water streams in the State. Removal could require replacement of the downstream culvert.	Consider Removal	Intermediate
Chipuxet River	Chipuxet River Tributary	Slocum Road Upper Dam (North Kingstown, RI)	High	Maurice N. and Kimberly P. Klein	NOVs were issued in 2011 and 2012 by RIDEM. The owner indicated that repairs were made but RIDEM has not confirmed. The impoundment supports limited recreational use. Dam removal should be considered if the owner is amenable.	Consider Removal	Intermediate
Lower Wood River	Wood River	Alton Pond Dam (Hopkinton/Richmond, RI)	Significant	RIDOT	Alton Pond Dam is the downstream-most dam on the Wood River, restricting aquatic passage to the river. Removal should be considered. Replacement or reconfiguration of the Church Street bridge would be required to accommodate dam removal.	Consider Removal	High

Table 4-2. High- and medium-priority dam management recommendations.

Subwatershed	Stream Name	Dam Name (Town)	Hazard Class	Owner	Description	Recommendation	Priority
Lower Wood River	Blue Pond Brook	Ashville Pond Dam (Hopkinton, RI)	Significant	Unidentified	The dam is not being maintained, is deteriorating, and supports a public road. Dam could be decommissioned by replacing the culvert with a larger structure and draining the impoundment over time. Repurposing was evaluated and determined not to be a priority based on location, lack of downstream hazards and hydrology.	Consider Removal and Replacing Culvert to Maintain Roadway	High
	Blue Pond Brook	Blue Pond Dam (Hopkinton, RI)	Significant	Ashville Corporation	The dam is partially breached, currently supporting a reduced impoundment. Further erosion and embankment failure could occur during high flows. Consider formalizing the partial breach. RIDEM has considered managing the impoundment as a waterfowl management area, which could also be reconsidered.	Consider Formalizing Partial Breach	Intermediate
	Moscow Brook	Centerville Pond Dam (Hopkinton, RI)	Low	Dietrich Baeu	The dam is deteriorating and not being maintained. The only current known use of the impoundment is private recreation. Removal should be considered. The hazard classification of the dam should be re-evaluated given the downstream infrastructure.	Consider Removal and Re-evaluating Hazard Class	Intermediate
	Canonchet Brook Tributary	Hoxie Farm Pond Dam (Hopkinton, RI)	Significant	RIDOT	Consider replacing culvert with larger structure and lowering invert to drain impoundment and decommission dam. Repurposing was evaluated and determined not to be a priority based on location, lack of downstream hazards and hydrology.	Consider Removal and Replacing Culvert to Maintain Roadway	Intermediate
	Brushy Brook Tributary	Langworthy Pond Dam (Hopkinton, RI)	Significant	Richard A. Mann	The impoundment is used for private recreation, and the owner has maintained the dam. Removal should be considered given its location and hazard classification. The dam is a significant hazard dam.	Consider Removal	Intermediate

Table 4-2. High- and medium-priority dam management recommendations.

Subwatershed	Stream Name	Dam Name (Town)	Hazard Class	Owner	Description	Recommendation	Priority
Lower Wood River	Brushy Brook	Locustville Pond Dam (Hopkinton, RI)	High	Georgia Ure	The dam is a hydropower dam and powers the commercial buildings downstream of the dam. Owners recently repaired but did not apply to RIDEM for permits for repairs. Repairs have not been inspected by RIDEM and current status is unknown. The dam should be maintained. An AOP structure should be considered once the downstream obstructions are removed.	Maintain, Consider AOP Structure	Intermediate
	Moscow Brook	Moscow Pond Dam (Hopkinton, RI)	Low	RIDEM Fish and Wildlife	Impoundment is used for fishing. Although the dam is deteriorating, a public road traverses the dam crest and there appears to be a house downstream of the dam. Removal should be considered, and the hazard classification should be re-evaluated.	Consider Removal and Re-evaluating Hazard Class	Intermediate
	Blue Pond Brook	Union Pond Dam (Hopkinton, RI)	Low	Bayou Line & Twine Co.	The impoundment supports private recreational uses. Owner lives out of state and does not actively maintain the dam. Secondary spillway was reportedly breached in 2010 when Blue Pond Dam breached, but has since been dammed by beavers. Dam removal should be considered.	Consider Removal	Intermediate
	Wood River	Woodville Pond Dam (Hopkinton/Richmond, RI)	Low	Unidentified	The impoundment supports no significant active uses and is in disrepair. Removal of the dam could promote connectivity and allow fish passage from the main stem of the Pawcatuck up Meadow Brook. Removal should be considered. Challenges to removal include owner support, use of the impoundment for fire suppression, impacts to upstream wetlands, scour on the downstream bridge, and potential impacts on adjacent dry wells.	Consider Removal and Re-evaluating Hazard Class	Intermediate
Middle Pawcatuck River	Pawcatuck River	Burdickville Dam (Charlestown/ Hopkinton, RI)	Low	Paul Bloomfield	The impoundment does not appear to support any active uses. The dam is partially breached but may currently prevent passage of some fish species such as shad.	Consider Removal	Intermediate

Table 4-2. High- and medium-priority dam management recommendations.

Subwatershed	Stream Name	Dam Name (Town)	Hazard Class	Owner	Description	Recommendation	Priority
Middle Pawcatuck River	Tomaquaug River Tributary	Harris Pond Dam (Hopkinton, RI)	Significant	Edward Carapezza	The owner wants to maintain the dam to provide a wildlife refuge and has completed repairs in the past. A 2013 inspection report indicates that the embankment was in fair to poor condition and was in need of repair (vegetation removal and establishment of grass cover).	Consider Repair	High
	Pawcatuck River	Potter Hill Dam (Hopkinton, RI)	Low	Renewable Resources, Inc.	Although the dam has a fish ladder, removal of the dam should be considered to enhance AOP and flood resiliency. Concerns exist about impacts to upstream wetland habitats based on previous evaluations by the U.S. Fish and Wildlife Service. Owner filed for FERC license, which was denied. Currently in discussions with RIDEM to purchase dam.	Consider Removal	High
Queen-Usquepaug River	Queen River	Edward's Pond Dam (Exeter, RI)	Significant	Exeter Country Club	The impoundment does not appear to support any active uses. A NOV was issued in 2015 for vegetation on the embankment. The dam is classified as a significant hazard. Removal should be considered.	Consider Removal	Intermediate
	Usquepaug River	Glen Rock Reservoir Dam (South Kingstown, RI)	Significant	Kenyon Cornmeal Company, Inc. (Paul E.T. Drumm III)	Breached in 2010 flood. Repaired in 2013. The owner wants to maintain and potentially operate the historic wheel house. The impoundment is heavily used for recreation. The dam is deteriorating and needs repair. There is no AOP structure and the dam is the downstream-most dam on the Usquepaug River, which discharges to the Pawcatuck River.	Consider Repair and AOP structure	Intermediate
Upper Pawcatuck River	White Brook	Tanner Pond Dam (Richmond, RI)	Low	Carolina Black Bass Hatchery	The hatchery is no longer in operation and the dam is in very poor condition. The dam and hatchery facilities should be considered for removal.	Consider Removal	Intermediate
	Meadow Brook	Wood River Junction Dam (Richmond, RI)	Significant	RIDOT	According to RIDEM Dam Safety, the dam is owned by RIDOT, but there is no official owner designation. Dam is in generally poor condition and is not being maintained although the impoundment has high recreational value. Removal should be considered.	Consider Removal	High

Table 4-2. High- and medium-priority dam management recommendations.

Subwatershed	Stream Name	Dam Name (Town)	Hazard Class	Owner	Description	Recommendation	Priority
Upper Wood River	Wood River	Barberville Pond Dam (Hopkinton/Richmond, RI)	Significant	RIDEM	Removal of the dam is not recommended due to the impoundment's recreational value. A fish passage structure is recommended as an intermediate priority given the downstream obstructions to fish passage.	Consider Nature-Like Fishway	Intermediate
	Breakheart Brook	Breakheart Pond Dam (Exeter, RI)	Low	RIDEM	This dam is located within the Arcadia Management Area, which has significant recreational value. The downstream watercourse has obstructions to fish passage, and the dam is in poor condition.	Consider Repair	High
	Roaring Brook	Browning Mill Pond Dam (Exeter, RI)	High	RIDEM	RIDEM owns the dam and operates a hatchery downstream. Browning Mill Pond has significant public recreational value. The dam is deteriorating.	Consider Repair	High
	Wood River	Porter Pond Dam (Sterling, CT)	Moderate	Unidentified	The impoundment supports limited recreation uses. The owner of the dam could not be identified. The dam is not being maintained and is in disrepair. Removal should be considered.	Consider Removal	Intermediate
	Wood River	Wyoming Pond Upper Dam (Hopkinton/Richmond, RI)	High	RIDEM	RIDEM plans to repair the dam. Dam removal would reduce flood risk to adjacent and upstream properties, improve stream connectivity and water quality. Significant public opposition to dam removal has been expressed by some Hopkinton residents and Town Council. The Richmond Town Council has expressed support for further evaluating the dam removal and other alternatives and requested that RIDEM publicly conduct such an evaluation prior to moving forward with the planned repairs.	Consider Repair	High

4.2 Culverts and Bridges

Reduce the flood risk and erosion hazards posed by culverts and bridges in the watershed, and restore the connectivity of streams for fish and other aquatic organism passage.

The Issue

While road stream crossings (i.e., culverts and bridges) are an integral part of transportation infrastructure, inadequate or undersized crossings can be flooding and washout hazards. Inadequately designed, outdated, or undersized crossings can increase flooding of upstream and adjacent areas or have significant impacts to the transportation system. Across the U.S., culvert failures cost communities millions of dollars every year in property and infrastructure damages (MADER, June 2012). Culverts can also serve as barriers to the passage of fish and other aquatic organisms along a river system, altering aquatic habitat and disrupting river and stream continuity.

Common Stream Crossing Problems

Undersized or Inadequate Crossings

Undersized or inadequate crossings can restrict natural streamflow during high flows, causing scour and erosion, backing up water and depositing sediment behind the crossing, creating higher flow velocity and erosion downstream, clogging, and washout. Crossings should be large enough to accommodate high flows and to pass fish and other wildlife.

Shallow Crossings

Shallow crossings have water depths that are too low for many organisms to move through, and the bottom may lack appropriate stream bed material. Crossings should have an open bottom or should be buried into the streambed. Natural substrate should be used within the crossing, it should match the upstream and downstream substrates, and it should resist displacement during floods.

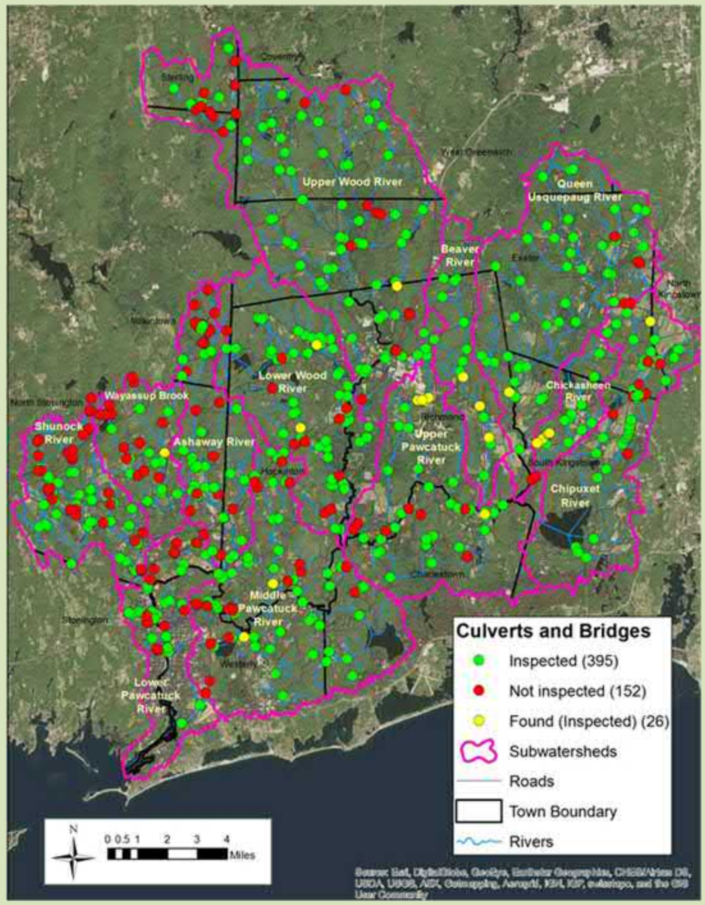
Perched Crossings

Perched crossings are above the level of the stream bottom at the downstream end, restricting upstream passage by fish and other aquatic organisms and contributing to downstream bed scour. Crossings should be open-bottomed or embedded into the bottom of the stream channel to prevent perching.

As described in Section 1, extreme rainfall in New England is expected to continue to increase with climate change, which is expected to increase the risk flooding in the watershed. Stream crossings and the associated transportation infrastructure will be more susceptible to flood damage because of more severe storms and heavy rainfall. In addition to climate change, some parts of the watershed are susceptible to future development pressure that, if not appropriately controlled, could place further stress on outdated or inadequate stream crossings.

Assessment of Road Stream Crossings in the Wood-Pawcatuck Watershed

An assessment was performed of the road stream crossings in the watershed to identify vulnerable crossings and prioritize structures for upgrade or replacement. Culverts and bridges were evaluated relative to hydraulic capacity under current and future (i.e., climate change) conditions, flooding impact potential, geomorphic vulnerability, and aquatic organism passage. The assessment is documented in a separate report entitled *Dams, Bridges and Culverts Assessment Technical Memorandum* (Fuss & O'Neill, 2016b) (see Appendix G).



The Wood-Pawcatuck watershed contains nearly 600 stream crossing structures (roads, railroads, and developed bicycle/hiking trails) that traverse mapped streams. Approximately 400 of these stream crossings were inspected and evaluated relative to flooding, erosion, and aquatic passage barriers as part of a watershed-wide road stream crossing vulnerability assessment (see text box above). The major findings of the assessment are as follows:

- An estimated 38% of the assessed stream crossings are hydraulically undersized relative to the 25-year design flow. 49% are predicted to be hydraulically undersized under a Year 2070 climate change scenario. Figure 4-2 shows the percentage of existing and predicted future hydraulic capacity ratings of the assessed stream crossings in the watershed. Hydraulic capacity rating reflects the largest recurrence interval peak discharge that a structure can convey without overtopping. An estimated 45% of the local road crossings are hydraulically undersized, while approximately 22% of state road crossings are hydraulically undersized. Circular pipes and box culverts make up the majority of the hydraulically undersized stream crossings in the watershed.

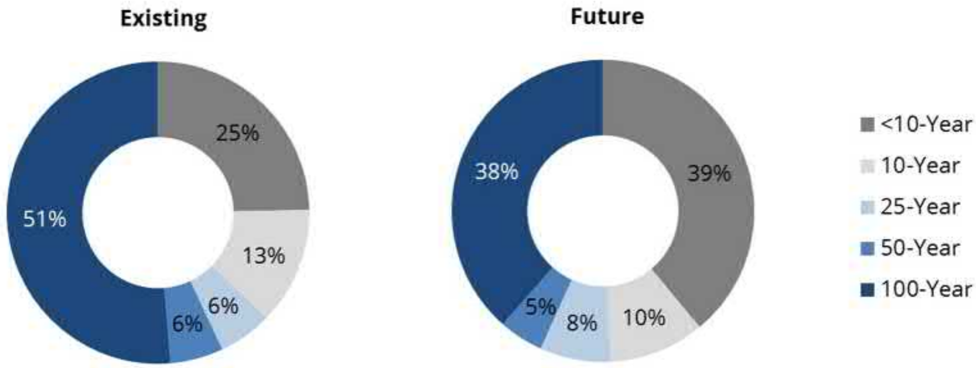


Figure 4-2. Existing and future hydraulic capacity ratings for assessed stream crossings in the Wood-Pawcatuck watershed.

- 47% of the assessed structures in the watershed have a high geomorphic vulnerability rating. Geomorphic vulnerability of a culvert or bridge refers to the likelihood of potential impacts of the structure on channel stability based on consideration of the physical characteristics of the structure and stream channel. The percentage of crossings with high geomorphic vulnerability ratings is relatively consistent between local roads, state roads, and railroads and across structure types (Figure 4-3).

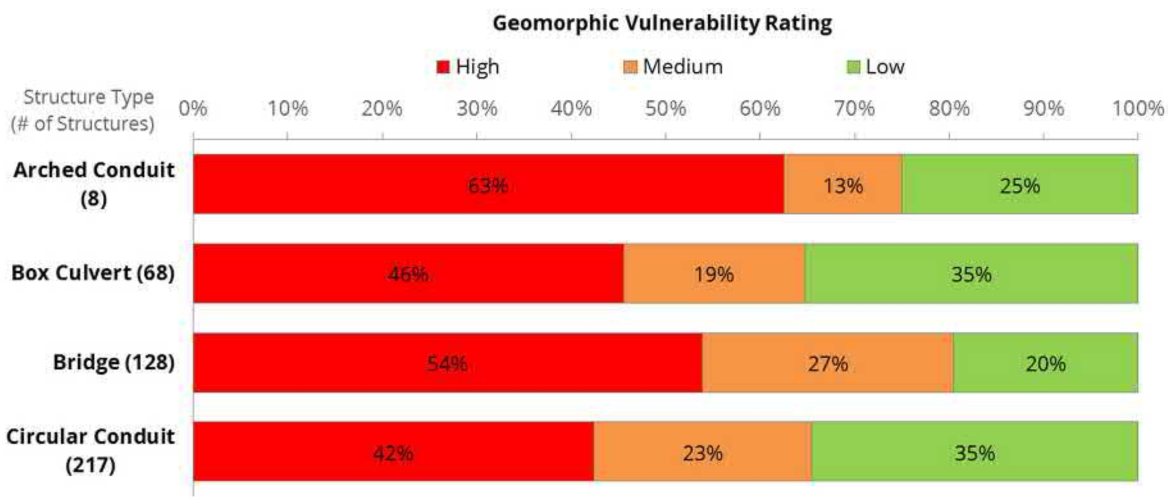


Figure 4-3. Culvert and bridge geomorphic vulnerability ratings by structure type.

- 43% of stream crossings provide for full passage of aquatic organisms. The percentage of assessed structures in the Wood-Pawcatuck watershed that were identified as moderate to severe barriers (57%) to aquatic organism passage is consistent with other regional stream crossing assessments in New England (Figure 4-4). Stream crossings associated with trails and local roads are more significant barriers to aquatic organism passage than crossings associated with state roads, railroads, and highways. Bridges (89% Full AOP) and arched conduits (75% Full AOP) generally have the largest openings and provide the greatest continuity, while box culverts

(41% Full AOP) and circular conduits (14% Full AOP) are the greatest barriers to aquatic organism passage in the watershed.

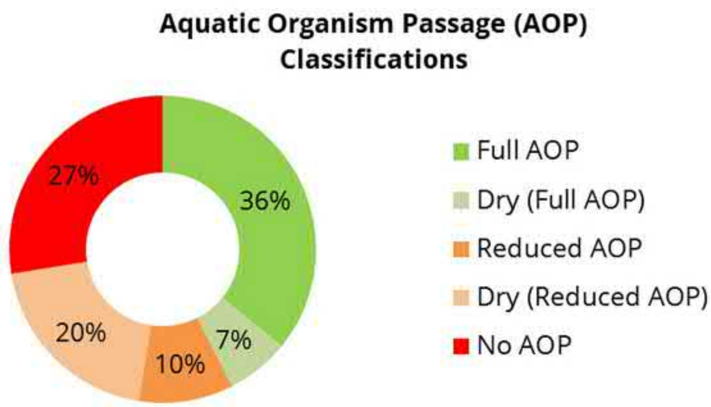


Figure 4-4. Percentage of stream crossing structures in the Wood-Pawcatuck watershed by aquatic organism passage (AOP) classification.

- 37% of the assessed structures in the watershed are rated as high priority for upgrade or replacement. The priority ratings are based on the combined consideration of hydraulic capacity, flooding impact potential, geomorphic vulnerability, and aquatic organism passage. 43% of the crossings are rated as intermediate priority, and 20% as low priority.

Replacing Outdated or Inadequate Crossings – Stream and Flood Friendly Culverts

Replacing outdated or inadequate crossings with crossings that maintain natural flow and substrate conditions enhances the resiliency of the transportation system, reduces expensive erosion and structural damage, reduces flood impacts on upstream and neighboring properties, and increases stream continuity for aquatic organism passage. Better standards and more effective design are critical for enhancing the resiliency and ecological benefits of new and replacement stream crossings. The text box on the following page highlights common stream crossing standards and elements of effective crossing designs.

Well-designed crossings should span the stream and banks, maintain comparable water velocities, have a natural streambed, and create no noticeable change in the river.

Stream crossing standards that promote stream continuity and flood resiliency have been adopted – as guidance and, in some cases, regulation – by several states in the northeast U.S. including Massachusetts, New Hampshire, Vermont, Connecticut, Maine, and New York. Such standards, which are generally based on Stream Simulation Design (Forest Service, May 2008), have also been incorporated to varying degrees into the U.S. Army Corps of Engineers state-specific general permits. Although stream crossing guidance is provided in the *RI DEM Wetland BMP Manual: Techniques for Avoidance and Minimization," Chapter 9 "Wetland Crossings,"* comprehensive statewide stream crossing standards have not yet been adopted in Rhode Island.

General Stream Crossing Standards (adapted from MA, CT, and NY)

Crossing Type

Bridges and bottomless arches, 3-sided box culverts, and open-bottom culverts are preferred and should be used whenever possible.

Embedment

Box and pipe culverts, if used, should be embedded into the streambed to at least 20 percent of the culvert height at the downstream invert (a minimum of 2 feet), used only on "flat" streambeds (slopes no steeper than 3 percent), and installed level.

Substrate

Natural substrate (rocks, gravel, etc.) should be used within the crossing, and it should match the upstream and downstream substrates. It should resist displacement during floods and should be designed so that appropriate material is maintained during normal flows.

Crossing Span/Width

The crossing opening should be at least 1.2 times the bankfull width of the stream, measured bank to bank at the ordinary high-water level or edges of terrestrial, rooted vegetation.

Openness

The crossing should have an openness ratio (cross-sectional area divided by crossing length) of at least 0.82 feet, with 1 to 1.5 feet preferred. The crossing should be wide and high relative to its length.

Water Depth and Velocity

At low flows, water depths and velocities should be the same as they are in natural areas upstream and downstream of the crossing.

Source: Massachusetts Stream Crossing Standards, Department of Fish and Game (MADER, June 2012)

Crossings designed to meet stream crossing standards have been found to be extremely effective in safely passing water, sediment, and debris during floods, while maintaining safe passage for emergency personnel and residents (MADER, June 2012). While upgrading culverts to larger and more flood-resilient and stream-friendly designs can be more expensive in the short term (sometimes 50% to 100% more than in-kind replacements), long-term costs are significantly reduced as the road crossing survives larger precipitation events (i.e., lasts longer) and generally requires less maintenance. When maintenance and replacement are considered, the average annual cost of an upgraded crossing can be lower over its lifetime than that of an undersized crossing over the same time (Industrial Economics, Incorporated, January 2015; Levine, August 2013; Gillespie, et al., February 2014). Undersized and outdated stream crossings are even less cost-effective when climate change considerations – more frequent intense storms – are factored in.

Recommended Actions

Table 4-3 contains recommendations relative to stream crossings (i.e., culverts and bridges) in the Wood-Pawcatuck watershed, including actions that can be taken at the local and state level.

Table 4-3. Stream crossing recommendations.

	Action	Lead Entity	Timeframe	Estimated Cost	Possible Funding Sources
1.	Incorporate priority stream crossings identified in this study into local hazard mitigation plans.	Watershed Municipalities	1-2 years	$	Municipal funds
2.	Upgrade existing vulnerable stream crossings by replacing crossings with more resilient and ecologically-friendly designs.	Watershed Municipalities, RIDOT, CTDOT	2-10 years	$$$ to $$$$$	BWRF, FEMA flood hazard mitigation assistance funding, cost-share grants, third-party compensatory mitigation, incentive programs
3.	Adopt statewide stream crossing standards in Rhode Island for new and replacement stream crossings, modeled after existing stream crossings standards in Massachusetts, Connecticut, Vermont, and New Hampshire.	RIDEM	2-5 years	$$$$	State funds
4.	Implement local standards for new and replacement stream crossings.	Watershed Municipalities	2-5 years	$$	Municipal funds
5.	Update design storm precipitation amounts in state and local land use regulations and policies to promote more resilient road crossing design.	Watershed Municipalities, RIDEM, CTDEEP	2-5 years	$$	Municipal funds
6.	Establish adequate, sustained sources of funding.	Watershed Municipalities, State Agencies	5-10 years	$$	See Recommendation 2

Table 4-3. Stream crossing recommendations.

	Action	Lead Entity	Timeframe	Estimated Cost	Possible Funding Sources
7.	Provide training to highway departments.	RIDEM, Watershed Municipalities	2-5 years	$$	State/municipal funds
8.	Implement ongoing inspection and maintenance programs.	Watershed Municipalities	1-2 years	$$	Municipal funds
9.	Update and integrate local comprehensive land use plans and hazard mitigation plans.	Watershed Municipalities	1-2 years	$	Municipal funds

$ = $0 to $5,000 $$ = $5,000 to $10,000 $$$ = $10,000 to $50,000 $$$$ = $50,000 to $100,000
$$$$$ = Greater than $100,000

1. *Incorporate priority stream crossings identified in this study into local hazard mitigation plans.*

   Communities with FEMA-approved hazard mitigation plans are eligible to apply for Hazard Mitigation Grant Program funding from FEMA for measures identified in their plans. Stream crossing upgrade priorities need to be included in these plans before floods occur. Vulnerable stream crossings identified in this watershed management plan and the accompanying *Dams, Bridges and Culverts Assessment Technical Memorandum* in Appendix G, particularly crossings identified as high- and medium-priority, should be included in the hazard mitigation plans of the watershed communities.

2. *Upgrade existing vulnerable stream crossings by replacing crossings with more resilient and ecologically-friendly designs.*

   The watershed municipalities and state transportation departments should replace existing vulnerable stream crossings with more flood-resilient and ecologically-beneficial designs. Replacement stream crossings should be upgraded to meet the stream crossing standards or guidelines currently in place in Connecticut or that have been adopted by other neighboring states including Massachusetts and New York (see Recommendations 3 and 4 below).

   The watershed-wide stream crossing vulnerability assessment classified stream crossings in the Wood-Pawcatuck watershed as high-, medium-, or low-priority for upgrade or replacement. Table 4-4 lists high-priority stream crossings by subwatershed and stream. A complete list of all of the assessed stream crossings in the Wood-Pawcatuck, including medium- and low-priority structures, is provided in the technical memorandum in Appendix G.

   Note that the priority ratings are relative. Upgrade or replacement of higher-rated or higher-priority structures will generally provide greater overall benefits relative to flood resiliency and stream continuity based on a number of factors. The priority ratings are not meant as definitive recommendations since the ratings do not account for cost and other site-specific factors. The individual assessment ratings (i.e., hydraulic capacity, flooding impact potential, geomorphic vulnerability, and aquatic organism passage) should also be considered on a case-by-case basis when evaluating replacement and upgrade of specific structures. Crossings that are rated as medium- or low-priority overall, based on consideration of all four factors, may still be good candidates for replacement or upgrade to achieve a particular objective such as increased hydraulic/geomorphic capacity or aquatic organism passage.

Table 4-4. High-priority stream crossings.

Subwatershed	Stream Name	Crossing ID	Town	Road Name	Road Type	Structure Type	Primary Structure Material	Hydraulic Capacity Rating	Flooding Impact Potential Rating	Geomorphic Vulnerability Rating	AOP Classification	Priority Rating Score (1-5)
Ashaway River	Glade Brook	AWR-GLA-0-1	North Stonington	East Clarks Falls Road	Local	circular	concrete	10-Year	Medium	Low	Dry (Reduced AOP)	3.29
	Glade Brook	AWR-GLA-0-2	North Stonington	Pine Woods Road	Local	circular	concrete	10-Year	Medium	High	Reduced AOP	3.71
	Green Fall River	AWR-GRE-0-3	North Stonington	Denison Hill Road	Local	bridge	stone	< 10-Year	Medium	High	Full AOP	3.86
	Green Fall River	AWR-GRE-0-4	North Stonington	Puttker Road	Local	box culvert	concrete	10-Year	Medium	Low	Reduced AOP	3.14
	Green Fall River	AWR-GRE-0-6	Voluntown	Sand Hill Road	Local	box culvert	stone	< 10-Year	Low	High	Full AOP	3.29
	Unnamed	AWR-GRE-3-1	North Stonington	Clarks Falls Road	State	circular	concrete	< 10-Year	Medium	Low	No AOP	3.86
	Unnamed	AWR-GRE-5-1	North Stonington	Denison Hill Road	Local	circular	concrete	< 10-Year	Low	Medium	Dry (Reduced AOP)	3.43
	Unnamed	AWR-GRE-5-2	North Stonington	Denison Hill Road	Local	circular	CMP	< 10-Year	Low	High	Dry (Full AOP)	3.43
	Unnamed	AWR-GRE-6-1	North Stonington	Loin Hill Road	Local	circular	HDPE	< 10-Year	Medium	High	No AOP	4.43
	Unnamed	AWR-GRE-7-1	North Stonington	Denison Hill Road	Local	circular	HDPE	< 10-Year	Low	High	No AOP	3.86
	Unnamed	AWR-GRE-8-2-1	Voluntown	Tom Wheeler Road	Local	circular	concrete	< 10-Year	Low	Medium	No AOP	3.57
	Unnamed	AWR-GRE-8-2-2	Voluntown	Sand Hill Road	Local	circular	CMP	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Parmenter Brook	AWR-PAR-0-2	Hopkinton	Clarks Falls Road	State	circular	CMP	< 10-Year	Medium	High	Dry (Reduced AOP)	4.29
Beaver River	Beaver River	BVR-BEA-0-1	Richmond	Shannock Hill Road	Local	bridge	concrete	< 10-Year	Medium	High	Reduced AOP	4.14
	Beaver River	BVR-BEA-0-2	Richmond	Schoolhouse Road	Local	box culvert	concrete	< 10-Year	Medium	High	Reduced AOP	4.14
	Beaver River	BVR-BEA-0-4	Richmond	Hillsdale Road	Local	circular	concrete	< 10-Year	Medium	High	No AOP	4.43
	Beaver River	BVR-BEA-0-5	Richmond	Old Mountain Road	Local	circular	concrete	< 10-Year	Medium	Medium	Reduced AOP	3.86
	Beaver River	BVR-BEA-0-6	Richmond	New London Turnpike	State	circular	CMP	25-Year	High	High	No AOP	4.14
	Unnamed	BVR-BEA-5-1	Richmond	New London Turnpike	State	circular	CMP	< 10-Year	High	High	Reduced AOP	4.71
	Unnamed	BVR-BEA-6-1	Richmond	New London Turnpike	State	circular	CMP	10-Year	High	High	No AOP	4.57
	Unnamed	BVR-BEA-6-2	Richmond	Dawley Park Road	Local	box culvert	stone	< 10-Year	Low	High	No AOP	3.86
	Beaver River	BVR-FOUND-20150630	Richmond	Punchbowl Road	Local	bridge	stone	10-Year	Medium	High	Full AOP	3.43
	Beaver River	BVR-FOUND-20150817	Richmond	Unnamed	Trail	bridge	concrete	< 10-Year	Medium	Medium	No AOP	4.14
	Beaver River	BVR-FOUND-20151015	Richmond	Unnamed	Driveway	bridge	timber	10-Year	Medium	High	Reduced AOP	3.71
Chickasheen Brook	Unnamed	CKR-CHK-1-1	South Kingstown	Liberty Road	Local	circular	concrete	10-Year	Medium	Medium	Dry (Reduced AOP)	3.57
	Unnamed	CKR-CHK-1-2	South Kingstown	South County Trail	State	circular	concrete	< 10-Year	Medium	High	No AOP	4.43
Chipuxet River	Alewife Brook	CPR-ALE-0-2	South Kingstown	Worden Pond Family	Local	circular	HDPE	< 10-Year	Medium	High	Reduced AOP	4.14
	Alewife Brook	CPR-ALE-0-3	South Kingstown	Ministerial Road	State	circular	CMP	50-Year	High	Medium	No AOP	3.43
	Chipuxet River	CPR-CHP-0-4	Exeter	Wolf Rocks Road	Local	box culvert	concrete	< 10-Year	Medium	Medium	No AOP	4.14
	Chipuxet River	CPR-CHP-0-5	Exeter	Yawgoo Valley Road	Local	circular	concrete	25-Year	High	High	No AOP	4.14
	Drainage Ditch	CPR-CHP-5-1-2-1	North Kingstown	Kayka Ricci Way	State	circular	concrete	< 10-Year	Medium	High	No AOP	4.43
	Unnamed	CPR-CHP-6-1	Exeter	Liberty Road	Local	circular	HDPE	< 10-Year	Low	High	No AOP	3.86
	Unnamed	CPR-CHP-7-2	Exeter	Deer Brook Lane	Local	circular	concrete	< 10-Year	Medium	High	No AOP	4.43
	Unnamed	CPR-CHP-7-3	Exeter	Mail Road	Local	circular	concrete	< 10-Year	Medium	High	Dry (Reduced AOP)	4.29
	Mink Brook	CPR-MIN-0-1	South Kingstown	Ministerial Road	State	circular	concrete	< 10-Year	High	High	Dry (Full AOP)	4.57
	Unnamed	CPR-WHB-2-1	South Kingstown	Peckham Farm Road	Local	circular	concrete	< 10-Year	High	Medium	No AOP	4.71
	Unnamed	CPR-WHB-2-7	South Kingstown	Walking Path	Trail	box culvert	concrete	10-Year	Medium	Medium	No AOP	3.71
	Unnamed	CPR-WHB-2-8	South Kingstown	Plains Road	Local	circular	concrete	< 10-Year	Medium	High	Dry (Reduced AOP)	4.29
	Unnamed	CPR-WHB-2-9	South Kingstown	Flagg Road	Local	circular	concrete	< 10-Year	Medium	High	Dry (Reduced AOP)	4.29
Lower Pawcatuck River	Mastuxet Brook	LPR-MAS-0-1	Westerly	Watch Hill Road	State	circular	concrete	50-Year	High	Low	No AOP	3.14
	Pawcatuck River	LPR-PAW-0-1	Westerly/Stonington	Broad Street	State	bridge	concrete	< 10-Year	High	High	Full AOP	4.43
	Pawcatuck River	LPR-PAW-0-3	Westerly/Stonington	Stillman Avenue	Local	bridge	concrete	10-Year	High	High	Full AOP	4.00
	Pawcatuck River	LPR-PAW-0-5	Westerly/Stonington	White Rock Road	Local	bridge	stone	10-Year	High	Low	Full AOP	3.43

Table 4-4. High-priority stream crossings.

Subwatershed	Stream Name	Crossing ID	Town	Road Name	Road Type	Structure Type	Primary Structure Material	Hydraulic Capacity Rating	Flooding Impact Potential Rating	Geomorphic Vulnerability Rating	AOP Classification	Priority Rating Score (1-5)
Lower Pawcatuck River	Pawcatuck River	LPR-PAW-0-6	Westerly	Boom Bridge Road	Local	bridge	concrete	< 10-Year	Medium	High	Full AOP	3.86
	Pawcatuck River	LPR-PAW-0-7	Westerly	Post Office Lane	Local	bridge	stone	< 10-Year	Medium	High	Full AOP	3.86
	Unnamed	LPR-PAW-5-1	Stonington	West Arch Street	Local	circular	concrete	< 10-Year	Medium	High	Dry (Reduced AOP)	4.29
	Unnamed	LPR-PAW-7-1	Westerly	White Rock Road	Local	circular	concrete	< 10-Year	High	Low	No AOP	4.43
	Unnamed	LPR-PAW-7-1-1	Westerly	Spring Brook Road	Local	box culvert	stone	< 10-Year	Medium	High	Dry (Full AOP)	4.00
	Unnamed	LPR-PAW-7-2	Westerly	Boom Bridge Road	Local	arched	stone	10-Year	Medium	High	No AOP	4.00
Lower Wood River	Brushy Brook	LWR-BRU-0-2	Hopkinton	Sawmill Road	Local	circular	concrete	10-Year	Medium	High	No AOP	4.00
	Unnamed	LWR-BRU-2-1	Hopkinton	Harningstuns Crossing	Local	bridge	concrete	25-Year	Medium	High	Dry (Full AOP)	3.14
	Unnamed	LWR-BRU-2-2	Hopkinton	Harningstuns Crossing	State	circular	concrete	< 10-Year	Medium	High	Reduced AOP	4.14
	Unnamed	LWR-BRU-3-1	Hopkinton	Fairview Avenue	Local	circular	concrete	< 10-Year	Low	Medium	Dry (Reduced AOP)	3.43
	Unnamed	LWR-BRU-5-2	Hopkinton	Dye Hill Road	Local	circular	HDPE	< 10-Year	Low	High	No AOP	3.86
	Unnamed	LWR-BRU-6-1	Hopkinton	Dye Hill Road	Local	circular	concrete	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Canonchet Brook	LWR-CAN-0-3	Hopkinton	Woodlawn Drive	Local	circular	concrete	50-Year	High	Medium	Reduced AOP	3.14
	Unnamed	LWR-CAN-1-1	Hopkinton	Palmer Circle	Local	circular	concrete	25-Year	Medium	High	Reduced AOP	3.29
	Diamond Brook	LWR-DIA-0-2	Richmond	Shippee Trail Road	Local	circular	CMP	< 10-Year	Low	High	No AOP	3.86
	Moscow Brook	LWR-MOS-0-2	Hopkinton	Woody Hill Road	Local	bridge	stone	100-Year	High	High	No AOP	3.29
	Moscow Brook	LWR-MOS-0-7	Hopkinton	Camp Yawgoog Road	State	circular	CMP	25-Year	Medium	High	Reduced AOP	3.29
	Unnamed	LWR-MOS-4-1	Hopkinton	Camp Yawgoog Road	Local	bridge	stone	10-Year	Low	High	No AOP	3.43
	Wood River	LWR-WOR-0-1	Hopkinton	Alton Bradford Road	State	bridge	concrete	50-Year	High	High	No AOP	3.71
	Wood River	LWR-WOR-0-2	Hopkinton	Woodville Road	State	bridge	concrete	< 10-Year	High	Medium	Full AOP	4.14
	Unnamed	LWR-WOR-4-1	Hopkinton	Crowthor Road	Local	circular	CMP	10-Year	Low	High	Dry (Reduced AOP)	3.29
	Unnamed	LWR-WOR-4-2	Hopkinton	Woodville Road	State	circular	concrete	< 10-Year	Medium	High	No AOP	4.43
	Unnamed	LWR-WOR-5-1	Hopkinton	Woodville Road	State	bridge	concrete	< 10-Year	Medium	High	Full AOP	3.86
	Unnamed	LWR-WOR-6-1-1	Hopkinton	Woodville Alton Road	Local	circular	concrete	< 10-Year	Medium	High	No AOP	4.43
	Unnamed	LWR-WOR-8-1	Hopkinton	Graniteville Road	Local	circular	CMP	< 10-Year	Low	High	No AOP	3.86
	Unnamed	LWR-WOR-9-2	Hopkinton	Nooseneck Hill Road	State	box culvert	stone	< 10-Year	High	High	Full AOP	4.43
Middle Pawcatuck River	Unnamed	MPR-ISO-NE	Westerly	Moorehouse Road	Local	box culvert	HDPE	< 10-Year	Low	High	No AOP	3.86
	McGowan Brook	MPR-MCG-1-1	Westerly	Westerly-Bradford Road	State	circular	CMP	< 10-Year	High	High	Dry (Reduced AOP)	4.86
	Mile Brook	MPR-MIL-0-2	Hopkinton	Main Street	State	box culvert	concrete	50-Year	High	High	Full AOP	3.14
	Mile Brook	MPR-MIL-0-3	Hopkinton	Ashaway Road	State	circular	concrete	10-Year	High	Medium	Full AOP	3.71
	Mile Brook	MPR-MIL-1-2	Hopkinton	Ashaway Road	State	box culvert	concrete	25-Year	Medium	High	Dry (Reduced AOP)	3.43
	Unnamed	MPR-PAW-16-1	Westerly	Hiscox Road	Local	circular	concrete	< 10-Year	High	Low	Reduced AOP	4.14
	Unnamed	MPR-PAW-16-1-1	Westerly	Potter Hill Road	State	circular	CMP	< 10-Year	Medium	High	No AOP	4.43
	Unnamed	MPR-PAW-16-2	Westerly	Forrestal Drive	Local	circular	concrete	< 10-Year	High	High	No AOP	5.00
	Perry Healy	MPR-PER-0-3	Westerly	Ross Hill Road	State	circular	CMP	< 10-Year	Medium	High	Reduced AOP	4.14
	Poquiant Brook	MPR-POQ-0-1	Charlestown	Buckeye Brook Road	Local	circular	concrete	10-Year	Medium	High	Full AOP	3.43
	Unnamed	MPR-POQ-1-2	Charlestown	Burlingame State Park - Mgmt	State	circular	concrete	< 10-Year	Low	High	No AOP	3.86
	Unnamed	MPR-POQ-1-3	Charlestown	Burlingame State Park - Mgmt	State	circular	concrete	< 10-Year	Low	High	No AOP	3.86
	Tomaquag Brook	MPR-TOM-0-1	Hopkinton	Chase Hill Road	State	bridge	stone	25-Year	High	High	Full AOP	3.57
	Unnamed	MPR-TOM-1-1	Hopkinton	Tomaquag Road	Local	box culvert	concrete	< 10-Year	High	High	Full AOP	4.43
	Unnamed	MPR-TOM-1-3	Hopkinton	Vuono Road	Local	circular	HDPE	< 10-Year	High	High	Reduced AOP	4.71
Queen-Usquepaug R.	Fisherville Brook	QUR-FIS-0-2	Exeter	Pardon Joslin Road	Local	circular	concrete	10-Year	Low	High	Reduced AOP	3.14
	Fisherville Brook	QUR-FIS-0-3	West Greenwich	Henry Brown Road	Local	circular	CMP	< 10-Year	Low	High	Reduced AOP	3.57

Table 4-4. High-priority stream crossings.

Subwatershed	Stream Name	Crossing ID	Town	Road Name	Road Type	Structure Type	Primary Structure Material	Hydraulic Capacity Rating	Flooding Impact Potential Rating	Geomorphic Vulnerability Rating	AOP Classification	Priority Rating Score (1-5)
Queen-Usquepaug River	Unnamed	QUR-FIS-3-2	West Greenwich	Shetucket Turnpike	Local	circular	concrete	< 10-Year	Low	High	No AOP	3.86
	Unnamed	QUR-FOUND-20150810	Exeter	Punchbowl Road	Local	circular	concrete	< 10-Year	Low	High	No AOP	3.86
	Unnamed	QUR-GLE-2-1-1	Richmond	James Trail	Local	circular	HDPE	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Unnamed	QUR-GLE-2-2-1	Richmond	James Trail	Local	circular	cement	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Queens Fort	QUR-QFB-0-1	Exeter	Ladd Drive	Local	bridge	concrete	25-Year	Medium	High	Reduced AOP	3.29
	Queens Fort	QUR-QFB-0-10	Exeter	Pinoak Drive	Local	circular	concrete	10-Year	Medium	Medium	Dry (Reduced AOP)	3.57
	Queens Fort	QUR-QFB-0-9	Exeter	Tarbox Drive	Local	circular	concrete	< 10-Year	High	Medium	Reduced AOP	4.43
	Reuben Brown	QUR-QFB-2-2	Exeter	Stony Lane	Local	circular	concrete	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Usquepaug River	QUR-QUR-0-3	Richmond	Old Usquepaug Road	State	bridge	concrete	25-Year	High	Medium	Full AOP	3.29
	Usquepaug River	QUR-QUR-0-4	Richmond	Old Usquepaug Road	State	bridge	concrete	50-Year	High	High	Full AOP	3.14
	Queen River	QUR-QUR-0-6	Exeter	Mail Road	Local	bridge	concrete	< 10-Year	Low	High	Full AOP	3.29
	Queen River	QUR-QUR-0-7	Exeter	William Reynolds Road	Local	box culvert	concrete	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Queen River	QUR-QUR-0-9	Exeter	Stony Lane	Local	circular	concrete	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Unnamed	QUR-QUR-10-1	Exeter	William Reynolds Road	Local	circular	HDPE	< 10-Year	Medium	Medium	Dry (Reduced AOP)	4.00
	Unnamed	QUR-QUR-1-1	South Kingstown	Glen Rock Road	Local	circular	concrete	< 10-Year	Low	Medium	No AOP	3.57
	Unnamed	QUR-QUR-11-1	Exeter	Purgatory Road	Local	circular	concrete	< 10-Year	Medium	High	Dry (Reduced AOP)	4.29
	Unnamed	QUR-QUR-7-1	Exeter	Liberty Church Road	Local	circular	concrete	10-Year	Medium	Low	Dry (Reduced AOP)	3.29
Shunock River	Shunock River	SNR-SHU-0-11	North Stonington	Bicentennial Trail	Local	bridge	timber	10-Year	Medium	High	Full AOP	3.43
	Shunock River	SNR-SHU-0-13	North Stonington	Norwich-Westerly Road	State	bridge	stone	100-Year	High	High	No AOP	3.29
	Shunock River	SNR-SHU-0-9	North Stonington	Main Street	Local	bridge	stone	< 10-Year	High	High	Full AOP	4.43
	Unnamed	SNR-SHU-1-1	North Stonington	Norwich-Westerly Road	State	circular	concrete	10-Year	Medium	High	No AOP	4.00
	Unnamed	SNR-SHU-6-3	North Stonington	Mains Crossing	Local	circular	concrete	< 10-Year	Medium	High	No AOP	4.43
	Unnamed	SNR-SHU-7-1	North Stonington	Wyassup Road	Local	circular	CMP	< 10-Year	Medium	High	Dry (Reduced AOP)	4.29
	Unnamed	SNR-SHU-7-1-1	North Stonington	Wyassup Road	Local	circular	CMP	< 10-Year	Medium	High	Dry (Reduced AOP)	4.29
	Unnamed	SNR-SHU-7-1-2	North Stonington	Chester Main Road	Local	circular	CMP	< 10-Year	Medium	High	No AOP	4.43
	Unnamed	SNR-SHU-8-1	North Stonington	Ryder Road	Local	circular	concrete	10-Year	Low	High	Dry (Reduced AOP)	3.29
	Yawbucs Brook	SNR-YAW-0-1	North Stonington	Ryder Road	Local	circular	CMP	10-Year	Medium	High	No AOP	4.00
	Yawbucs Brook	SNR-YAW-0-2	North Stonington	Yawbux Valley Road	Local	circular	CMP	< 10-Year	Medium	High	Full AOP	3.86
	Unnamed	SNR-YAW-1-1	North Stonington	Yawbux Valley Road	Local	circular	CMP	< 10-Year	Low	High	No AOP	3.86
Upper Pawcatuck River	Unnamed	UPR-CED-1-1	Charlestown	Shumankanuac Hill Road	Local	circular	concrete	< 10-Year	Low	High	Dry (Full AOP)	3.43
	Unnamed	UPR-CED-7-1	Charlestown	Narragansett Trail	Local	circular	concrete	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Unnamed	UPR-CED-8-1	Charlestown	Saw Mill Road	Local	circular	concrete	< 10-Year	Low	High	Dry (Full AOP)	3.43
	Meadow Brook	UPR-FOUND-	Richmond	Unnamed	Trail	circular	CMP	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Meadow Brook	UPR-FOUND-	Richmond	Unnamed	Trail	circular	CMP	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Meadow Brook	UPR-FOUND-	Richmond	Unnamed	Trail	circular	concrete	10-Year	Low	Medium	No AOP	3.14
	Meadow Brook	UPR-FOUND-	Richmond	Unnamed	Trail	circular	concrete	< 10-Year	Low	Medium	No AOP	3.57
	Meadow Brook	UPR-MEA-0-2	Richmond	Church Street	State	box culvert	concrete	50-Year	High	High	No AOP	3.71
	Meadow Brook	UPR-MEA-0-3	Richmond	Pine Hill Road	Local	box culvert	concrete	10-Year	Medium	High	No AOP	4.00
Upper Wood River	Carson Brook	UWR-CAR-0-1	Voluntown	Bailey Pond Road	State	circular	CMP	< 10-Year	High	High	Full AOP	4.43
	Carson Brook	UWR-CAR-0-5	Sterling	Newport Road	Local	box culvert	stone	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Coney Brook	UWR-CON-0-2	West Greenwich	Tillinghast Pond Road	Local	box culvert	stone	< 10-Year	Medium	High	Dry (Reduced AOP)	4.29
	Unnamed	UWR-FAC-1-1	West Greenwich	Shetucket Turnpike	Local	circular	HDPE	< 10-Year	Medium	High	No AOP	4.43
	Flat River	UWR-FLA-0-1	Exeter	Midway Rail Road	Local	bridge	timber	10-Year	Medium	High	Full AOP	3.43

Table 4-4. High-priority stream crossings.

Subwatershed	Stream Name	Crossing ID	Town	Road Name	Road Type	Structure Type	Primary Structure Material	Hydraulic Capacity Rating	Flooding Impact Potential Rating	Geomorphic Vulnerability Rating	AOP Classification	Priority Rating Score (1-5)
Upper Wood River	Flat River	UWR-FLA-0-2	Exeter	Flat River Road	Local	bridge	timber	10-Year	Medium	High	Full AOP	3.43
	Wood River	UWR-WOR-0-13	West Greenwich	Falls River Road	Local	bridge	stone	< 10-Year	Medium	High	Full AOP	3.86
	Wood River	UWR-WOR-0-14	West Greenwich	Hazard Road	Local	circular	CMP	< 10-Year	Medium	High	Reduced AOP	4.14
	Wood River	UWR-WOR-0-18	Sterling	Pachaug Trail	State	bridge	timber	< 10-Year	Low	High	Full AOP	3.29
	Wood River	UWR-WOR-0-20	Sterling	Cedar Swamp Road	Local	box culvert	stone	< 10-Year	Low	High	No AOP	3.86
	Unnamed	UWR-WOR-13-1	Richmond	Nooseneck Hill Road	State	box culvert	concrete	100-Year	High	High	Dry (Reduced AOP)	3.14
	Unnamed	UWR-WOR-14-1	Richmond	K and G Ranch Road	Local	circular	concrete	10-Year	High	Low	Dry (Reduced AOP)	3.86
	Unnamed	UWR-WOR-14-4	Richmond	Buttonwood Road	Local	circular	concrete	< 10-Year	High	Medium	No AOP	4.71
	Unnamed	UWR-WOR-17-1	Hopkinton	Blitzkrieg Trail	Local	box culvert	stone	< 10-Year	Low	High	Full AOP	3.29
	Unnamed	UWR-WOR-18-4-1	Exeter	Old Voluntown Road	Local	circular	concrete	< 10-Year	Low	Medium	No AOP	3.57
	Unnamed	UWR-WOR-19-2	Exeter	Arcadia Management Area	State	circular	concrete	< 10-Year	Low	High	Full AOP	3.29
	Unnamed	UWR-WOR-19-3	Exeter	Ten Rod Road	State	circular	concrete	< 10-Year	Low	High	Dry (Reduced AOP)	3.71
	Unnamed	UWR-WOR-24-2	Sterling	Gallup Homestead Road	Local	circular	concrete	10-Year	Low	High	No AOP	3.43
	Unnamed	UWR-WOR-25-2	Sterling	Gallup Homestead Road	Local	circular	concrete	< 10-Year	Low	High	Dry (Full AOP)	3.43
Wyassup Brook	Hetchel Swamp	WPB-HET-0-2	North Stonington	Wyassup Road	Local	circular	CMP	< 10-Year	Low	High	No AOP	3.86
	Pendleton Hill Bk	WPB-PHB-0-1	North Stonington	State Highway 49	State	bridge	concrete	10-Year	High	High	Full AOP	4.00
	Pendleton Hill Bk	WPB-PHB-0-5	North Stonington	State Highway 49	State	box culvert	HDPE	< 10-Year	Medium	High	Dry (Full AOP)	4.00
	Unnamed	WPB-PHB-1-1	North Stonington	State Highway 49	State	circular	CMP	< 10-Year	High	High	Dry (Reduced AOP)	4.86
	Unnamed	WPB-PHB-3-2	North Stonington	Grindstone Hill Road	Local	circular	CMP	< 10-Year	Low	High	No AOP	3.86
	Wyassup Brook	WPB-WAY-0-2	North Stonington	State Highway 49	State	bridge	concrete	10-Year	Medium	High	Full AOP	3.43
	Wyassup Brook	WPB-WAY-0-4	North Stonington	Grindstone Hill Road	Local	circular	CMP	< 10-Year	Medium	High	Dry (Reduced AOP)	4.29
	Wyassup Brook	WPB-WAY-0-6	North Stonington	Wyassup Road	Local	circular	CMP	< 10-Year	Low	High	Dry (Reduced AOP)	3.71

Recommended Approach for Stream Crossing Replacement

- Start with high-priority crossings identified in this study (see **Table 4-4**).
- Consider other upstream and downstream crossings (including intermediate- and low-priority crossings) and dams on the same river system.
- Generally replace downstream crossings first to:
  1. Avoid inadvertently increasing downstream peak flows at outdated or undersized stream crossings by enlarging upstream crossings, and
  2. Open up stream segments to passage of fish and other aquatic organisms by starting downstream and progressing upstream.

  Upstream and downstream communities should coordinate their efforts on shared river systems.
- Intermediate- and low-priority crossings downstream of high priority crossings should be considered for replacement if they are hydraulically undersized
- Include priority crossings in Capital Improvement Plans.
- Implement upgrades as part of planned capital improvements such as road rehabilitation or reconstruction.
- Perform site-specific data collection, geotechnical evaluation, hydrologic and hydraulic evaluation, and structure type evaluation to support design and permitting (see below for typical requirements).

Site Assessment Needs for Stream Crossing Replacement

Geotechnical Evaluation

Perform subsurface investigation and soils analysis.

Site Reconnaissance and Wetland Delineation

Delineate wetlands, perform a riverbed substrate analysis to understand the existing riverbed substrate and provide data to calculate the design bed material; identify the type and integrity of stream grade controls; identify and flag bankfull width measurement locations and representative cross-sections to be surveyed upstream and downstream of culvert; determine appropriate reference reaches.

Topographic Survey

Perform topographic survey and include other relevant features such as wetlands and waterbodies, headwall/wingwall locations and elevations, centerline elevation of the road, and geotechnical boring locations, river longitudinal profiles, culvert invert elevations, top of culvert, representative cross-sections above and below the culvert, mean annual high water, property lines and roadway right-of-way.

Hydrologic and Hydraulic Study

Conduct a hydrologic analysis of the site, using appropriate methods. Identify typical low flows, the bankfull discharge, and peak flows required for the engineering and design process. The hydraulic analysis should assess existing water depths, velocities and water surface profiles and potential upstream and downstream impacts of stream crossing modifications.

Traffic Analysis

Analyze the traffic over the project culvert, including volume, peak volume, and type of vehicle traffic.

Structure Type Selection

Compare various crossing types (3-sided culverts, arches, embedded box culverts, and large diameter pipes) based on relative construction cost, ease of construction, and anticipated benefits. For recommended alternative, provide opinion of probable cost and structure characteristics.

3. *Adopt statewide stream crossing standards in Rhode Island for new and replacement stream crossings, modeled after existing stream crossings standards in Massachusetts, Connecticut, Vermont, and New Hampshire.*

   The State of Rhode Island should adopt formal stream crossing standards modeled after similar standards in neighboring states. Establishing state-level standards can help ensure that new and replacement stream crossings are designed to promote flood-resiliency and the natural functions of streams. States that have clear requirements and standards are better positioned to receive funding assistance toward upgraded stream crossings following major disasters. FEMA post-disaster Public Assistance funding may be used to *improve* rather than simply *replace* stream crossings that sustain significant damage if the state or municipality has adopted, implemented, and consistently applied a set of standards prior to the disaster (Levine, August 2013).

4. *Implement local standards for new and replacement stream crossings.*

   The watershed municipalities should also incorporate improved stream crossing standards into local land use regulations and design guidance for new permanent stream crossings (roads, driveways, paths, etc.) and replacement crossings. As discussed in Recommendation 3, adoption and implementation of local stream crossing standards can better position communities to receive post-disaster assistance from FEMA and a greater share of state funding from various programs.

5. *Update design storm precipitation amounts in state and local land use regulations and policies to promote more resilient road crossing design.*

   Both mean and extreme precipitation in the region has increased during the last century, with the highest number of extreme events occurring over the last decade. Continued increases in frequency and intensity of extreme precipitation events are projected. According to the National Climate Assessment, "the Northeast has experienced a greater increase in extreme precipitation over the past few decades than any other region in the United States; between 1958 and 2010, the Northeast saw a 74% percent increase in the amount of precipitation falling in very heavy events" (Melillo, Richmond, T.C., & Yohe, G.W., 2014). Rainfall in New England is expected to continue to increase due to climate change, which is expected to increase the risk of river-related flooding in the future. Bridges, roads and dams will be more susceptible to flood damage because of more severe storms and heavy rainfall.

   Updated extreme precipitation data is available from Cornell University's Northeast Regional Climate Center (NRCC). The NRCC design storm rainfall amounts offer significant advantages over previous products (e.g., "Rainfall Frequency Atlas of the United States", Technical Paper No. 40, U.S. Department of Commerce, Weather Bureau and NOAA Technical Memorandum "NWS Hydro-35", June 1977, U.S. Department of Commerce, National Weather Service) since the design storm rainfall amounts are based on a much longer period of record, including more recent data. The most recent rainfall frequency statistics for the region were published by NOAA in October 2015 in Atlas 14, Volume 10. This publication replaces the 1961 National Weather Bureau TP-40 report and supersedes the 2013 NRCC data products.

   While NOAA Atlas 14 provides more reliable precipitation data for design purposes, it assumes climatic stationarity and therefore does not account for future climate change. Communities should account for potential climate change (i.e., more frequent and intense precipitation) in drainage and flood mitigation design policies and standards. Although reliable projections of precipitation extremes as a result of climate change are not yet readily available in the published climate change literature, guidance is available for estimating potential future changes in extreme rainfall statistics using EPA's

Climate Resilience Evaluation and Awareness Tool (CREAT), SWMM-CAT (Storm Water Management Model Climate Adjustment Tool), and other similar tools.

At a minimum, stormwater and drainage-related infrastructure should be designed with storm intensities based on NOAA Atlas 14 (or NRCC atlas) to represent current precipitation conditions. For more resilient water infrastructure design, including improved stream crossings, consider some percentage increase, such as 15% which is consistent with estimates of future changes in extreme rainfall using the CREAT tool described above, to account for potential future increases in extreme precipitation events. Ongoing review of extreme precipitation projections is recommended.

6. *Establish adequate, sustained sources of funding.*

With widespread aging and vulnerable infrastructure in many places in the Wood-Pawcatuck watershed, a sustained source of funding will be required to offset the higher initial cost of upgrading stream crossings, which can reduce future damages and save money in the long term. Funding for stream crossing upgrades is extremely limited, with local highway departments maintaining the majority of roads in the watershed and carrying most of the financial burden for stream crossing improvements. In addition to FEMA post-disaster funding programs, other potential funding streams for culvert replacement include:

- Cost-share programs in which government agencies provide a portion of the funding through grant programs (e.g., the Eastern Brook Trout Joint Venture and grant programs of the National Fish and Wildlife Foundation) and the local town responsible for the crossing covers the remaining amount,
- Third-party compensatory mitigation such as the U.S. Army Corps of Engineers in-lieu fee program in Connecticut, and
- Incentive programs that encourage towns to adopt local stream crossing standards such as Vermont's incentive program where towns that adopt a minimum set of codes and standards receive an additional 10% of state funding from two state road grants programs.

7. *Provide training to highway departments.*

Once state and local stream crossing standards have been implemented, training should be provided for local highway departments, engineers, and contractors involved in stream crossing replacement. Stream crossing training programs have been developed in other states in the region including:

- Vermont's Rivers and Roads Training
  http://floodready.vermont.gov/improve_infrastructure/roads_culverts#training

- UMass Amherst RiverSmart Communities
  https://extension.umass.edu/riversmart/resources-municipalities

- U.S. Forest Service Workshops on Designing for Aquatic Organism Passage at Road-Stream Crossings
  https://www.fs.fed.us/biology/education/workshops/aop/

- Maine's Stream Smart Road Crossing Workshops
  http://maineaudubon.org/streamsmart/training-resources/

8. Implement ongoing inspection and maintenance programs.

The watershed municipalities should implement regular inspection and maintenance programs for local road stream crossings. Vulnerable stream crossings should be inspected for debris removal and to check the structural integrity of the structure such as the headwalls and pipe. Public works staff should also inspect and remove existing debris from vulnerable road stream crossings prior to an anticipated flood event.

9. Update and integrate local comprehensive land use plans and hazard mitigation plans.

The watershed communities should update and integrate their comprehensive land use plans and hazard mitigation plans. Local planning and zoning staff are often not involved in the preparation of hazard mitigation plans, and emergency management personnel are often not involved in the comprehensive land use planning process. If the two planning processes are not coordinated, they could result in plans that are inconsistent and potentially conflicting. Coordinating these two planning processes can ensure that stakeholders involved in resilience planning, such as emergency managers, also help develop the comprehensive plan and that planners help develop the hazard mitigation plan. The Town of Charlestown is a good example of a community in the Wood-Pawcatuck watershed that has used an integrated approach to update its comprehensive plan and hazard mitigation plan.

Future updates to comprehensive land use plans and hazard mitigation plans of the watershed communities should include or incorporate by reference recommendations of the Wood-Pawcatuck Watershed Flood Resiliency Management Plan.

4.3 Floodplains and River Corridors

Conserve and restore floodplains and river corridors in a natural condition to mitigate flood and erosion hazards, attenuate sediment loads, and create and enhance habitat.

Restore impacted stream channels to an equilibrium condition by addressing the underlying causes of channel instability.

The Issue

A geomorphic[1] assessment of the Wood-Pawcatuck watershed was conducted in 2015 as part of this flood resiliency planning effort. The objective of the assessment was to identify flood hazards, areas of stream channel instability, and the underlying causes for channel adjustments threatening human infrastructure and aquatic habitat in the watershed.

The assessment found that flood and erosion hazards in the Wood-Pawcatuck watershed have been exacerbated by human modification of the stream channels, combined with historical development along river corridors and flood-prone areas (see text box on the following page).

> Fluvial Geomorphic Assessment of the Wood-Pawcatuck Watershed
>
> A 2015 geomorphic assessment of the Wood-Pawcatuck watershed is documented in *Fluvial Geomorphic Assessment and River Corridor Planning in the Wood-Pawcatuck Watershed, RI and CT* (Field, 2015) (see **Appendix H**). Based on the results of the geomorphic assessment, river corridor planning guidance for the Wood-Pawcatuck watershed was developed to identify restoration projects that could reduce flood hazards and downstream sediment loading and improve aquatic habitat (Field, 2016).

> *Dams, stream crossings, and artificial channel straightening have exacerbated flooding, erosion, and channel migration along the Pawcatuck River and its tributaries.*

Most of the reaches assessed in the Wood-Pawcatuck watershed are in unconfined valleys, have banks composed of fine sediment, and are, thus, sensitive to change. If meanders reform along straightened reaches, either naturally or as part of a restoration project, flow energy and sediment can be attenuated and a main driving force of bank erosion and channel migration minimized. The creation of meanders along straightened reaches has the potential to reduce channel sensitivity, habitat degradation, and flood hazards in downstream areas.

[1] The science of fluvial geomorphology is devoted to understanding how the natural setting and human land use in a watershed affect river and stream channel processes and form (i.e., channel dimensions and shape).

Geomorphic Issues in the Wood-Pawcatuck Watershed

Dams

Numerous dams on the Pawcatuck River and its tributaries reduce flow velocities and stream power in riverine reaches upstream of impoundments, leading to sediment deposition, stream channel migration, and changes in stream channel planform (i.e., stream geometry as seen from above). Downstream, sediment deposition is limited, channel evolution slowed, and channel incision or downcutting is sometimes significant due to the loss of sediment throughput past the dams.

Stream Crossings

Undersized stream crossings have similar effects as dams but are more localized. The impacts, however, can cause damage to the structures themselves as the rivers and streams in the watershed adjust to the sudden narrowing of the channel and/or blockage of the floodplain at the crossings. The deposition of sediment upstream of undersized crossings can lead to flow deflection into the banks leading to bank erosion, channel migration, and the formation of bifurcated or multi-threaded channels

Channel Straightening and Bank Armoring

Historic artificial channel straightening and bank armoring has occurred along most of the watershed's watercourses and greatly reduced flow complexity and the quality of aquatic habitat throughout the watershed. In areas more sensitive to change (i.e., upstream of dams and undersized crossings), meanders are reforming as the straightened channels widen, sediment is deposited, and flow is deflected into the banks or onto the adjacent floodplain. A straightened configuration persists to this day in areas less sensitive to change such as downstream of dams.

River Corridor Development

Development within the river corridor increases the risk of inundation flooding and erosion hazards. Many of the encroachments in the river corridor are buildings and other structures that were once part of old mill complexes or other former industries.

Floodplain and Stream Restoration

Floodplains are the low, flat, periodically flooded lands adjacent to rivers, lakes and other waterbodies and are subject to geomorphic and hydrologic processes (RIEMA, 2014). Floodplains of rivers and streams absorb runoff and buffer upland areas from flood damage. Floodplains in portions of the Wood-Pawcatuck watershed were historically developed for agricultural and industrial uses and later for commercial and residential uses. Development of the floodplain has increased risk of flood inundation and erosion hazards, and reduced the natural ability of floodplains to store water, which can increase flooding in downstream areas.

Riverine floodplain and stream restoration can reduce flood risk and improve water quality and habitat for fish and wildlife, recreational opportunities, and erosion control. Restoration of impacted, flood-prone river systems can be accomplished by restoring floodplains and associated wetlands through connectivity and storage, and by modifying the physical stability, hydrology, and biological functions of the floodplain and river corridor to a more natural condition.

Floodplain and stream restoration involves re-establishing the structure and function of ecosystems and floodplains as closely as possible to natural conditions and functions. Such projects typically mitigate erosion and flood risk and are eligible for FEMA Hazard Mitigation Assistance and other funding.

A variety of reach-scale floodplain and stream restoration techniques can be used to mitigate flood and erosion hazards, reduce sediment and nutrient loads, and improve aquatic habitat. Restoration options that are potentially suitable for use in the Wood-Pawcatuck watershed are:

Streambank Stabilization – Short-term bank stabilization may be required where human infrastructure is imminently threatened, a reduced rate of lateral erosion on a reach is necessary to give riparian buffer plantings ample time to mature, or a valuable resource might be permanently lost such as fertile floodplain soils. Bank stabilization efforts should avoid permanently armoring the banks, especially on

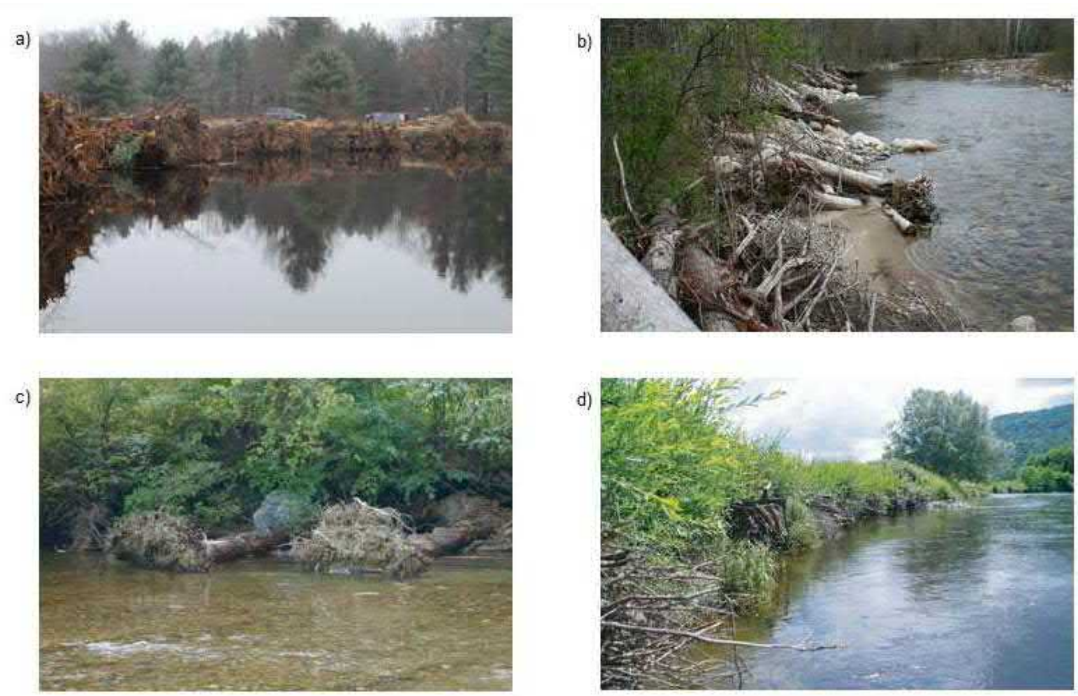


Figure 4-5. Examples of bioengineering techniques for bank stabilization. Use of a) marginal log jams (Souhegan River in Merrimack, NH), b) boulder and log deflectors (Sunday River in Newry, ME), c) root wad revetments (Batten Kill in Arlington, VT), and d) willow stakes above root wad revetment (Connecticut River in Colebrook, NH) (Field, 2016).

incised reaches, because the necessary adjustments to achieve equilibrium will be hindered. Ideally, bank stabilization should consist of bioengineering methods that reduce the flow energy impinging on the banks through flow deflection (Figure 4-5). Bioengineering treatments, such as willow staking, are less successful if not accompanied with the toe treatments required to reduce erosive forces along the bank. Flow deflection techniques, such as log jam or boulder deflectors could be used to prevent new mass failures from forming adjacent to stabilized areas.

Riparian Buffer Restoration – Riparian buffers are naturally vegetated areas adjacent to streams, ponds, and wetlands. Healthy riparian buffers help encourage infiltration and provide absorption for high stream flows, which helps reduce flooding and drought, in addition to providing water quality and ecological benefits. The time required for the full habitat and morphological benefits of riparian buffers to be realized is several decades from the initial planting, since significant time is required for the trees to mature. Consequently, other restoration actions are often needed. Furthermore, in areas where rapid erosion is occurring, other bank stabilization techniques would be required to provide sufficient time for the planted buffer to grow to maturity. Despite these shortcomings, planting buffers along riverbanks and their adjacent floodplains should be considered a high priority in the Wood-Pawcatuck watershed given the potential long-term advantages and the minimal effort, finances, and expertise required to do so.

Floodplain Restoration/Reconnection – Straightened reaches, a common feature in the Wood-Pawcatuck watershed, tend to be slightly incised. Reconnecting the channel to its floodplain is the best way to restore incised reaches. This type of restoration consists of creating a floodplain "bench" or terrace adjacent to the stream channel, which creates additional volume to temporarily store floodwater and attenuate peak flows and sediment (Figure 4-6). Bioengineering techniques are used to stabilize the streambanks, thereby improving habitat value and providing some natural filtration and vegetative uptake of runoff that drains across these areas. Another approach to restoring incised reaches involves the addition of wood to the channel such that sediment accumulation will raise the channel bed, allowing smaller floods to once again access the floodplain. The placement of engineered log jams in the river can also form new meanders by encouraging flows to "break out" of the channel and carve a new meander on the floodplain, as occurs naturally on straightened reaches elsewhere in New England. These techniques may also include acquiring at-risk structures for removal.

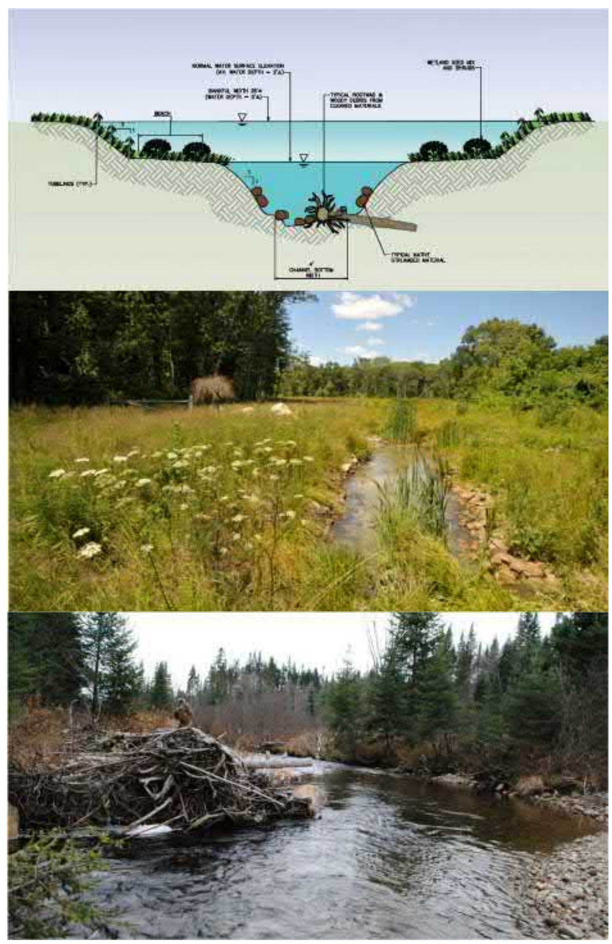


Figure 4-6. Example floodplain restoration cross-section, West Warwick, RI (top), completed Pocasset River floodplain restoration project, Cranston, RI (middle), and engineered log jam (bottom).

Removing Floodplain Constraints – Floodplain constraints along portions of some assessed reaches are preventing the attenuation of flow and sediment across the floodplain. Likewise, raised road and railroad grades crossing the floodplain create artificial valley constrictions even when stream crossings are adequately sized with respect to channel width. Floodplain constraints include berms and railroad and highway grades paralleling the river that are built higher than the surrounding floodplain and cut off access to a portion of the floodplain. Complete removal of a highway or railroad grade is impractical, but allowing flow to pass through floodplain relief culverts installed under an elevated highway or railroad grade might be sufficient to allow flows to spread across the entire floodplain, access side or “relief” channels, and reduce flow velocities in the main channel.

Removing/Replacing Stream Crossing Structures – As described previously, replacing undersized culverts and bridges with larger spans and removing certain dams in the watershed could significantly enhance flood resiliency and hydraulic conditions for aquatic organism passage.

Restoration Costs - The cost associated with floodplain restoration techniques varies and is highly site-specific. Basic bank stabilization costs using wood are approximately $200 per linear foot. Floodplain and river restoration together – such as boulder weirs, wood additions, floodplain lowering, and berm removal – generally costs $400 per linear foot. More comprehensive floodplain restoration involving channel realignment, significant fill removal to re-establish the floodplain, and wood additions to the channel typically costs $1,000 per linear foot. The total project cost for a recently completed floodplain restoration project (1,000 linear feet) along Sheffield Brook in Old Lyme, Connecticut was approximately $310,000 including design, permitting and construction ($310 per linear foot). Similarly, the estimated cost of an ongoing floodplain restoration project along approximately 1,800 linear feet of the Maidford River in Middletown is approximately $875,000 or $486 per linear foot. Total project costs for two floodplain restoration projects completed in 2011, one in Cranston (Pocasset River/Blackamore Pond) and another in West Warwick (Janet Drive), were approximately $625,000 each.

River Corridor Protection

In the Wood-Pawcatuck watershed, roads, buildings, and other infrastructure are somewhat limited within the river corridor (i.e., that portion of the floodplain which the river must be free to migrate in order to achieve and sustain an equilibrium condition over time). Development within the river corridor can be damaged during floods and can also alter the natural evolution of the river channel and thereby exacerbate potentially hazardous fluvial processes.

One of the most effective ways for communities to become more resilient to flooding is by conserving land and discouraging development in flood-prone areas. Vulnerable land in floodplains and river corridors can be protected through land use planning and regulations that prevent or discourage development within floodplains and river corridors, by purchasing land or acquiring conservation easements from willing sellers, coordinating buyouts of properties that are repeatedly flooded, and implementing a Transfer of Development Rights program.

Protection of the river corridor through land conservation and effective land use planning is a high priority for the Wood-Pawcatuck watershed. Protecting river corridors along straightened reaches should be considered a high priority, so flow and sediment attenuation can occur in an unconstrained manner. The river corridors to be protected for conservation planning purposes should encompass, as much as possible, the river corridor protection areas established by the geomorphic assessment (Field, 2016).

Recommended Actions

Table 4-5 contains recommendations relative to floodplains and river corridors in the Wood-Pawcatuck watershed.

Table 4-5. Floodplain and river corridor recommendations.

	Action	Lead Entity	Timeframe	Estimated Cost	Possible Funding Sources
1.	Seek funding for and implement stream and floodplain restoration recommendations.	WPWA, Watershed Municipalities	2-10 years	$$$ to $$$$$	BWRF, FEMA flood hazard mitigation assistance funding, cost-share grants, third-party compensatory mitigation
2.	Purchase land or acquire conservation easements.	WPWA, land trusts, property owners	Ongoing	$$$ to $$$$$	Land conservation funding programs – RI & CT NRCS Floodplain Easement
3.	Consider implementing a Transfer of Development Right (TDR) ordinance specifically to discourage development in floodplains.	Watershed Municipalities	2-5 years	$$	Municipal funds
4.	Consider implementing fluvial erosion hazard zoning.	Watershed Municipalities	2-5 years	$$	Municipal funds
5.	Conduct fluvial geomorphic assessments of the remaining stream segments in the watershed.	WPWA, consultant	2-5 years	$$$$	
6.	Review and amend existing conservation development or cluster development ordinances and subdivision regulations.	Watershed Municipalities	2-5 years	$$	Municipal funds
7.	Consider modifications to zoning and subdivision ordinances and regulations to go beyond the minimum NFIP standards.	Watershed Municipalities	2-5 years	$$	Municipal funds

$ = $0 to $5,000 $$ = $5,000 to $10,000 $$$ = $10,000 to $50,000 $$$$ = $50,000 to $100,000
$$$$$ = Greater than $100,000

1. *Seek funding for and implement stream and floodplain restoration recommendations.*

   The river corridor management plan that was prepared for the Wood-Pawcatuck watershed (see Appendix I) identified over 40 potential restoration projects that could reduce flood hazards and downstream sediment loading and improve aquatic habitat (Field, 2016). The Wood-Pawcatuck Watershed Association should continue to work with the watershed municipalities, state and federal agencies, and other partner organizations to seek funding for and implement high-priority stream and floodplain restoration projects that are identified in the river corridor management plan. Successful restoration at a subset of these sites will provide examples of how to proceed with similar sites elsewhere in the watershed.

   Table 4-6 lists high-priority restoration recommendations, organized by restoration technique, including corridor protection, bank stabilization, restoration of straightened/incised channels and floodplain reconnection, removal or retrofitting of encroachments, and riparian restoration. Recommendations relative to culverts, bridges, and dams are not included in the table since these are addressed in other sections of this plan. A complete list of restoration recommendations for all of the assessed stream reaches in the watershed is provided in Table 3 of the report entitled *River Corridor Plan for the Wood-Pawcatuck Watershed, RI and CT* (Field, 2016) (see Appendix I).

   River corridor restoration concepts were also developed for approximately ten priority restoration sites. Figure 4-7 is an example restoration concept for the Pawcatuck River downstream of Bradford Dam in Hopkinton/Westerly, Rhode Island. The concept sheets include a brief description of the site issues and recommended restoration concepts, an annotated aerial photograph or base map, and photographs of similar restoration techniques that have been applied successfully elsewhere. Restoration concept sheets are provided in Appendix J.

   In addition to the proposed restoration projects, certain activities should be discouraged, so channel instabilities along the river are not exacerbated. These discouraged activities include:

   - Gravel mining in the floodplain
   - Development that fills or blocks access to large portions of the floodplain
   - Removal of wood and sediment from stream channels, other than debris removal from stream crossing structures or minor, selective debris removal to maintain recreational water access for canoes and kayaks.

2. *Purchase land or acquire conservation easements.*

   Communities should continue to partner with willing landowners and land trusts or other organizations such as the Wood-Pawcatuck Watershed Association to purchase land outright or acquire conservation easements. Conservation easements allow local governments (or designated land trusts) to acquire easements on land of environmental value as a means to protect property containing natural resources. This is often accomplished by purchasing development rights from a landowner, which will then attach a deed restriction prohibiting any further development that would alter the environment.

Table 4-6. High-priority stream and floodplain restoration sites by project type.

River & Reach ID	Reach Description (upstream to downstream)	Town	Description	Photograph
Corridor Protection				
Ashaway River (GAS-1)	Downstream of Laurel Street in downtown Ashaway to junction with Pawcatuck River	Hopkinton, RI	Entire reach should be protected given dynamic nature and high quality habitat, future developments could encroach into reach if not protected See restoration concept sheet in Appendix J.	
Ashaway River (GAS-4)	Just downstream of the confluence with Parmenter Brook to upstream influence of Bethel Pond	Hopkinton, RI	Dynamic channel, recent avulsion, good habitat so protection from encroachment is warranted	
Green Fall River (GAS-8)	Upstream of Puttker Road to confluence with Shingle Mill Pond Brook	North Stonington, CT	Valuable archaeological sites, good habitat potential, little modern encroachment	

Table 4-6. High-priority stream and floodplain restoration sites by project type.

River & Reach ID	Reach Description (upstream to downstream)	Town	Description	Photograph
Bank Stabilization				
Ashaway River (GAS-1)	Downstream of Laurel Street in downtown Ashaway to junction with Pawcatuck River	Hopkinton, RI	Logjams at the toe of mass failure hint at possible stabilization approaches, house frontage being eroded	
Ashaway River (GAS-1)	Downstream of Laurel Street in downtown Ashaway to junction with Pawcatuck River	Hopkinton, RI	House frontage being eroded	
Restoration of Straightened/Incised Channels and Floodplain Reconnection				
Ashaway River (GAS-4)	Just downstream of the confluence with Parmenter Brook to upstream influence of Bethel Pond	Hopkinton, RI	Reoccupy old meandering channel downstream of I-95 by plugging straightened channel with log jams and diverting flow See restoration concept sheet in Appendix J.	

Table 4-6. High-priority stream and floodplain restoration sites by project type.

River & Reach ID	Reach Description (upstream to downstream)	Town	Description	Photograph
Lower Wood River (WOR-01)	Alton Dam to confluence with Pawcatuck River (along former Charbert Facility site)	Hopkinton/Richmond, RI	Artificially straightened channel. Meander development could be enhanced with addition of log jam structures on margins of channel that would deflect flow into opposite bank. Floodplain restoration would need to be coordinated with site remediation of former industrial facility. See restoration concept sheet in Appendix J.	
Upper Wood River (WOR-16 and 15)	Arcadia Management Area south of Ten Rod Road	Exeter, RI	Artificially straightened channel flowing through forested land. Proposed design consists of marginal wood cover structures and wood additions to encourage meander formation and sediment storage. See restoration concept sheet in Appendix J.	
Green Fall River (GAS-8)	Upstream of Puttker Road to confluence with Shingle Mill Pond Brook	North Stonington, CT	Install marginal log jams to encourage meander formation downstream of Puttker Road	

Table 4-6. High-priority stream and floodplain restoration sites by project type.

River & Reach ID	Reach Description (upstream to downstream)	Town	Description	Photograph
Beaver River (BER-6-7)	Upstream of Hillsdale Road to downstream of Punchbowl Trail	Richmond, RI	Wood additions to create habitat complexity in straightened portions and increase flow in side channels	
Middle Pawcatuck River (PAR-12)	Downstream of Bradford Dam	Hopkinton/Westerly, RI	Pawcatuck River channelized and confined by a berm along the left bank. Propose berm breaching and/or removal to allow floodplain access. See restoration concept sheet in Appendix J.	
Upper Pawcatuck River (PAR-21b)	Village of Carolina along Route 112	Richmond/Charlestown, RI	River occupies steep straight mill race channel built of granite blocks which confine the channel and cut off side channel access. Upstream, the impoundment is maintained by a partially breached dam. Propose breaching granite bank / berm (removing floodplain obstruction) and potentially using some blocks in the construction of instream structures. See restoration concept sheet in Appendix J.	

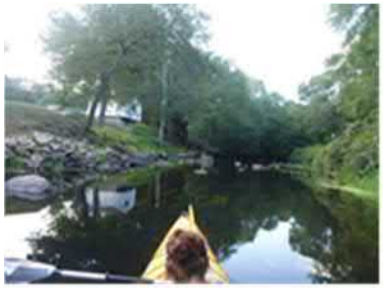
Table 4-6. High-priority stream and floodplain restoration sites by project type.

River & Reach ID	Reach Description (upstream to downstream)	Town	Description	Photograph
Pawcatuck River (PAR-18)	USGS gauge weir to confluence with Meadow Brook	Charlestown, RI	Build marginal log jams to encourage meander formation	
Meadow Brook (MEB-8b)	Downstream of undersized culvert at Route 138	Richmond, RI	Scour and channel incision has occurred downstream of the undersized culvert at Rt 138. Replace culvert with appropriately-sized bottomless arch culvert that spans full channel width and add roughness elements in channel to encourage aggradation and reverse incision. See restoration concept sheet in Appendix J.	
Removal or Retrofitting of Encroachments				
Pawcatuck River (PAR-07 and 06)	Downstream of Potter Hill Dam in Ashaway	Hopkinton/Westerly, RI	Wide shallow channel with degraded habitat and impaired geomorphic function, could benefit from instream structures designed to narrow the channel, sort and store sediment, and provide cover for aquatic organisms. See restoration concept sheet in Appendix J.	

Table 4-6. High-priority stream and floodplain restoration sites by project type.

River & Reach ID	Reach Description (upstream to downstream)	Town	Description	Photograph
Pawcatuck River (PAR-5)	Downstream of Boom Bridge to top of former White Rock Dam impoundment	Westerly, RI	Right bank berm from past gravel mining activities prevents floodplain access at the upstream end of the reach	
Riparian Vegetation Planting				
Upper Wood River (WOR-9)	Wyoming Dam to beginning of Old Stone Dam impoundment	Hopkinton, RI	Replanting of vegetation on right bank, best completed with simultaneous bank stabilization project See restoration concept sheet in Appendix J.	
Chipuxet River (CHIP-10)	Slocum Reservoir Dam to downstream of Railroad Road	North Kingstown, RI	Encourage riparian plantings along the left bank of the river where residential properties abut the channel	

Table 4-6. High-priority stream and floodplain restoration sites by project type.

River & Reach ID	Reach Description (upstream to downstream)	Town	Description	Photograph
Pawcatuck River (PAR-23)	Shannock Mill historic site to upstream extent of Carolina Pond	Charlestown, RI	Encourage planting of riparian vegetation at residential river frontages	
Meadow Brook (MEB-8b)	Upstream of Richmond Elementary School to downstream of Meadow Brook Golf Course	Richmond, RI	Riparian plantings should be completed in conjunction with reduction in water withdrawals from ponds in order to restore flow to channel by the golf course during low flow periods	
Pawcatuck River (PAR-03)	At former location of White Rock Dam to Route 78 Bridge	Westerly, RI	Riparian plantings on right bank by gravel pit, some erosion occurring where vegetation absent	

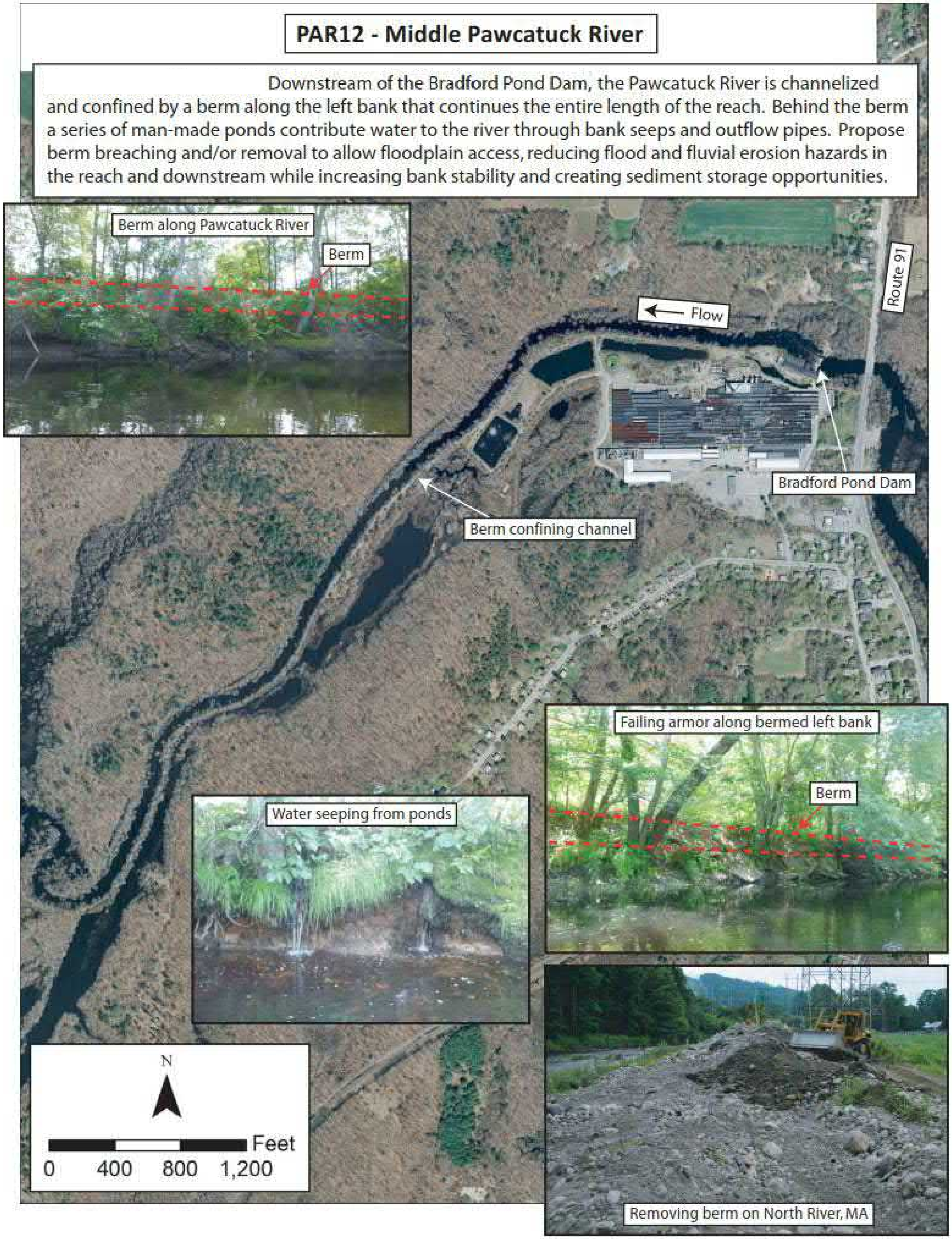


Figure 4-7. Example floodplain restoration concept for the Pawcatuck River downstream of Bradford Dam in Hopkinton/Westerly, Rhode Island.

3. Consider implementing a Transfer of Development Right (TDR) ordinance specifically to discourage development in floodplains.

Communities should consider implementing a Transfer of Development Right (TDR) ordinance modeled after similar programs in Exeter, North Kingstown, and other communities in the region. A TDR ordinance allows the transfer of development rights of one parcel to another, thereby shifting density from areas designated for protection (such as floodplain and other sensitive natural areas) to areas more suitable for development. The program is designed to limit potential development in vulnerable areas, while compensating property owners for the reduction. The municipality can identify vulnerable "sending" areas, where development intensity should be lowered, and upland "receiving" areas where higher density can be incorporated. A market can be established where landowners in the sending area can be compensated for the transfer of some of their development rights to a property owner in the receiving area. Localities may also choose to compensate these landowners through tax credits. A TDR program can protect ecologically valuable land like floodplains and wetlands that have flood mitigation benefits. It can also help shift development upland, where it will be less susceptible to flooding and sea level rise.

TDR programs are used in areas where there is significant development pressure and no alternate mechanism to exceed density levels. If rezoning or variance is easier to obtain, a TDR program will likely not be used by a developer.

Exeter and North Kingstown are the only communities in the Wood-Pawcatuck watershed that currently have a TDR ordinance and program. The Exeter and North Kingstown TDR programs, a shared program which was originally intended to protect open space and farmland from development, is designed to preserve sensitive resources including groundwater reserves, wildlife habitat, agricultural lands and public access to surface water as well as to direct development to places better suited for increased development. The program could be used to include conservation of floodplains and riparian wetlands. TDR programs also exist in Narragansett, RI and Windsor, CT.

4. Consider implementing fluvial erosion hazard zoning.

The watershed communities should consider implementing fluvial erosion hazard zoning. The Pawcatuck River and its tributaries are prone to flooding-induced erosion that can threaten human infrastructure given the legacy of human alteration in the watershed, which creates channel instabilities. While overbank flooding and the inundation of homes, agricultural fields, and other infrastructure causes significant damage in the watershed, the most dangerous and costly hazards are often caused by bank erosion.

Federal guidelines for flood hazard mapping and model floodplain ordinances do not address riverine erosion hazards. Federal legislation authorizing riverine erosion mapping and integration of erosion hazards into the National Flood Insurance Program (NFIP) has been enacted, but not implemented.

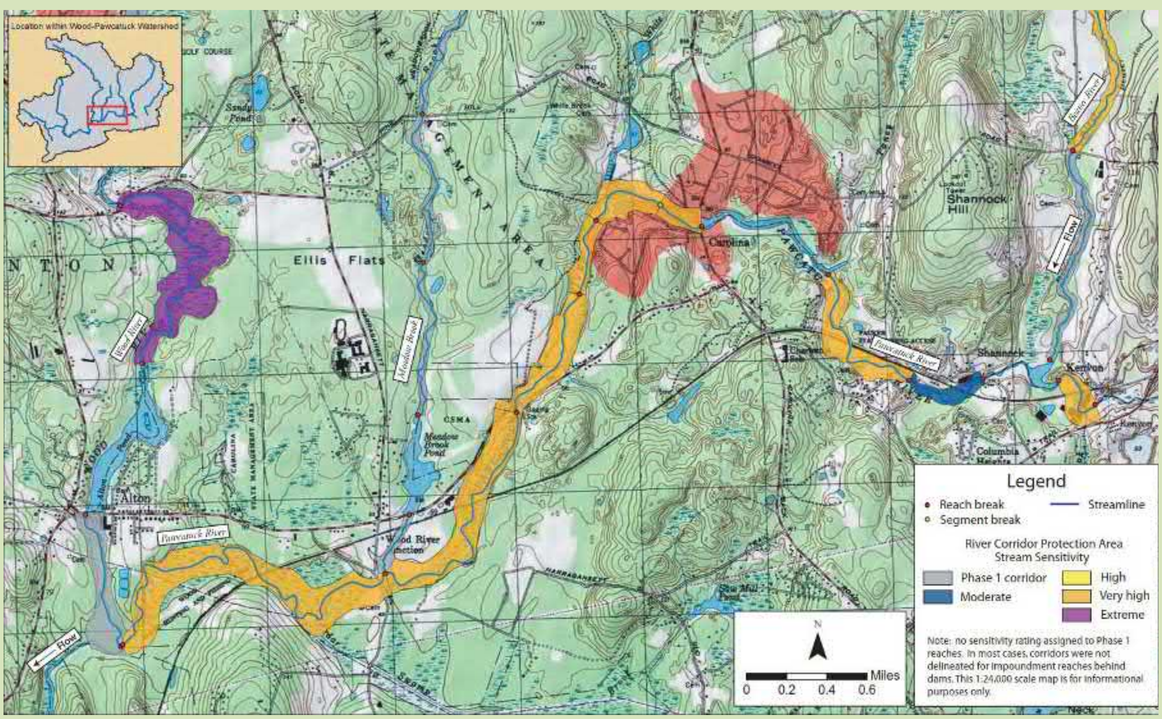
To further protect vulnerable land and avoid exacerbating downstream flooding, communities in the watershed should explore fluvial erosion hazard zoning for land along rivers and streams. Such zoning, which is based on river corridors and flood hazard areas, can limit or prohibit development in fluvial erosion hazard areas. This technique is being implemented by communities in Vermont and New Hampshire, although it requires fluvial erosion hazard mapping. If the statutory basis for such zoning does not exist, an alternative to establishing formal overlay zoning would be to incorporate fluvial erosion hazards and river corridor protection concepts into local hazard mitigation plans and comprehensive plans.

Fluvial erosion hazard mapping has been developed as part of this watershed planning effort for the Wood-Pawcatuck. River Corridor Protection (RCP) areas – corridors of a defined width within which the river is considered to have the potential to migrate through time and re-establish equilibrium channel dimensions – have been mapped based on geomorphic assessments of the watershed (see text box below). RCP areas are similar to the "Active River Area" concept (The Nature Conservancy, 2008), although developed using more detailed methods.

River Corridor Mapping for the Wood-Pawcatuck Watershed

Human developments that lie within River Corridor Protection (RCP) areas are potentially susceptible to erosion hazards over time, especially in areas of high sensitivity. Wider corridors are defined along reaches considered more sensitive to channel migration including lower gradient reaches where sediment tends to accumulate, reaches with sandy soils, or those that were artificially straightened.

RCP areas are not the same as the 100-year flood zone on FEMA flood insurance rate maps, but the areas often overlap. The FIRMs show areas that are likely to be inundated by floodwaters that overtop the riverbanks during a flood with a 1 percent probability of occurring in any given year. In contrast, the RCP area maps identify areas, sometimes outside the 100-year flood zone, where the channel can potentially migrate over time through bank erosion or channel avulsions. Discrepancies between RCP area maps and FIRMs are possible especially along incised channels where a large flood may not spread across the floodplain, but may have sufficient force to cause bank erosion, channel widening, and meander formation. RCP maps for the Wood-Pawcatuck watershed are provided in the River Corridor Plan in **Appendix I** (Field, 2016).



5. *Conduct fluvial geomorphic assessments of the remaining stream segments in the watershed.*

   Detailed field-based geomorphic assessments were conducted on approximately one-third of the stream miles and river reaches in the Wood-Pawcatuck watershed. Detailed (Phase 2) geomorphic assessments are recommended for the unassessed portions of the watershed, particularly developed portions of the Queen-Usquepaug River, Beaver River, Meadow Brook, Green Fall River, and Shunock River. The additional assessments would allow identification of additional river corridor protection and restoration opportunities in the watershed, but also development of detailed Phase 2 River Corridor Protection maps for most of the watershed.

6. *Review and amend existing conservation development or cluster development ordinances and subdivision regulations.*

   Many of the watershed communities already have existing conservation development or cluster development ordinances and regulations that encourage or require new development to protect tracts of intact open space (including sensitive natural areas like rivers, floodplains, and stream corridors) while clustering development into a smaller section of the parcel.

   Watershed communities with conservation/cluster development ordinances should consider the following changes or additions to their regulatory requirements:

   - Require the floodplain to be conserved, and require that new lots have adequate buildable areas above the natural 100-year flood elevation.
   - Consider density bonus provisions, such as a maximum 10% increase in exchange for creation of contiguous (not fragmented) greenspace, the addition of trails, or an increase in riparian buffer widths.
   - Permit density bonuses when coupled with restrictive covenants and easements. Require conservation and drainage easements in floodplain communities where lots may not be developed.
   - Conservation development ordinances are generally preferred over older, "cluster zoning" ordinances. Older cluster style projects successfully created open spaces but often resulted in less useful open spaces uncoordinated with the surrounding properties and fragmentation of natural habitat and recreation areas.

   Watershed communities that do not have conservation (or cluster) development ordinances should consider adopting one to protect floodplains and other intact open space.

7. *Consider modifications to zoning and subdivision ordinances/regulations to go beyond the minimum NFIP standards.*

   Most of the watershed communities regulate land use in floodplains based on National Flood Insurance Program (NFIP) recommended minimum standards, which allow new structures, fill, and other uses in the floodplain, as long as the development meets minimum protective standards (i.e., residential structures are elevated 1 foot above base flood elevation). The experiences of communities across the country demonstrate that simply adopting the minimum standards does not guarantee avoidance of flood damage and losses. Standards and ordinances that exceed NFIP minimum requirements will make communities more resilient to future flooding (ASFPM, March 2013).

   Higher regulatory standards also require increased documentation and enforcement at the local level. Therefore, the watershed communities should assess their administrative and enforcement capacity when considering higher floodplain standards. Overall, higher standards can potentially reduce administrative burden by preventing flood damage and post-flood permitting associated with repairs.

The watershed municipalities should consider the following modifications to their zoning and subdivision ordinances/regulations to go beyond the minimum NFIP standards and make their communities more resilient to future flooding. Additional details and suggested regulatory language are provided in the *Land Use Policy and Regulatory Review* (Fuss & O'Neill, 2016d) in Appendix K.

- Incorporate the Association of State Floodplain Managers (ASFPM) "No Adverse Impact Floodplain Management" policy into local floodplain management programs and municipal plans. No Adverse Impact (NAI) Floodplain Management is based on the principle that the actions of one property owner are not allowed to adversely affect the rights of other property owners in terms of increased flood peaks, increased flood stages, higher flood velocities, increased erosion and sedimentation, or other impacts.

- Increase participation by the watershed communities in the National Flood Insurance Program Community Rating System. The National Flood Insurance Program Community Rating System (CRS) is a voluntary program that recognizes and encourages a community's efforts that exceed the NFIP minimum requirements for floodplain management. The CRS program emphasizes the reduction of flood losses, facilitating accurate insurance rating, and promoting the awareness of flood insurance. By participating in the CRS program, communities can earn a discount for flood insurance premiums based upon the activities that reduce the risk of flooding within the community. Currently, only four (4) communities in the Wood-Pawcatuck watershed – Charlestown, North Kingstown, Westerly, and Stonington – participate in the CRS program, receiving discounts for flood insurance premiums of between 5% and 15% (RIEMA, 2016).

- Consider amendments to local zoning ordinances/regulations to adopt more stringent flood management standards. The watershed communities should consider adopting the following more stringent standards into local zoning ordinances, as recommended by the Association of State Floodplain Managers (ASFPM). Several of these requirements can increase a community's score under the CRS and increase the likelihood of reduced flood insurance premiums.
    - Continue to adopt and enforce future revisions of the International Building Code (IBC) and the International Residential Code (IRC).
    - Adopt more stringent freeboard requirements.
    - Amend nonconforming use provisions.
    - Require elevation of all building additions.
    - Adopt more stringent substantial improvement standard.

4.4 Wetlands

Conserve and restore watershed wetlands to benefit flooding, water quality, and wildlife habitat.

The Issue

Wetlands comprise approximately 34,000 acres or almost 18% of the Wood-Pawcatuck watershed. The watershed is home to a variety of wetland types from forested swamps to marshes, bogs and fens. The watershed is dominated by forested wetlands – approximately 71% of the wetlands in the Rhode Island portion of the watershed (Miller & Golet, 2000). Several large and notable wetlands are found within the watershed, including Chapman Swamp in Westerly, Great Swamp in South Kingstown, and Indian Cedar Swamp in Charlestown (Pawcatuck Watershed Partnership, 1999).

Combined with upland floodplains adjacent to rivers, streams, and man-made impoundments, wetlands play an important role in flood de-synchronization and flood storage, in addition to many other ecological functions. The role that wetlands play in flood control, flood attenuation, and flood resiliency is complex and can be affected by many conditions, including antecedent water storage prior to flood events, groundwater hydrology, and the location of the wetlands within the watershed.

Wetlands function as natural sponges that trap and slowly release surface water, rain, snowmelt, groundwater and flood waters. Wetland vegetation also spreads out and slows the speed of flood waters over the floodplain.

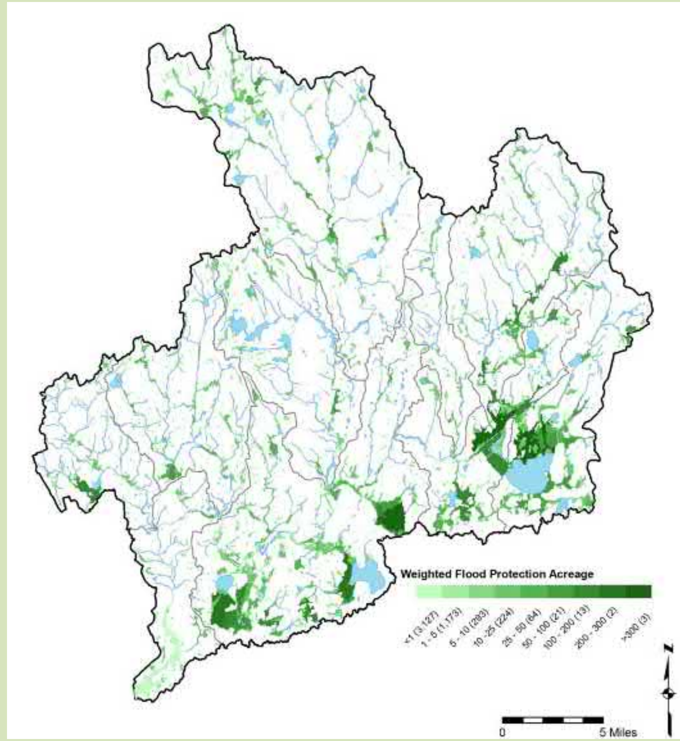
Historical development of river corridors, floodplains, and upland areas adjacent to water bodies in the watershed has contributed to wetland loss and degradation. Historical damming of the rivers and streams in the watershed has created numerous man-made impoundments and associated open water and bordering wetlands. Future development pressure in the watershed has the potential to further reduce the effectiveness of natural and man-made wetland systems for mitigating flooding in the Wood-Pawcatuck.

A watershed-scale assessment was performed of the wetlands in the Wood-Pawcatuck watershed (Fuss & O'Neill, 2016a). The assessment involved desktop and field evaluation methods to identify potential wetland conservation and restoration opportunities to enhance flood resiliency as well as habitat and water quality (see text box on the following page). Key findings of the assessment include:

- Of the assessed wetlands, those associated with impoundments provide the greatest combined flood protection, habitat, and water quality functions. The majority of these impoundments are headwater impoundments, which tend to have smaller drainage areas relative to the size of the impoundment and associated wetlands. Wetlands associated with run-of-river impoundments with larger drainage areas rated lower in terms of flood protection function.

Watershed-Scale Wetlands Assessment of the Wood-Pawcatuck Watershed

A technical assessment was conducted to evaluate potential wetland conservation and restoration opportunities in the Wood Pawcatuck watershed to enhance flood resiliency, habitat, and water quality. The assessment is documented in a separate technical memorandum entitled *Watershed-Scale Wetlands Assessment, Wood-Pawcatuck Watershed Flood Resiliency Management Plan* (Fuss & O'Neill, 2016a) (see **Appendix L**).



- From a conservation perspective, most "undisturbed" wetlands in the watershed with significant flood protection function are generally less than 5 acres in size.

- Numerous smaller riverine wetlands are located throughout the watershed, many located within developed and undeveloped floodplain areas, providing conservation and restoration opportunities for enhancing flood storage, habitat, and water quality.

- Nine of the impoundments and associated wetlands that were evaluated were also included in the dams, bridges, and culverts assessment (Fuss & O'Neill, 2016b). Impoundments associated with Hazard Pond Dam, Dolly Pond Dam, and Kasella Farm Pond Dam provide significant flood protection, water quality, and ecological functions. As discussed in Section 4.1 (Dams and Impoundments), a more detailed feasibility study is recommended to evaluate potential removal of each dam, including:
    - Hydraulic modeling to evaluate post-removal flooding impacts.
    - Determination of post-removal water surface elevations and the resulting net loss of wetland area.
    - Determination of expected changes in wetland vegetation.
    - Qualitative loss assessment of all wetland functions, including habitat.

- Four wetlands were identified as having moderate restoration potential including Wetland 12 (a former commercial cranberry bog) and Wetland 13 (former quarrying activity) in the Lower Pawcatuck River subwatershed, and Wetlands 16 and 21, both of which are in close proximity to active farmland in the northern part of the watershed (Queen-Usquepaug and Chipuxet River subwatersheds).

Wetland Preservation and Restoration

Wetland preservation and restoration are important elements of a comprehensive flood protection strategy. As described in the previous section, one of the most effective ways for communities to become more resilient to flooding is by conserving land and discouraging development in flood-prone areas, including wetlands. Wetlands in the Wood-Pawcatuck are currently protected by regulations at the federal, state, and local levels. The U.S. Army Corps of Engineers regulates discharge of dredged or fill material into the "waters of the United States" (a term which includes wetlands and all other aquatic areas) under Section 404 of the Clean Water Act through state-specific general permits. In Connecticut, the Inland Wetlands and Watercourses Act is implemented by municipalities, with guidance from the Connecticut Department of Energy and Environmental Protection (CTDEEP). In Rhode Island, wetlands are regulated both by the Rhode Island Department of Environmental Management (RIDEM) and the Coastal Resources Management Council (CRMC). In addition, many Rhode Island communities enforce wetland buffers or setbacks through zoning regulations. RIDEM is in the process of revising the Rhode Island Freshwater Wetlands Act, which will result in more consistent statewide standards for wetland resources, buffers, and jurisdictional areas, as well as greater consistency between RIDEM and CRMC wetland programs.

Wetland restoration typically involves restoring “natural” or historical wetland hydrology. Restoration may involve filling or blocking existing ditches or restoring streamflow, diverted flow, or floodplain connectivity. Removing historic fill from wetlands is also a common restoration technique. Creating floodplain wetlands as part of floodplain restoration is another common wetland restoration technique. Enhancement is a type of restoration, but typically does not include modification of existing hydrology. Buffer plantings and limited invasive plant control are typical enhancement techniques. Minor changes in existing drainage may be involved, including culvert outlet improvement/replacement, and removal of flow obstructions. Removal of invasive plants is a common restoration technique, as many wetlands support monoculture growths of invasive species, particularly *Phragmites australis* and purple loosestrife.

Recommended Actions

Table 4-7 contains recommendations relative to wetland conservation and restoration in the Wood-Pawcatuck watershed.

Table 4-7. Wetland conservation and restoration recommendations.

Action	Lead Entity	Timeframe	Estimated Cost	Possible Funding Sources
1. Prioritize the flood protection function of wetlands in local and state land use regulations and policies to preserve existing wetlands that provide significant flood protection benefits.	Watershed municipalities, land trusts, RIDEM, CTDEEP	Ongoing	$$	Municipal funds
2. Strategically incorporate wetland restoration/creation into river corridor restoration projects.	WPWA, Watershed Municipalities	Ongoing	$$$ to $$$$	BWRF, FEMA flood hazard mitigation assistance funding, cost-share grants, third-party compensatory mitigation

$ = $0 to $5,000 $$ = $5,000 to $10,000 $$$ = $10,000 to $50,000 $$$$ = $50,000 to $100,000
$$$$$ = Greater than $100,000

1. *Prioritize the flood protection function of wetlands in local and state land use regulations and policies to preserve existing wetlands that provide significant flood protection benefits.*

   Given the extensive, high-quality wetlands that exist in the Wood-Pawcatuck watershed, the most effective approach for enhancing wetland-related flood resiliency is through conservation and protection of existing wetlands. The headwater impoundments and associated wetlands that provide significant flood protection benefits (in addition to habitat and water quality functions), as identified in the watershed-scale wetlands assessment, should be highlighted or prioritized for preservation. These priorities should be reflected in local planning documents (comprehensive plans), land use decision-making, and open space preservation priorities.

2. *Strategically incorporate wetland restoration/creation into river corridor restoration projects.*

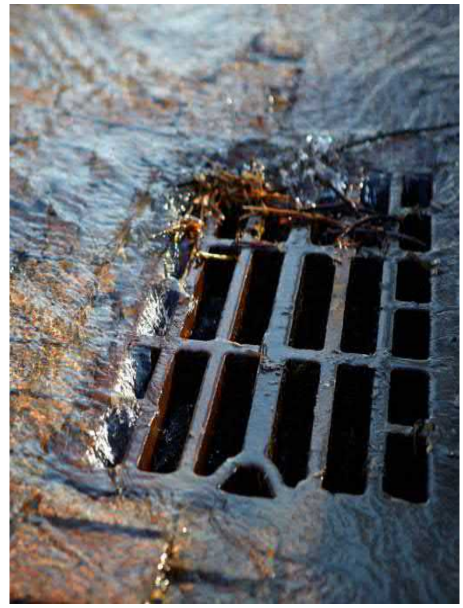
   Large-scale wetland restoration can be very expensive and technically challenging and therefore is not recommended in the Wood-Pawcatuck watershed, which is characterized by significant wetland complexes with relatively minimal alteration. Instead, a more strategic approach to wetland restoration is recommended. Wetland restoration and enhancement should be incorporated into other river corridor restoration efforts that are described elsewhere in this plan, including:

   - Floodplain restoration – wetlands could be integrated into floodplain restoration projects by including riparian wetlands within created floodplain benches or by reconnecting existing wetlands that have become hydraulically disconnected as a result of past berming or channel incision.

   - Riparian buffer restoration – creation or expansion of riverine/riparian wetlands could be incorporated into riparian buffer restoration projects to provide additional flood storage.

   - Dam removal – dam removals typically result in changes in the type or specific location of wetland resources. While providing many benefits, dam removal may result in the loss of upstream bordering vegetated wetlands due to changes in hydrology. Often, when bordering vegetated wetlands are lost at one elevation around the impoundment, bordering vegetated wetlands may be established at a lower elevation associated with the restored river corridor (Massachusetts Department of Environmental Protection, December 2007). Dam removal provides an opportunity to establish riparian/riverine wetlands within the footprint of the former impoundment through careful design.

4.5 Stormwater



Reduce runoff volumes, flooding, and water quality impacts through improved stormwater management and the use of green stormwater infrastructure throughout the watershed.

The Issue

Stormwater runoff from buildings, pavement, and other compacted or impervious surfaces contributes to drainage-related and riverine flooding in the Wood-Pawcatuck watershed. Stormwater runoff is also a source of nonpoint source pollution and a cause of water quality impairments, particularly in the lower portion of the watershed where impervious cover exceeds 20%. There are a number of drainage-related flooding problems in developed areas of the watershed due to outdated or inadequate drainage systems, and stormwater runoff volumes exacerbate riverine flooding during both small and large storms.

Rainfall in New England is expected to continue to increase due to climate change, which is expected to increase the risk of river-related flooding in the Wood-Pawcatuck watershed. Rising sea levels could also lead to new development in the watershed as populations retreat inland from a receding shoreline. Development pressure in the watershed will continue to result in the conversion of natural areas to impervious surfaces, putting additional stress on existing drainage systems and contributing further to riverine flooding and water quality issues if such development and associated stormwater impacts are not managed appropriately.

Green Infrastructure

A green infrastructure approach reduces stormwater volumes and runoff rates, reduces the risk of downstream flooding, and provides incremental flood benefits as each component is installed.

Green infrastructure, also referred to as "green stormwater infrastructure" and "low impact development or LID," is an alternative approach to traditional stormwater management. The green infrastructure approach encourages the infiltration of stormwater into the ground close to where precipitation falls, similar to what occurs in undeveloped areas. By using natural materials including vegetation and soils, these practices restore natural stormwater recharge and filtration processes while reducing downstream flooding. Additionally, green infrastructure can be constructed in stages, as funding and resources are available. Unlike traditional drainage systems that need to be constructed in whole to provide any benefit, green infrastructure solutions can provide incremental benefits as they are implemented.

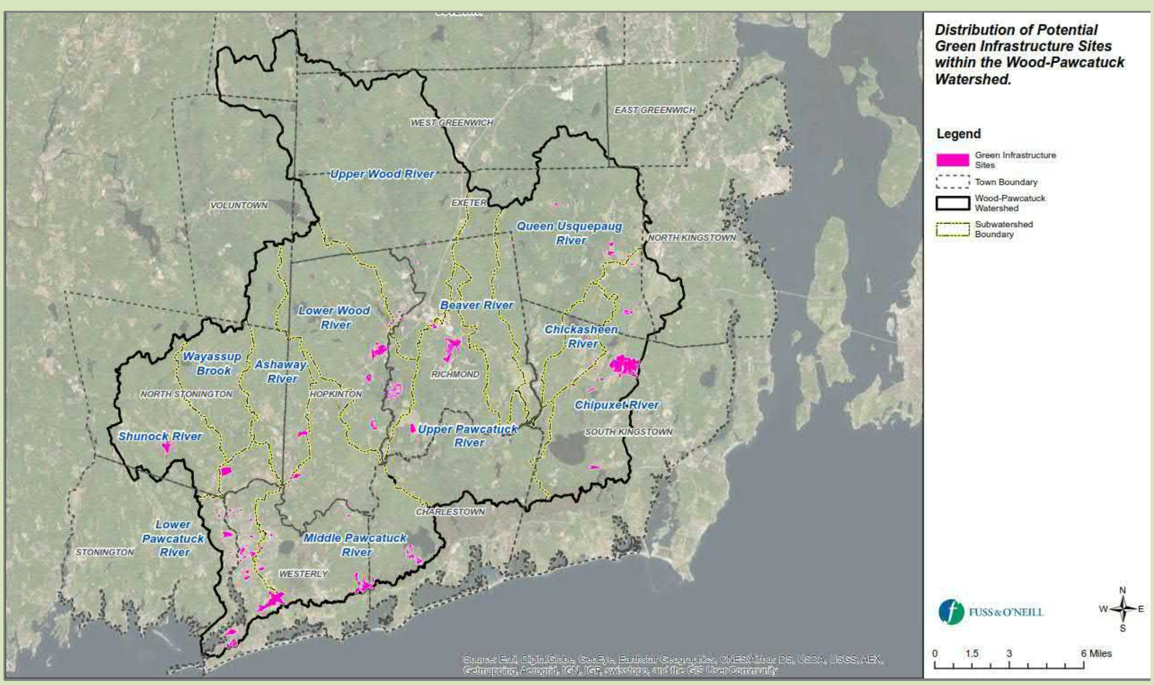
Green infrastructure includes a variety of stormwater management practices, such as bioretention, engineered wetland systems, permeable pavement, green roofs, green streets, infiltration planters, tree boxes, and rainwater harvesting. These practices capture, manage, and/or reuse rainfall close to where it falls, thereby reducing stormwater runoff and keeping it out of drainage systems and receiving waters.

In addition to reducing polluted runoff and improving water quality, green infrastructure can improve flow conditions in streams and rivers by infiltrating water into the ground, thereby reducing peak flows during wet weather and sustaining or increasing stream base flow during dry periods, which can be important for aquatic habitat, fisheries, and groundwater supplies. When applied throughout a watershed, green infrastructure can help mitigate flood risk and increase flood resiliency. At a smaller scale, green infrastructure can also reduce erosive velocities and streambank erosion.

Green infrastructure and LID are the preferred approach for stormwater management in Rhode Island and Connecticut, and all of the larger watershed communities have adopted requirements for green infrastructure or LID in their local land use regulations and policies. The Town of Westerly is developing a TMDL implementation plan, which includes the use of green infrastructure practices to address water quality impairments in the lower Pawcatuck River and Little Narragansett Bay. Other Rhode Island communities, such as the Town of West Warwick, are using green stormwater infrastructure to alleviate drainage related flooding and improve downstream water quality (see text box on page 45).

Green Infrastructure Assessment of the Wood-Pawcatuck Watershed

A green infrastructure assessment was performed for the Wood-Pawcatuck watershed to identify green infrastructure retrofit opportunities that increase flood resiliency and improve or protect water quality. The assessment consisted of 1) a screening-level evaluation to identify areas of the watershed with the greatest feasibility for and potential benefits from green infrastructure retrofits, 2) field inventories of the most promising green infrastructure retrofit opportunities in the watershed, and 3) development of concept designs for selected retrofit sites. The assessment identified approximately 30-site-specific retrofit concepts in the watershed and is documented in a separate technical memorandum entitled *Green Infrastructure Assessment, Wood-Pawcatuck Watershed Flood Resiliency Management Plan* (Fuss & O'Neill, 2016c) (see **Appendix M**).



Recommended Actions

Table 4-8 contains stormwater and green infrastructure recommendations for the Wood-Pawcatuck watershed.

Table 4-8. Stormwater and green infrastructure recommendations.

	Action	Lead Entity	Timeframe	Estimated Cost	Possible Funding Sources
1.	Incorporate green infrastructure into municipal stormwater infrastructure planning and capital projects. Implement identified retrofit projects.	Watershed municipalities	5-10 years	$$$$$	319 NPS Grant, Narragansett Bay and Watersheds Restoration Fund, CDBG, Stormwater Utility, General Fund
2.	Implement recommendations of TMDL Implementation Plan to address the TMDL for the Pawcatuck River and Little Narragansett Bay Waters.	Town of Westerly	5-10 years	$$$$$	319 NPS Grant, Narragansett Bay and Watersheds Restoration Fund, CDBG, Stormwater Utility, General Fund
3.	Update existing municipal land use regulations and policy to require the use of GI and LID for new development and redevelopment projects and to meet MS4 Permit requirements.	Watershed municipalities	2-5 years	$$	Municipal funds
4.	Update design storm precipitation amounts in state and local land use regulations and policies to promote more resilient stormwater drainage design.	Watershed municipalities, RIDEM, CTDEEP	2-5 years	$$	Municipal funds
5.	Update state and local stormwater drainage and BMP design standards and guidance to account for climate change impacts in coastal areas, including the estuarine portion of the Wood-Pawcatuck watershed.	Town of Stonington, Town of Westerly	2-5 years	$$	Municipal funds
6.	Pursue sustainable, long-term funding sources for large-scale GI implementation.	Watershed municipalities, regional organizations	5-10 years	$$$$	Stormwater utility districts, enterprise funds, or similar fee-based system

$ = $0 to $5,000 $$ = $5,000 to $10,000 $$$ = $10,000 to $50,000 $$$$ = $50,000 to $100,000
$$$$$ = greater than $100,000

1. *Incorporate green infrastructure into municipal stormwater infrastructure planning and capital projects.*

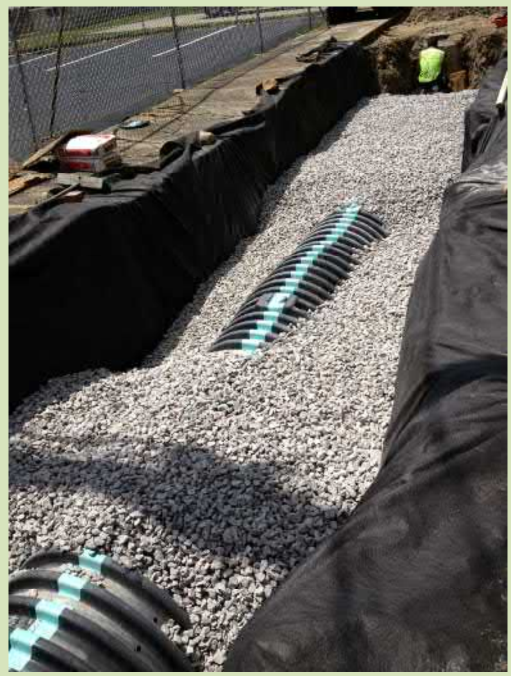
The watershed municipalities should incorporate green infrastructure approaches into municipal stormwater infrastructure planning and capital improvement plans to address drainage, flooding, and water quality priorities including MS4 Permit requirements. Green infrastructure can be implemented on public sites including existing municipal parking lots using techniques such as bioretention, permeable pavement, and subsurface infiltration, as well as within the public right-of-way through the use of roadside bioswales, subsurface infiltration below roads and sidewalks, infiltrating catch basins, permeable pavement, and tree boxes.

The green infrastructure retrofit concepts presented in *Green Infrastructure Assessment, Wood-Pawcatuck Watershed Flood Resiliency Management Plan* (Fuss & O'Neill, 2016c) (see Appendix M) provide potential on-the-ground projects for future implementation. They also serve as examples of the types of projects that could be implemented at similar locations throughout the watershed.

Table 4-9 lists proposed green infrastructure retrofit concepts that have been developed for the Wood-Pawcatuck watershed. Figure 4-8 is an example green infrastructure retrofit concept sheet for the Rhode Island State Police Barracks in Richmond. The concept sheets include a site description, the proposed retrofit concept, field images with renderings of retrofit opportunities (where available), typical details of recommended BMPs, estimates of pollutant removal and runoff reduction, and planning-level cost estimates (see Appendix M).

Green Infrastructure to Address Flooding in the Town of West Warwick

The Town of West Warwick installed subsurface stormwater infiltration chambers to manage flooding issues on Gendron Street, shown below. The Town is also implementing bioretention basins, roadside bioswales, and subsurface sidewalk storage systems to alleviate flooding in the Shippee Avenue neighborhood.



The RIDEM Narragansett Bay and Watershed Restoration Fund (BWRF), which include Nonpoint Source & Stormwater Pollution Control Grants and Flood Prevention and Mitigation Grants, as well as the RIDEM Nonpoint Source (NPS) Pollution Abatement Implementation Grants (Clean Water Act - Section 319) are a potential source of grant funding for green infrastructure projects in the Rhode Island portion of the watershed. The Wood-Pawcatuck has been identified as a priority watershed for the Clean Water Act - Section 319 grant program for 2017. Refer to Section 6 (Funding Sources) of this watershed pan for additional information on these and other funding sources.

Table 4-9. Proposed green infrastructure retrofit concepts.

Site No.	Site Name	Location	Green Infrastructure BMP Type
21	Vin Gormley Trailhead Parking	Sanctuary Road, Charlestown, RI	Underground Infiltration, Bioretention
41	URI Tennis Courts	Kingstown Road, South Kingstown, RI	Rain Gardens
50	Wyoming Dam Fishing Access	Nooseneck Hill Road, Wyoming, RI	Pervious Pavers, Articulated Concrete Mat, Bioretention
73	Exeter Town Animal Shelter	South County Trail, Exeter, RI	Bioretention
93	US Post Office in Westerly	Tom Harvey Road, Westerly, RI	Bioretention
102	United Methodist Church	Spruce Street, Westerly, RI	Bioretention
108	Bradford School	Church Street, Westerly, RI	Green Roof, Underground Infiltration
114	US Post Office in Ashaway/Hopkinton	Main Street, Ashaway, RI	Underground Infiltration
125	Trinity Lutheran Church	High Street, Hopkinton, RI	Rain Gardens, Bioretention
129	St. Mary's Catholic Church	Carolina Back Road, Charlestown, RI	Bioretention
139	Courthouse Center for the Arts	Kingstown Road, South Kingstown, RI	Bioretention
157	Richmond Police Department	Main Street, Richmond, RI	Underground Infiltration
159	RI State Police Barracks	Nooseneck Hill Road, Richmond, RI	Bioretention
173	Exeter Town Hall	Ten Rod Road, Exeter, RI	Bioretention, Rain Gardens
185,194	Wheeler High/Middle School	North Westerly Road, North Stonington, CT	Bioretention
185A	Wheeler Library	Main Street, North Stonington, CT	Bioretention
191	West Vine Street School	West Vine Street, Stonington, CT	Rain Gardens
194	North Stonington Elementary and Administration Buildings	North Westerly Road, North Stonington, CT	Bioretention
206	Browning Mill Pond Parking Access	Arcadia Road, Exeter, RI	Forested Buffer, Bioretention
227	Hopkinton Recreation Department	Nooseneck Hill Road, Hopkinton, RI	Bioretention
229	Tuckertown Park	Tuckertown Road, South Kingstown, RI	Bioswales
252	Chariho Little League	Nooseneck Hill Road, Hope Valley, RI	Rain Gardens
272A	Westerly Senior Center	State/Westminster Street, Westerly, RI	Bioretention
272	State Street School	State Street, Westerly, RI	Rain Gardens, Bioretention
274	Westerly High School	Park Avenue, Westerly, RI	Underground Infiltration
275	Westerly Town Hall	Broad Street, Westerly, RI	Bioretention
276	Tower Street School and Community Center	Tower Street, Westerly, RI	Bioretention
280	Ashaway Elementary School	Hillside Avenue, Ashaway, RI	Underground Infiltration, Bioretention
283	West Kingston Elementary	Ministerial Road, South Kingstown, RI	Underground Infiltration, Bioretention
284	URI Lot at Boss Arena	Keaney Road, Kingston, RI	Underground Infiltration
286	Richmond Elementary School	Kingstown Road, Richmond, RI	Bioretention

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Retrofit Site 159 – Rhode Island State Police Barracks Bioretention

Nooseneck Hill Road, Richmond, Rhode Island

Site Description

The proposed retrofit concept is located at the Rhode Island State Police Barracks on Nooseneck Hill Road in Richmond, RI. Currently there is no structural drainage infrastructure along the road. Sheetflow runoff from the road discharges to a tributary of Wyoming Pond to the northeast. This retrofit opportunity would serve an approximately 1.4-acre drainage that includes portions of Nooseneck Hill Road and some residential properties on the south side of the road.

Proposed Concept

Install a bioretention/infiltration practice southwest of the driveway and barracks. The site has enough available space to treat over 5 times the 1" WQv. The design should include an overflow and discharge outlet to convey higher flows to nearby Wyoming Pond. Construction of new drainage infrastructure could expand the area served by the proposed bioretention/infiltration system to create a larger, regional stormwater practice.

Retrofit Concept Summary
Total Drainage Area: 1.4 acres
Total Impervious Area: 0.8 acres
Total Water Quality Volume: 2,890.1 ft^3
Runoff Reduction Volume: 1,714.0 ft^3

Estimated Pollutant Removal
Bioretention Area
Total Phosphorus ≈ **1.3 lbs/year**
Total Nitrogen ≈ **14.8 lbs/year**
Total Suspended Solids ≈ **877.9 lbs/year**
Bacteria (FC) ≈ **248.8 billion colonies/year**

Estimated Cost
Bioretention Area: $38,872

Images 1 & 2: Before and after views of a bioretention area. First image shows installation and planting. Second image shows a functioning practice and overflow structure.

Figure 3: proposed location of bioretention area along Nooseneck Hill Road in Richmond, RI, at the State Police Barracks.

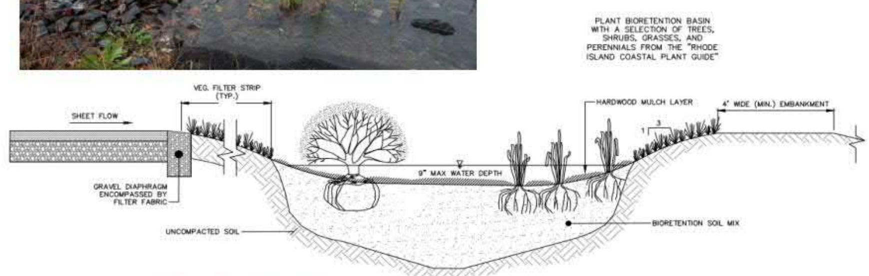

Figure 4: Typical detail of a bioretention area.

Green Infrastructure Assessment – Wood-Pawcatuck Watershed Flood Resiliency Management Plan

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Figure 4-8. Example green infrastructure retrofit concept for Rhode Island State Police Barracks, Richmond, Rhode Island.

2. *Implement recommendations of TMDL Implementation Plan to address the TMDL for the Pawcatuck River and Little Narragansett Bay Waters.*

Once completed, the Town of Westerly should pursue funding to implement the green infrastructure recommendations in its TMDL implementation plan to address water quality impairments in the lower Pawcatuck River and Little Narragansett Bay. Future phases of the TMDL implementation plan are anticipated to include the contributing area from the confluence with the Mastuxet Brook downstream to Route 1 and the expanded MS4 regulated areas of Avondale and Watch Hill. While the focus of these measures are on improving water quality in the lower Pawcatuck River and Little Narragansett Bay, implementation of infiltration-based green stormwater infrastructure practices can also address storm infrastructure capacity issues and drainage-related flooding in the lower, urbanized portions of the watershed.

3. *Update existing municipal land use policy and regulations to require the use of GI and LID for new development and redevelopment projects and to meet MS4 Permit requirements.*

Flood resiliency can be enhanced through well-informed land use policy and municipal land use regulations by preserving undeveloped land, siting development in locations less vulnerable to flooding, and promoting designs that reduce runoff and are less likely to be damaged in a flood. Municipal land use policies and regulations also play an important role in protecting water quality and natural resources.

> Land Use Policy and Regulatory Review for the Wood-Pawcatuck Watershed
>
> A review was conducted of the existing land use policies, plans, and regulations of the municipalities in the Wood-Pawcatuck watershed relative to flood and stormwater management. The review identified new or modified land use policies and/or regulations that could be implemented by the watershed municipalities to enhance flood resiliency in the Wood-Pawcatuck watershed. The review is documented in a separate technical memorandum entitled *Land Use Regulatory Review, Wood-Pawcatuck Watershed Flood Resiliency Management Plan* (Fuss & O'Neill, 2016d) (see Appendix K).

Most of the watershed communities have adopted requirements for green infrastructure or LID in their local land use regulations and policies, and most reference the LID standards and design guidance contained in the respective statewide stormwater manuals - *Rhode Island Stormwater Design and Installation Standards Manual* and the *Connecticut Stormwater Quality Manual* (including LID Addendum). However, not all of the watershed communities have land use regulations that specifically require the use of LID or green infrastructure, as the first option, for all new development and redevelopment projects. For example, South Kingstown's zoning regulations include provisions for the use of LID only in one specific zoning district, rather than Town-wide. The watershed communities should amend local land use regulations to require that new development and redevelopment projects comply with LID standards consistent with the respective statewide stormwater guidance manuals.

In 2013, each of the municipalities in the Rhode Island portion of the watershed completed an *Ordinance Checklist for LID Stormwater Site Planning and Design*, which was developed by RIDEM as a statewide planning tool. The ordinance checklist was designed to allow communities to determine what specific LID site planning and design techniques they have adopted or may need to adopt to more effectively encourage LID practices for new development and redevelopment. The checklist findings indicated that many of the watershed communities still have provisions in their zoning ordinances and subdivision regulations that promote the creation of excessive impervious cover and limit the use of certain LID techniques. Since streets and parking lots typically account for a significant percentage of the impervious surfaces in a watershed, the watershed municipalities should amend the design standards for streets and parking lots in their zoning ordinances and subdivision regulations to minimize the creation of impervious cover and more effectively promote the use of LID.

The Rhode Island watershed communities should review and update their municipal NPDES Phase II Stormwater Management Programs (SWMPs) in anticipation of potential future reissuance of the MS4 Permit in Rhode Island or enhanced enforcement of the existing MS4 Permit. Stonington, the only MS4 regulated community in the Connecticut portion of the watershed, should implement its revised SWMP to comply with the new Connecticut MS4 General Permit, including review and update of its land use regulations to incorporate LID and green infrastructure provisions of the new MS4 Permit.

4. *Update design storm precipitation amounts in state and local land use regulations and policies to promote more resilient stormwater drainage design.*

   As discussed in the Culverts and Bridges recommendations, stormwater and drainage-related infrastructure should be designed with storm intensities based on NOAA Atlas 14 (or NRCC atlas) to represent current precipitation conditions. For more resilient water infrastructure design, consider some percentage increase, such as 15% which is consistent with estimates of future changes in extreme rainfall using EPA's Climate Resilience Evaluation and Awareness Tool (CREAT), to account for potential future increases in extreme precipitation events. Ongoing review of extreme precipitation projections is recommended. State and local stormwater policies and regulations should be modified accordingly.

5. *Update state and local stormwater drainage and BMP design standards and guidance to account for climate change impacts in coastal areas, including the estuarine portion of the Wood-Pawcatuck watershed.*

   Sea level has risen more than 9 inches since 1930 at Newport, RI, faster than the global average. A recent assessment by the National Oceanic and Atmospheric Administration projects a possible worst-case sea level rise scenario for Rhode Island of 9-10 feet by 2100, which is significantly higher than previous projections of sea level rise in the region, which have generally ranged from 1 to 4 feet by 2100 (Runkle, et al., 2017). Increases in sea level will likely increase coastal flooding and erosion during winter storms (nor'easters) and hurricanes, threatening coastal infrastructure and populations.

   Coastal stormwater BMPs are potentially vulnerable to sea level rise resulting in submerged outfalls or inundation of other components of the BMP, rising groundwater and shrinking separation distance between the BMP and the groundwater table, physical impacts of storm surges, and chronic exposure to wind, sand, and salt.

   The following recommendations are provided for siting and design of stormwater BMPs and green infrastructure in the tidal portion of the Wood-Pawcatuck watershed (i.e., Westerly and Stonington) to ensure long-term effectiveness of these systems. These recommendations incorporate principles and guidance from the Massachusetts Office of Coastal Zone Management (CZM) and Massachusetts Department of Environmental Protection (MassDEP) funded Assessment of Climate Change Impacts on Stormwater BMPs and Recommended BMP Design Considerations in Coastal Communities:

   - Use a 50-year planning horizon for BMP design and evaluate potential climate change impacts for this period during BMP design to ensure effectiveness of the BMP, including maintenance, over the life of the system.

- BMPs close to the shoreline are at greatest risk of climate change impacts. Select BMPs locations, particularly for retrofits, in conjunction with sea level rise and coastal flood projection maps to understand the implications of climate change over the design life of the BMP. A distributed approach consisting of several smaller structural BMPs and (i.e., LID) and non-structural practices is generally preferred over the use of a single larger BMP located close to the coast.

- If the BMP must be sited close to the shoreline due to other constraints, consider the following:
    1. Avoid installing BMPs in areas where they will be exposed to significant storm impacts or sand sources (if clogging is a concern, such as with permeable pavement or infiltration practices).
    2. Site the BMP away from salt marsh edges to minimize disturbance and spread of invasive plants.
    3. Retain the water quality volume on-site to the extent possible, through the use of retention or infiltration, to minimize the introduction of freshwater into salt marshes and estuarine areas.
    4. Avoid siting BMPs, particularly infiltration systems, near high groundwater if the BMP cannot function with higher groundwater or will be impacted by groundwater intrusion into the system.
    5. Only select infiltration practices (such as subsurface infiltration systems) for areas where the minimum required depth to groundwater can be sustained in light of expected sea level rise and associated groundwater rise.
    6. Also ensure the selected BMP can adapt to wetter conditions. Typically, this approach will prioritize above-ground, vegetated practices over below-ground "gray" infrastructure. For example, a rain garden can convert to a wetland over time as groundwater rises, while an underground infiltration chamber will simply fail when groundwater levels rise too high.
    7. Choose materials that are appropriate to existing and future site conditions, such as native, salt-tolerant plant species and materials that do not corrode from salt exposure.
    8. Increase the size of a sediment forebay to accommodate heavier sediment loads in the BMP drainage area to help prolong the effective lifespan of the BMP.
    9. Use flexible designs that allow the system to adapt to new conditions.
    10. Green infrastructure practices that rely on vegetated surface systems are generally preferred over underground gray infrastructure. Vegetated BMPs can generally adapt more easily over time in response to storm surge and rising groundwater, provided that the design incorporates redundancy and flexibility.

- BMPs in the coastal zone will require even more maintenance to ensure effective operation than BMPs in other areas.

6. Pursue sustainable, long-term funding sources for large-scale GI implementation.

A stormwater utility operates much like a drinking water or sewer utility. Fees collected from property owners go into a dedicated fund to pay for the operation and maintenance of stormwater infrastructure. Stormwater utilities, which create a more equitable relationship between revenues collected and runoff generated from a site, are common in many parts of the U.S., although only a few have been implemented in New England and none to date in Rhode Island or Connecticut.

Stonington and several other Connecticut communities have explored the feasibility of implementing a stormwater utility, but none has been successful in implementing a utility largely due to insufficient public support. Preliminary feasibility studies have also been completed by several Rhode Island communities including Middletown, Westerly, Bristol, North Providence, and West Warwick. Cities and towns in the Upper Narragansett Bay region also examined the feasibility of implementing a regional stormwater utility, and several of these communities are pursuing individual stormwater utilities.

In the Wood-Pawcatuck watershed, stormwater utilities could provide a dedicated source of funding for municipalities to construct and maintain green stormwater infrastructure, implement drainage system improvements (including culvert upgrades or replacements), and address MS4 permit compliance.

5 Funding Sources

In addition to traditional municipal funding sources (i.e., the use of General Funds and municipal bonds), a variety of state and federal sources are also available to provide financial assistance for implementation of the plan recommendations. The funding sources highlighted in this section provide the best opportunities for funding of projects associated with the short- and mid-term plan recommendations. The funding sources should be re-evaluated periodically to account for potential changes to existing funding programs (i.e., priorities, eligibility, funding cycles, and amounts) and to identify new or emerging sources of funding for flood mitigation, climate resiliency, and habitat restoration projects.

5.1 State Funding Sources

Narragansett Bay and Watersheds Restoration Fund (BWRF)

RIDEM has proposed changes in its regulations that govern the financial assistance program known as the Narragansett Bay and Watersheds Restoration Fund. The goal of the Narragansett Bay and Watersheds Restoration Fund is to restore and protect the water quality and enhance the economic viability and environmental sustainability of Narragansett Bay and the state's watersheds. This established fund provides financial assistance on a competitive basis in the form of grants for various projects that protect and restore water quality and aquatic habitats.

Under the new Flood Prevention and Mitigation Sub-fund of the BWRF, RIDEM is seeking proposals for projects that will address the flooding of coastal or inland areas in a manner that incorporates and enhances natural ecosystem functions including the maintenance of natural hydrologic regimes. These projects would be expected to mitigate a known flooding problem while also delivering ecological co-benefits. Examples of projects eligible for the Flood Prevention and Mitigation Sub-fund include:

- Restoration of floodplains
- Restoration/re-vegetation of stream banks that reduce peak flows and/or velocities
- Removal of impervious surfaces and associated re-vegetation to increase the on-site retention of stormwater in flood-prone areas
- Replacement of culverts that prevent flooding through improved management of peak flows and enhanced stream continuity
- Creation of floodplain storage capacity
- Aquifer recharge that reduces flooding while maintaining a natural hydrologic regime
- Repairs/enhancements to dams that result in increased capacity for upstream flood storage
- Removal of dams to reduce the risk of flooding in flood-prone areas
- Projects that enhance the resiliency of vulnerable coastal and inland habitats in specific locations that mitigate flooding risks to building, structures or other infrastructure.

Proposed projects submitted for funding should be consistent with approved local hazard mitigation plans or updated hazard mitigation plans that have been formally submitted to the Federal Emergency Management Agency (FEMA) for review and approval. RIDEM will award grants of up to fifty percent

(50%) of eligible costs and, at its discretion, will consider funding up to seventy-five percent (75%) of project costs. Proposals are due June 30, 2017.

http://www.dem.ri.gov/programs/benviron/water/finance/pdf/bwrfrfp17.pdf

Clean Water Act, Section 319 Nonpoint Source Implementation Grants

Section 319 Grants are available to assist projects that promote restoration and protection of water quality through reducing and managing nonpoint source pollution. These grants are made possible by federal funds provided to RIDEM and CTDEEP by the USEPA under Section 319 of the Clean Water Act. Eligible applicants include municipal, state, or regional governments, quasi-state agencies, public schools and universities, and non-profit watershed, environmental, or conservation organizations. Pursuant to federal guidelines for Section 319 funding, projects can only be funded in those areas in which a Watershed-Based Plan has been completed. RIDEM is currently preparing a WBP for the Rhode Island portion of the Wood-Pawcatuck watershed.

Clean Water Act Section 319 grants may be used for green stormwater infrastructure projects (if not mandated by a stormwater permit) and certain restoration activities such as dam removal. The EPA's guidance, "Nonpoint Source Program and Grants Guidelines for States and Territories," includes hydrologic modification as a type of nonpoint source pollution and therefore projects that address hydrologic modification such as dam removal are potentially eligible for funding. Dam removal projects need to be consistent with a state's written Nonpoint Source Management Program Plan. Dam removal projects that are included in local watershed-based plans that are consistent with EPA Guidelines would also be eligible for 319 funds.

Rhode Island: http://www.dem.ri.gov/programs/water/finance/nonpoint-source-funding.php
Connecticut: http://www.ct.gov/deep/cwp/view.asp?a=2719&q=325594&deepNav_GID=1654

CRMC Coastal Habitat Restoration Program

The Rhode Island Coastal Resources Management Council (CRMC) administers a state grant program capped at $250,000 per year that provides grants to support planning and implementation of coastal habitat projects including the restoration of anadromous fish passage.

http://www.crmc.state.ri.us/habitatrestoration.html

CIRCA Municipal Resilience Grant Program

The Connecticut Institute for Resilience and Climate Adaptation (CIRCA) is a partnership of the University of Connecticut and the Connecticut Department of Energy and Environmental Protection. The mission of CIRCA is to assist Connecticut towns and cities to adapt to a changing climate and to enhance the resilience of their infrastructure. The CIRCA Municipal Resilience Grant Program provides funding to Connecticut municipal governments and councils of government for initiatives that advance resilience, including the creation of conceptual design, construction (demonstration projects or other) of structures, or the design of practices and policies that increase their resilience to climate change and severe weather. This program is focused on implementation and proposals must review and consider integration of CIRCA's research products projects (see link to CIRCA Research Projects report below) into proposed projects. Up to $200,000 in funds is typically available statewide on an annual basis.

http://circa.uconn.edu/funds-muni/

Connecticut In-Lieu Fee Program

The National Audubon Society, Inc., through its Connecticut program (Audubon-CT) is the sponsor of an "in-lieu fee" (ILF) program for aquatic resource compensatory mitigation required by Department of the Army authorizations. This program provides an alternative to Corps permittees who are required to compensate for their impacts to wetlands and waters of the United States in the State of Connecticut.

As sponsor, Audubon Connecticut administers a competitive grant funding program, soliciting proposals for wetland and waters restoration, enhancement, creation and/or preservation. These proposals are given to an advisory committee to be ranked using a scoring methodology. Ultimately, the proposals are presented with their funding requests to an Interagency Review Team, which recommends the finalists to the Corps for selection. Once the projects are chosen, Audubon Connecticut is responsible for funding, execution and long-term stewardship. Funding amounts and availability depend on the impact fees received for a given geographic area (i.e., Southeast Coastal Watershed in the case of the Wood-Pawcatuck).

http://www.nae.usace.army.mil/Missions/Regulatory/Mitigation/In-Lieu-Fee-Programs/CT/
http://ct.audubon.org/conservation/in-Lieu-fee-program

Land Conservation Program Funding – Rhode Island

- Local Open Space Grants Program. This program provide up to 50% matching funds to municipalities, land trusts and non-profit conservation land organizations to preserve valuable open space.

- State Land Conservation Program. This program is administered by the RIDEM Land Acquisition Committee, which makes recommendations to the Director regarding real estate transactions that will enhance RIDEM's Management Areas, Parks and Forest Lands. Funding for these real estate acquisitions is provided by State Open Space bonds, with contributions from municipalities and land trusts, from local partners such as The Nature Conservancy and the Champlin Foundations, and from various federal programs including the U.S. Forest Services' Forest Legacy program, U.S. Fish and Wildlife Service, the National Oceanic and Atmospheric Administration, the Federal Highway Administration, and the National Park Service's Land and Water Conservation Fund.

- Agricultural Land Preservation Program. This program, run by the Agricultural Land Preservation Commission (ALPC) and staffed by the RIDEM, preserves agricultural lands through the purchase of farmland development rights. Purchasing development rights from farmers enables them to retain ownership of their property while protecting their lands for agricultural use. At the same time, it provides farmers with a financially competitive alternative to development. Funding for this program is obtained through the Open Space Bond; The Nature Conservancy, through grants from the Champlin Foundations; the United States Department of Agriculture's (USDA) Farm and Ranch Lands Protection Program; and through the leveraging of land trust and municipal funds.

Land Conservation Program Funding – Connecticut

- Long Island Sound Watershed Regional Conservation Partnership Program (LISW-RCPP). Led by the Connecticut Council on Soil and Water Conservation and numerous regional partners, the purpose of the LISW-RCPP is to assist landowners, on a voluntary basis, in helping to restore, enhance, and protect forestland resources on private lands through permanent conservation easements.

- Open Space and Watershed Land Acquisition Grant Program. The CTDEEP Open Space and Watershed Land Acquisition Grant Program provides financial assistance to municipalities and nonprofit land conservation organizations to acquire land for open space.

- Recreation and Natural Heritage Trust Program. Through the Recreation and Natural Heritage Program, the CTDEEP acquires open space of "statewide significance that represents the ecological and cultural diversity of Connecticut, with a focus on unique features such as rivers, mountains, rare natural communities, scenic qualities, historic significance, connections to other protected land, and access to water."

- Farmland Preservation Program. The Connecticut Department of Agriculture supports the protection of Connecticut's farmland resources through the purchase of development rights to agricultural properties. The landowner continues to own and use the land, within the limits of restrictions on non-agricultural activities.

Small Town Economic Assistance Program (STEAP)

The Small Town Economic Assistance Program (STEAP) provides funding for economic development, community conservation and quality of life projects for localities that are ineligible to receive Urban Action (CGS Section 4-66c) bonds. This program is managed by the Office of Policy and Management, and the grants are administered by various state agencies. STEAP funds are issued by the State Bond Commission and can only be used for capital projects. Eligible projects include projects involving economic and community development, transportation, environmental protection, and public safety. All of the Connecticut communities in the Wood-Pawcatuck watershed are eligible for STEAP funding. The Town of Sterling was recently awarded STEAP funding to replace culverts and resurface a portion of Gibson Hill Road. Other communities including Fairfield and Beacon Falls were also awarded 2016 STEAP grants to construct drainage and flood mitigation improvements.

http://www.ct.gov/opm/cwp/view.asp?Q=382970

5.2 Federal Funding Sources

Southeast New England Program for Coastal Watershed Restoration Grants

The Southeast New England Program (SNEP) is a geographically-based program intended to serve as a collaborative framework for advancing ecosystem resiliency, protecting and restoring water quality, habitat, and ecosystem function, and developing and applying innovative policy, science, and technology to environmental management in southeast coastal New England. The SNEP Coastal Watershed Restoration Grant Program funds projects that are intended to identify, test, and promote effective new regional approaches in critical areas such as water monitoring, watershed planning, nutrient and/or septic management, and resilience to climate change. In 2016, approximately $4.6 million was awarded to eight grant recipients focused on coastal watershed efforts in southeast Rhode Island and Massachusetts. Applicants must provide a minimum non-federal match of 10 percent of the federal award. This grant program is presently funding a project led by the Town of Westerly and Save the Bay to implement stormwater quality improvements in downtown Westerly.

https://www.epa.gov/snecwrp

NOAA Coastal Resiliency Grants

The objective of the NOAA Coastal Resilience Grants program, jointly administered by NOAA's National Ocean Service and National Marine Fisheries Service, is to implement projects that build resilient U.S. coastal communities, economies and ecosystems. This program is intended to build resilience by reducing the risk to coastal communities, economies and ecosystems from extreme weather events and climate-related hazards. Projects that build resilience include activities that protect life and property, safeguard people and infrastructure, strengthen the economy, and/or conserve and restore coastal and marine resources.

NOAA anticipates awarding approximately $15 million, although funds are subject to fiscal year 2017 appropriations. Typical award amounts will range from $250,000 to $1 million for projects lasting up to 36 months. The minimum allowable request is $100,000, and the maximum is $2 million. Cost-sharing through cash or in-kind match will be required at a 2:1 ratio of federal to non-federal contributions. Recipients provide one-third of the total project cost. Eligible funding applicants are nonprofit organizations, private (for-profit) entities, institutions of higher education, regional organizations, and state, territorial, tribal, and local governments (which includes counties, municipalities, and cities). Projects in coastal watershed counties - located along inland rivers and streams with a significant impact on coastal and ocean resources – are eligible for funding.

https://www.coast.noaa.gov/funding/_pdf/NOAA-NOS-NRPO-2017-2005159-FFO.pdf

NOAA Community-Based Coastal and Marine Habitat Restoration Grants

This funding opportunity focuses on coastal habitat restoration projects that aid in recovering listed species and rebuilding sustainable fish populations or their prey. The grant program funds feasibility analyses, engineering design, and construction. Applicants may submit one or more projects to be completed in one, two, or three years. The Community-based Restoration Program is currently seeking applications for restoration projects that use a habitat-based approach to promote productive and sustainable fisheries, improve the recovery and conservation of protected resources, and promote healthy ecosystems and resilient communities.

Proposals selected for funding through this solicitation are funded through cooperative agreements. One year or multi-year awards up to three funding years will be considered, and additional releases of funds may be used to fund selected proposals through FY19 without further competition. NOAA anticipates typical federal funding awards will range from $300,000 to $1.5 million over one to three years. NOAA will not accept proposals with a federal funding request of less than $100,000 or more than $4 million over three years. NOAA anticipates up to $5 million will be available under this FFO in FY17. Funds will be administered by the Community-based Restoration Program within the NOAA Restoration Center. Awards are dependent upon the amount of funds Congress makes available to NOAA for this purpose in the FY17-FY19 budgets.

High priority will be given to habitat restoration proposals that:

- Provide sustainable and lasting ecological benefits of regional or national significance for the species targeted by the project and its habitat. Projects that restore natural ecosystem function and processes such as dam removal projects will receive higher priority than projects that install structures that require maintenance, such as fish passage devices.

- Increase the amount of habitat accessible to diadromous species through dam and culvert removal projects in high priority watersheds in the Northeast, as identified by the Restoration Center's regional fish passage prioritization.

http://www.habitat.noaa.gov/funding/coastalrestoration.html

Eastern Brook Trout Joint Venture

The Eastern Brook Trout Joint Venture (EBTJV) funds projects that restore and conserve habitat necessary to support healthy and productive populations of wild brook trout. Federal funding is provided under the National Fish Habitat Action Plan through the U.S. Fish and Wildlife Service (USFWS). The maximum award amount for an individual project is $50,000. All proposed projects must be developed in coordination with the nearest USFWS Sponsoring Office.

http://easternbrooktrout.org/funding-opportunities/2017-ebtjv-fws-nfhp-project-funding-opportunity

HUD Community Development Block Grants

Title 1 of the Housing and Community Development Act of 1974 authorized the Community Development Block Grant program. The program is sponsored by the US Department of Housing and Urban Development. The Rhode Island program is administered through the State of Rhode Island Office of Housing and Community Development, while the Connecticut program (Small Cities Program) is administered through the Connecticut Department of Housing.

CDBG-DR (disaster recovery) funds may be used to restore public facilities and infrastructure, rehabilitate or replace housing, acquire property, promote economic revitalization, and support hazard mitigation planning. CDBG-DR funds are intended to support long-term recovery from a specific natural disaster and may not be applied to recovery activities associated with other disasters. Annual CDBG Program funds may also be used for certain eligible hazard mitigation and disaster recovery activities (RIEMA, 2014). Implementation of green stormwater infrastructure and drainage system upgrades to mitigate drainage-related flooding is potentially eligible for CDBG funding.

Rhode Island: http://ohcd.ri.gov/community-development/cdbg/
Connecticut: http://www.ct.gov/doh/cwp/view.asp?a=4513&q=530474

Army Corps of Engineers Aquatic Ecosystem Restoration Program

Under Section 206 of the Water Resources Development Act of 1996 (33 U.S.C. 2330), the Army Corps of Engineers can participate in the study, design and implementation of ecosystem restoration projects. Projects conducted in New England under this program have included eelgrass restoration, salt marsh and salt pond restoration, freshwater wetland restoration, anadromous fish passage and dam removal, river restoration, and nesting bird island restoration. Projects must be in the public interest and cost effective and are limited to $10 million in Federal cost.

Non-Federal project sponsors must be public agencies or national non-profit organizations capable of undertaking future requirements for operation, maintenance, repair, replacement and rehabilitation (OMRR&R), or may be any non-profit organization if there are no future requirements for OMRR&R. The Corps of Engineers provides the first $100,000 of study costs. A non-Federal sponsor must contribute 50 percent of the cost of the feasibility study after the first $100,000 of expenditures, 35 percent of the cost of design and construction, and 100 percent of the cost of operation and maintenance.

http://www.nae.usace.army.mil/Missions/Public-Services/Continuing-Authorities-Program/Section-206/

NFWF New England Forests and Rivers Fund

The National Fish and Wildlife Foundation (NFWF) New England Forests and Rivers Fund is dedicated to restoring and sustaining healthy forests and rivers that provide habitat for diverse native bird and freshwater fish populations in the six New England states. This program annually awards competitive grants ranging from $50,000 to $200,000 each. In its first year, the program has awarded thirteen grants that will restore early successional habitat, modify and replace barriers to fish movement, restore riparian and instream habitat, and engage volunteers in forest habitat restoration and stream connectivity projects. Major funding for the New England Forests and Rivers Fund is provided by Eversource Energy, the U.S. Fish and Wildlife Service, and the U.S. Department of Agriculture's Natural Resources Conservation Service and Forest Service.

http://www.nfwf.org/newengland/Pages/home.aspx

USDA NRCS Funding Programs

The USDA Natural Resources Conservation Service (NRCS) works with land owners in Rhode Island and Connecticut to improve and protect soil, water, and other natural resources. NRCS has several funding programs in Rhode Island and Connecticut that help property owners address flooding and water quality issues.

- The Emergency Watershed Protection (EWP) Program is designed to help people and conserve natural resources by relieving imminent hazards to life and property caused by floods, fires, wind-storms, and other natural occurrences. EWP is an emergency recovery program, which responds to emergencies created by natural disasters. It is not necessary for a national emergency to be declared for an area to be eligible for assistance. EWP is designed for installation of recovery measures. Activities include providing financial and technical assistance to remove debris from stream channels, road culverts, and bridges, reshape and protect eroded banks, correct damaged drainage facilities, establish cover on critically eroding lands, repair levees and structures, and repair conservation practices.

- The Emergency Watershed Protection - Floodplain Easement Program (EWP-FPE) provides an alternative measure to traditional EWP recovery, where it is determined that acquiring an easement in lieu of recovery measures is the more economical and prudent approach to reducing a threat to life or property. The easement area is restored to the maximum extent practicable to its natural condition using structural and nonstructural practices to restore the flood storage and flow, erosion control, and improve the practical management of the easement. Floodplain easements restore, protect, maintain and enhance the functions of floodplains while conserving their natural values such as fish and wildlife habitat, water quality, flood water retention and ground water recharge. Structures, including buildings, within the floodplain easement must be demolished and removed, or relocated outside the 100-year floodplain or dam breach inundation area.

- The Watershed and Flood Prevention Operations Program provides technical and financial assistance to States, local governments and Tribes to plan and implement watershed project plans for the purpose of watershed protection, flood mitigation, water quality improvement, fish and wildlife enhancement, wetlands and wetland function creation and restoration, groundwater recharge, and wetland and floodplain conservation easements. This program has funded flood studies in Johnston and Cranston to address flooding in the Pocasset River, which resulted in repetitive damage to homes and businesses (RIEMA, 2014).

Rhode Island: https://www.nrcs.usda.gov/wps/portal/nrcs/main/ri/programs/financial/
Connecticut: https://www.nrcs.usda.gov/wps/portal/nrcs/main/ct/programs/financial/

FEMA Hazard Mitigation Assistance Grant Programs

The Federal Emergency Management Agency's (FEMA) administers two major programs related to hazard mitigation: the National Flood Insurance Program (see Section 1.2 of this plan) and the Hazard Mitigation Assistance Program. FEMA's hazard mitigation assistance grant programs provide funding to protect life and property from future natural disasters. In Rhode Island, these programs are administered by the Rhode Island Emergency Management Agency (RIEMA) and in Connecticut by the Department of Emergency Services & Public Protection – Emergency Management and Homeland Security. FEMA flood hazard mitigation assistance funding is available to Rhode Island and Connecticut communities through the following programs (RIEMA, 2014):

- Pre-Disaster Mitigation (PDM) provides funds for hazard mitigation planning and the implementation of mitigation projects prior to a disaster. The goal of the PDM program is to reduce overall risk to the population and structures, while at the same time, also reducing reliance on Federal funding from actual disaster declarations. Funding is available on an annual basis (as available). The program provides funding with 75% federal share and 25% non-federal share (local government or other organization).

- Flood Mitigation Assistance (FMA) provides funds for projects to reduce or eliminate risk of flood damage to buildings that are insured under the National Flood Insurance Program (NFIP) on an annual basis. These are cost share grants for pre-disaster planning and projects, with a federal share (up to 100%) and non-federal share (local government or other organization).

- Severe Repetitive Loss (SRL) is designed to reduce flood damages to residential properties that have experienced SRLs under flood insurance coverage. The program provides funds that measures can be taken to reduce or eliminate risk of flood damage to buildings insured under the NFIP. Funding is available on an annual basis (as available). SRL provides up to 90% Federal funding for eligible projects.

- Hazard Mitigation Grant Program (HMGP) assists in implementing long-term hazard mitigation measures following Presidential disaster declarations. Funding is available to implement plans or projects in accordance with State, Tribal, and local priorities. HMGP grants are post-disaster cost share grants consisting of 75% federal share and 25% non-federal share (local government or other organization).

- Public Assistance (PA) Grants provide assistance to local, tribal and state governments and certain types of Private Non-Profit (PNP) organizations so that communities can quickly respond to and recover from major disasters or emergencies declared by the President. Through the PA Program, supplemental Federal disaster grant assistance is provided for debris removal, emergency protective measures, and the repair, replacement, or restoration of disaster-damaged, publicly owned facilities and the facilities of certain PNP organizations. The PA Program also encourages protection of these damaged facilities from future events by providing assistance for hazard mitigation measures during the recovery process.

Rhode Island: http://www.riema.ri.gov//grants/index.php
Connecticut: http://www.ct.gov/demhs/cwp/view.asp?a=4062&q=515030&demhsNav=|

5.3 Other Funding Sources

National Wild & Scenic Rivers System

Once designated under the National Wild & Scenic Rivers System program, the Wood, Pawcatuck, Beaver, Chipuxet, Queen, Shunock, and Green Falls Rivers may be eligible for funding through the National Park Service for restoration and management projects. These projects must meet guidelines set forth in the Stewardship Plan as adopted by the towns of the Wood-Pawcatuck watershed. Wild & Scenic designation may also help restoration projects in the watershed receive a higher priority for competitive federal grants and leverage other funding opportunities.

Stormwater Utilities

A stormwater utility operates much like a drinking water or sewer utility. Fees collected from property owners go into a dedicated fund to pay for the operation and maintenance of stormwater infrastructure. Stormwater utilities, which create a more equitable relationship between revenues collected and runoff generated from a site, are common in many parts of the U.S., although only a few have been implemented in New England and none to date in Rhode Island or Connecticut.

Stonington and several other Connecticut communities have explored the feasibility of implementing a stormwater utility, but none has been successful in implementing a utility largely due to insufficient public support. Preliminary feasibility studies have also been completed by several Rhode Island communities including Middletown, Westerly, Bristol, North Providence, and West Warwick. Cities and towns in the Upper Narragansett Bay region also examined the feasibility of implementing a regional stormwater utility, and several of these communities are pursuing individual stormwater utilities.

In the Wood-Pawcatuck watershed, stormwater utilities could provide a dedicated source of funding for municipalities to construct and maintain green stormwater infrastructure, implement drainage system improvements (including culvert upgrades or replacements), and address MS4 permit compliance.

Healthy Watersheds Consortium Grant Program, U.S. Endowment for Forestry and Communities

The goal of the Healthy Watersheds Consortium Grant Program is to accelerate strategic protection of healthy, freshwater ecosystems and their watersheds. This goal will be achieved by:

- Developing funding mechanisms, plans, or other strategies to implement large-scale watershed protection, source water protection, green infrastructure, or related landscape conservation objectives.
- Building the sustainable organizational infrastructure, social support, and long-term funding commitments necessary to implement large-scale protection of healthy watersheds.
- Supporting innovative or catalytic projects that may accelerate funding for or implementation of watershed protection efforts, or broadly advance this field of practice.

Eligible applicants include not-profit organizations, for-profit companies, tribes, intertribal consortia, interstates, state, and local government agencies including water utilities and wastewater facilities, and colleges and universities. Funding amounts range from $50,000 to $300,000.

http://www.usendowment.org/healthywatersheds.html

Resilient Communities Program

In 2017, Wells Fargo and National Fish and Wildlife Foundation launched the Resilient Communities Program, designed to prepare for future environmental challenges by enhancing community capacity to plan and implement resiliency projects and improve the protections afforded by natural ecosystems by investing in green infrastructure and other measures. The program will focus on water quality and quantity declines, forest health concerns, and sea level rise. The program will emphasize community inclusion and assistance to traditionally underserved populations in vulnerable areas. In the northeast, eligible project types include wetland restoration and aquatic organism passage. The program will award approximately $2 million in grants to projects in 2017. Each grant will range from $100,000 to $500,000 depending on category and will be awarded to eligible entities working to help communities become more resilient. This program has one round of applications per year and awards approximately 3 to 6 grants annually.

http://www.nfwf.org/resilientcommunities/Pages/home.aspx

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Appendix A

Wood-Pawcatuck Watershed Baseline Assessment

Appendix B

Project Steering Committee Meeting Documents

Appendix C

Watershed Survey

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Appendix D

Community Meeting Documents

Appendix E

Subwatershed Recommendation Maps

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Appendix F

Town Summary Sheets

Appendix G

Dams, Bridges and Culverts Assessment Technical Memorandum

Appendix H

Fluvial Geomorphic Assessment

Appendix I

River Corridor Plan

Appendix J

River Corridor Restoration Concept Sheets

Appendix K

Land Use Policy and Regulatory Review

Appendix L

Watershed-Scale Wetlands Assessment

Appendix M

Green Infrastructure Assessment

Wood-Pawcatuck Watershed Association

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