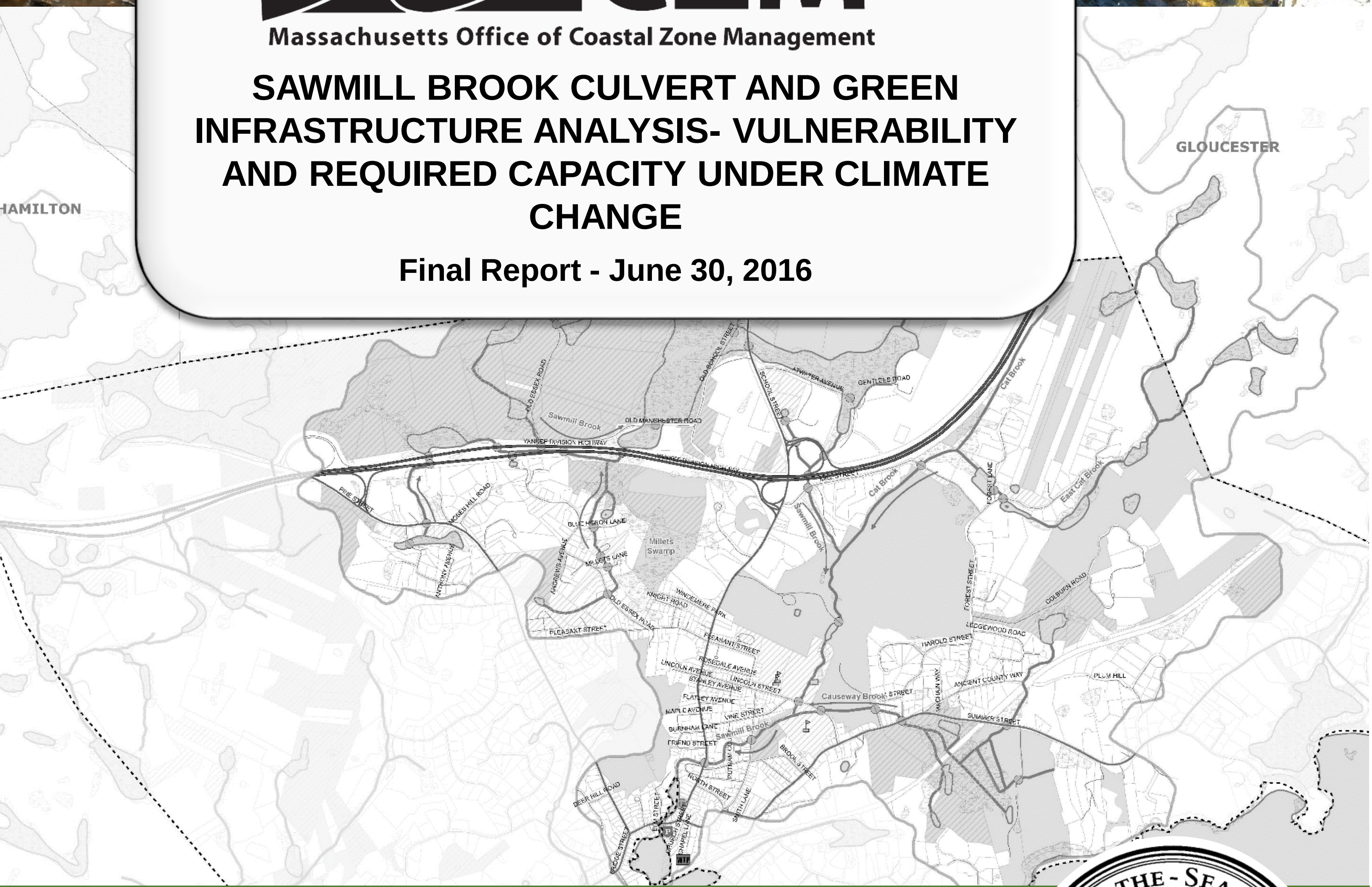
Massachusetts Office of Coastal Zone Management

SAWMILL BROOK CULVERT AND GREEN INFRASTRUCTURE ANALYSIS- VULNERABILITY AND REQUIRED CAPACITY UNDER CLIMATE CHANGE

Final Report - June 30, 2016



MANCHESTER-BY-THE-SEA

Acknowledgements

For providing data, other plans and studies, editorial assistance, and guidance to the consulting team, special thanks go to the following Manchester-by-the-Sea town department heads and staff: Greg Federspiel, Town Administrator, Mary Reilly, Grants Administrator, Carol Murray, Interim Director, Department of Public Works; Barbara Warren, Salem Sound Coastwatch, Jessica Lamothe, and members of the Manchester Coastal Stream Team, Sue Brown, Town Planner, Bion Pike, Harbormaster, the Manchester Essex Regional High School Green Team, the Manchester-by-the-Sea Board of Selectmen for their continued support, the Manchester Historical Society, resident volunteers, and the Downtown Business owners who assisted with this plan.

We gratefully acknowledge the hard work and commitment of the Coastal Resource Advisory Group, who reviewed draft report documents and met regularly throughout this planning process to provide invaluable input and guidance.

- Greg Federspiel, Town Manager
- Mary Reilly, Grants Administrator
- Carol Murray, P.E., Interim Director Department of Public Works
- Lieutenant Todd Fitzgerald, Manchester Police
- Tod Biggar, Fire Captain/EMT, Manchester Fire and Rescue
- Susan Brown, Town Planner
- Bion Pike, Harbor Master
- Barbara Warren, Salem Sound Coastwatch
- Jessica Lamothe, Manchester Coastal Stream Team
- Rick Gibson, Downtown Improvement Committee
- Ben Rossi, Downtown Improvement Committee
- Jori Everitt, Citizen Volunteer
- Lise Koufman, Citizen Volunteer
- Kathryn Glenn, Mass CZM, North Shore Regional Coordinator
- Patricia Bowie, Mass CZM, Coastal Resiliency Specialist
- Mary Beth Groff, Massachusetts Emergency Management Agency

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List of Acronyms

Commonly Used Abbreviations	Definitions
BMP	Best Management Practice
CRAG	Coastal Resilency Advisory Committee
CZM	Coastal Zone Management
DMF	Division of Marine Fisheries
DPW	Department of Public Works
EPA	Environmental Protection Agency
FEMA	Federal Emergency Manamgnet Agency
FIRMs	Flood Insurance Rate Maps
GIS	Geographic Information System
GSI	Green Stormwater Infrastructure
IRM	Innudation Risk Model
LID	Low Impact Development
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MEMA	Massachusetts Emergency Management Agency
MEPA	Massachusetts Environmental Policy Act
MESA	Massachusetts Endangered Species Act
NFIP	National Flood Insurance Program
NHESP	Natural Heritage and Endangered Species Program
USACE	United States Army Corps of Engineers

CONTENTS

Tighe&Bond

C O N T E N T S

Section 1 Executive Summary

Manchester-by-the-Sea experiences frequent flooding in downtown and other areas of the Sawmill Brook Watershed due to a combination of hydraulic restrictions from culverts and the Central Street tidal dam, increased stormwater runoff from impervious surfaces on developed areas, a highly channelized stream system, and poor infiltration conditions. Impacts from flooding include property damage and water quality degradation in the Brook, which affects aquatic species including rainbow smelt, a diadromous fish listed as a federal Species of Concern. Flooding and water quality problems will be magnified in coming years due to climate change and potential expansion of impervious areas from future development.

The Town was awarded a Massachusetts Coastal Zone Management (CZM) Coastal Resiliency Grant to improve understanding of existing flood conditions and potential future flooding from increased intensity and duration of precipitation, storm surge, and sea level rise due to climate change. The goal of the grant was to identify opportunities for flood reduction including flood storage, culvert improvements, and green stormwater infrastructure throughout the watershed to mitigate current and potential future flooding, while simultaneously providing water quality and habitat benefits.

The scope of work completed under the CZM Resiliency Grant was modeled after the *Oyster River Culvert Analysis Project* in Durham, NH, but was enhanced to include projected future climate change conditions by coupling an inland flooding model with a coastal watershed model developed for 25, 50, and 100 year planning horizons (2025, 2050, 2100). Under the grant, an iterative modeling analysis was completed to evaluate the benefit of culvert improvement, flood storage, and green infrastructure projects. Based on the modeling, solutions were identified throughout the watershed that will ultimately reduce downtown flooding and help restore diadromous fish passage.

Nine conceptual mitigation designs were prepared, including tide-gate removal, culvert resizing and bridge improvements, stream channel restoration, and flood storage projects. The projects were prioritized considering cost, health and safety, flood mitigation benefit, water quality and habitat improvement, permitting needs, long term maintenance needs and coordination with other town projects. Utilizing a multi-variate matrix to prioritize projects helped to reduce controversy and allowed engineers to move forward with design for the most important projects. Based on the results of the optimization process, three projects were selected by the town for planning level design.

By modeling the entire watershed with inland and coastal climate change modeling components, the Town has assessed potential impacts to critical Town assets (e.g. emergency response facilities, municipal buildings, etc.) resulting from climate change, and evaluated flood reduction projects that will have both short and long term benefits. The modeling is set up to reevaluate future climate change impacts as science evolves.

Public participation and involvement was critical to the success of the project. A stakeholder group, called the Coastal Resiliency Advisory Group (CRAG), attended meetings, reviewed material, and provided local perspective to guide decisions. The CRAG was vital in helping reach consensus on the climate change models selected, planning horizons, and acceptable degree of risk for future planning. Town staff and stakeholders connected with regular meetings, two public forums were held, and transparency was maintained throughout the duration of the project by posting deliverables on the Town's website. These activities substantially contributed to the project's success.

This final report provides highlights on each task completed as part of the grant. A project CD is included with complete copies of all project deliverables.

Section 2 Introduction

2.1 Overview

The Town of Manchester-by-the-Sea experiences frequent flooding from inland and coastal sources. This is due to a combination of hydraulic restrictions from culverts, bridges, and a dam and tide gate, increased stormwater runoff volumes and rates from impervious developed areas, a highly channelized stream system, poor infiltration conditions, high tides, wave action and storm surge. Over 75% of the town's critical assets (including water and sewer treatment facilities, and emergency service buildings) are vulnerable to flooding due to location and elevation. Historically and during recent years, property and infrastructure have been damaged, water quality and habitat of inland and coastal waterways have been degraded, and fish passage has been impeded in the watershed. Flooding and water quality problems will be magnified in coming years due to climate change related increased frequency and duration of storms, sea level rise, and the expansion of impervious areas from future development.

The Town recognized that a comprehensive understanding of current and future flood risks and planning strategic, cost-effective capital improvements required a watershed-wide evaluation and consideration of coastal impacts and climate change. Solutions developed based on the holistic watershed assessment simultaneously considered flood mitigation, improving water quality, and restoring habitat. Goals for the projects include making water quality improvements (reduce sedimentation, increase aeration), improving fish passage (eliminate tide gate and culvert restrictions), increasing stream habitat diversity (creation of riffles, islands and instream planting), all paired with flooding mitigation (increase flow through downtown and reduce hydraulic restrictions) and roadway and pedestrian safety (widen road and install new guardrails).

Figure 1: Low tide range north of Central Street, Sawmill Brook

2.2 Grant Scope of Work

The 18-month long project involved seven (7) major tasks, detailed below with subtasks:

Task 1: Data Collection and Review

- Steering committee, Coastal Resilience Advisory Group (CRAG), was established.
- Information that characterizes existing and future conditions was obtained and reviewed.
- Meetings were held including a kickoff meeting and meeting with municipal staff and CRAG to transfer knowledge about local conditions/develop strategies for field efforts.
- A public forum was held on April 22, 2015 to outline project goals and highlight climate adaptation benefits and challenges. The public had the opportunity to provide additional local knowledge about historic flooding and ongoing flood concerns.
- Task 1 deliverables included the final technical memorandum, "Areas Prone to Flooding in Sawmill Brook Watershed" and supporting graphics that capture the major flooding locations and issues. A flood awareness survey was conducted concurrently with Task 1. The flood survey results are included as an additional deliverable for Task 1.

Task 2: Stream Crossing Survey

- Field assessment of culverts and road crossings was completed.
- Professional vertical survey of key culvert outlets/inlets was completed (added task).
- An evaluation of the tide gate, culvert, and seawall at Central Street was completed.
- Task 2 deliverable included: 1) Memorandum, "Sawmill Brook Central Street Culvert Observations" June 18, 2015 that summarized the tide gate/dam/culvert observations of existing conditions; 2) the final technical memorandum, "Stream Crossing Evaluation in Sawmill Brook", July 28, 2015 that documented field and survey critical culvert dimensions and observations on physical and environmental attributes at each stream crossing; and 3) a scrap book documenting the efforts of volunteers who assisted with the stream crossing evaluation.

Task 3: Opportunities to Mitigate Floods in Watershed

- Opportunities to reduce runoff volumes and flows and store floodwaters were identified through desktop GIS evaluation, development of maps, and additional field investigations.
- The Task 3 deliverable included the final technical memorandum, "Identifying Opportunities for Flood Mitigation within Sawmill Brook Watershed, Town of Manchester-by-the-Sea", July 27, 2015. The memorandum summarizes the types of urban green stormwater infrastructure (GSI) for potential use in the Sawmill Brook Watershed, the desktop methodology and field screening results which identified 17 feasible locations for GSI practices, an overall permitting review for Sawmill Brook Flood Storage and GSI Projects, and a summary of the sites with best potential opportunities for GSI or Flood Control within the watershed. Supporting graphics include 15 GIS desktop assessment maps and a map with the 17 watershed flood mitigation opportunities.

Task 4: Identify Locations to Mitigate Flooding

- A watershed model was developed and calibrated against historic flooding events. Modeling runs were completed to evaluate culvert capacity during peak flow conditions under sea level rise, storm surge and two extreme precipitation emissions scenarios (emission resulting from fossil fuel use balanced with green energy, and fossil fuel only emissions, consistent with the *Oyster River Culvert Analysis Project* in Durham, NH) for three future planning periods: years 2025, 2050, and 2100.
- Task 4 deliverable included, "Task 4 Final Report: Evaluation of Locations for Flood Mitigation", February, 2016. The report detailed the process for establishing the existing conditions model, inputs and the approach for the future conditions model, iterative results for flood mitigation improvements including

increasing flood storage, culvert right sizing (e.g. removal of the Central Street tide-gate), GSI projects, and combined project flood benefits.

Task 5: Conceptual Plans and Permitting Strategy

- Nine conceptual level designs were developed for stream crossing reconstruction and management of floods.
- Three planning level designs were developed including refined costs.
- A list of permits and permitting strategy was developed.
- Preliminary and final meetings were held with the town and the CRAG to discuss recommendations, next steps and the permitting approach.
- Task 5 deliverable included nine conceptual designs, three planning level designs, feasibility level opinions of probable cost, and final memorandum, "Identification and Assessment of permits needed for Sawmill Brook Culvert, Flood Mitigation and Green Infrastructure Projects", January 30, 2016. The memorandum presents an overview and preliminary assessment of permitting and regulatory review that will likely be needed for the nine conceptual level infrastructure improvement projects, including applicability, permit timelines, hurdles, and the studies needed to support permit applications. Potential opportunities to optimize the cost and effort to file the required project permits is also discussed.

Task 6: Refine and Prioritize Recommendations

- Alternatives to alleviate drainage and/or flooding problems were identified and evaluated using a multi varlet matrix. The results of this effort helped prioritize projects and select three priority locations for planning level designs and a permitting strategy.
- A meeting was held with the Town and CRAG to review and prioritize recommendations.
- A public forum was held on February 11, 2016, to present and discuss the identified options.
- The Task 6 deliverable included a final memorandum, "The Optimization Process: Project Selection and Recommendations," February 29, 2016. The memorandum summarized the optimization methodology that included iterative assessment and refinement of projects that can be realistically and cost-effectively implemented, and the use of a "pair-wise" comparison to systematically rank the nine conceptual designs and to inform which projects to advance to the planning design level. Next steps for the selected project and opportunities to reduce costs were discussed including, permitting considerations, coordination with Town Projects, and taking advantage of new grant opportunities.

Task 7: Meetings and Deliverables

- The Task 7 deliverable consists of this final report describing results of the project. This report includes a summary of each task, focusing on key task-related protocols and methodology as well providing data summaries and recommendations. A draft final report was presented at a CRAG meeting on June 8, 2016. This final report, including recommended next steps, was originally intended to be presented at a public forum, however the work was further along and therefore recommendations and next steps were discussed at the second public forum. Therefore, a final CRAG meeting was substituted for the public forum by consensus with CZM and the Town.

2.3 Public Participation

Public outreach and education were incorporated into all of the grant tasks including creation of dedicated websites to post project deliverables, a public survey to solicit information about localized flooding, a day-long volunteer field event to obtain information on culvert and watershed features, an informational article series appearing in a local newspaper, and regularly scheduled public meetings for the CRAG. Two public forums were held to inform the public about the grant project and provide general education about impacts of climate change and the need for resiliency planning. In addition, a webpage was created to communicate project progress and post resulting documents, plans and maps.

Table 2-1 below summarized the meeting dates, main meeting purpose, and audience that participated. Meeting summaries and PowerPoint slides are included in Appendix F. This final report also discusses transferability of the project methodology to other coastal communities in Section 7.3.

TABLE 2-1
Schedule of Public Participation Meetings and Educational Events

Meeting Date	Topic	Audience / Purpose
February 18, 2015	Task 1 Kickoff	CRAG Meeting #1
April 22, 2015	Public Forum #1	Public Outreach Event
May 18, 2015	Task 3 Desktop Evaluation	Town Internal Discussion
May 31, 2015	Task 2 Culvert Field Survey	CRAG and Public Outreach Event
June 11, 2015	Tide Gate Evaluation	Town & DMF Site Inspection
July 21, 2015	Task 2 and 3	CRAG Meeting #2
October, 26, 2015	Task 4	Town Internal Discussion and CRAG Meeting #3
December 9, 2015	Task 4	Town Internal Discussion
January 13, 2015	Task 4 and Task 5	CRAG Meeting #4
February 11, 2016	Public Forum #2	Public Outreach Event
May 2, 2016	Board of Selectmen Briefing	Public
June 8, 2016	Final Draft Report	CRAG Meeting #5

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Section 3 Sawmill Brook Watershed

Sawmill Brook and its tributaries drain rocky uplands, expansive wetlands, and developed impervious areas, before discharging to Manchester Harbor through a narrow tide gate. Many areas of the town are subject to flooding during extreme storm events due to the combination of storm surge, hydraulic restrictions from undersized culverts and the tide gate, stormwater runoff from impervious areas, the channelized stream system in the lower portion of the watershed, and poor infiltration conditions. Impacts from climate change, including increased precipitation and sea level rise, will exacerbate flooding. **Figure 2** below shows the Sawmill Brook Watershed boundary, outlined in purple, the waterbodies and flow direction, and the locations of key culverts (orange dots).

To better understand existing and future opportunities for mitigation of flood waters in the Sawmill Brook Watershed, a watershed-wide assessment was completed. Identification of historic flood events and known locations of historic flooding was prepared in Task 1 and is summarized in this section.

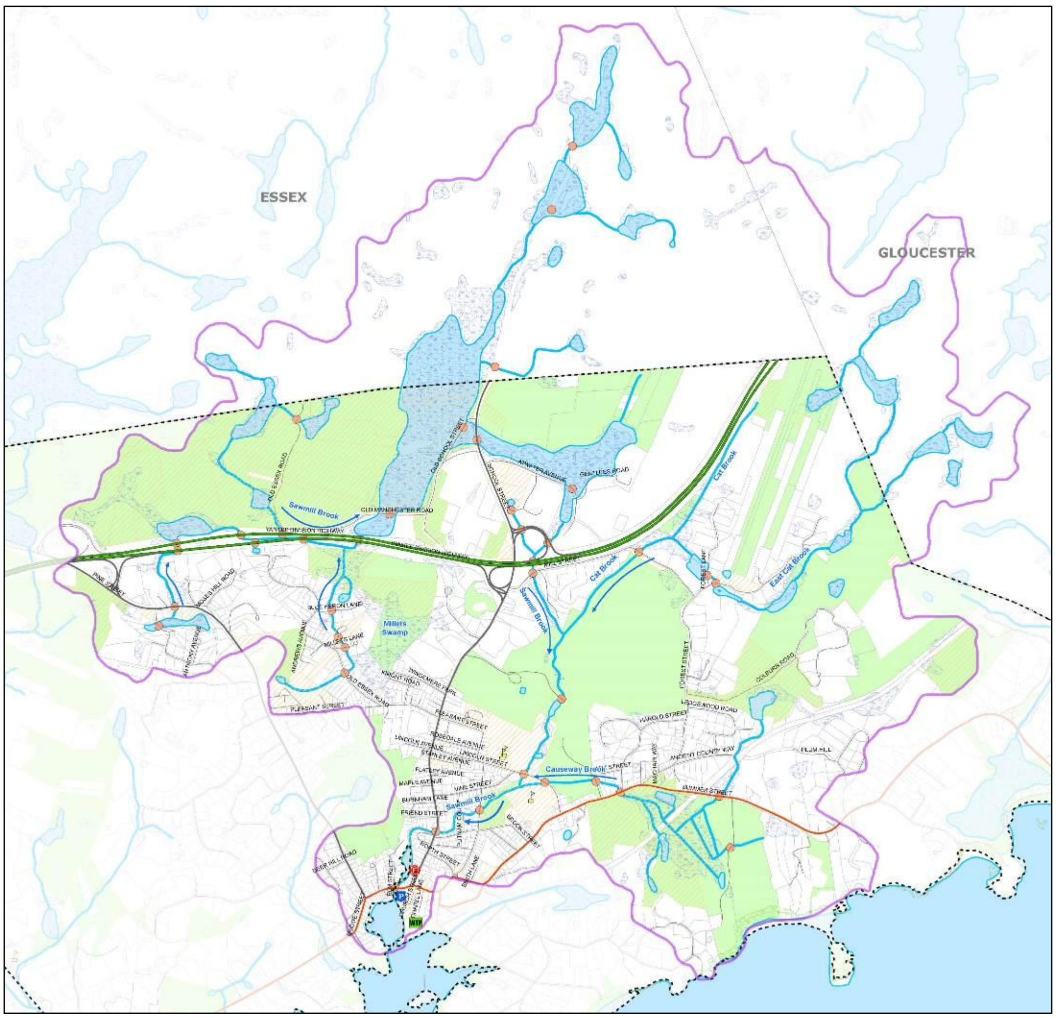

Figure 2: Sawmill Brook Watershed

3.1 Historic Flooding

There have been 20 flood-related Federal disaster declarations in the Commonwealth from 1954 to 2015 including coastal nor'easters and riverine flooding from extreme precipitation. Eighteen of these flooding events directly impacted Essex County and Manchester-by-the-Sea, more than any other county in the Commonwealth. The most notable coastal events include: the Great Hurricane of September, 1938, (a category 3 hurricane), the Blizzard of 1978 (the most devastating Nor'easter in Massachusetts history) and the "No-name, or "Perfect Storm" in October 1991 (a nor'easter that coincided with astronomical high tide). Trees were leveled, roads swept away, bath-houses plucked off the shore and smashed, and Singing Beach washed out to sea. The "Mother's Day Storm" of 2006 produced some of the worst inland flooding in recent history and resulted in the highest number of local Flood Insurance Claims to date.

3.2 Areas Impacted by Flooding

In Manchester, coastal flooding impacts low lying areas adjacent to the coast, embayments, and tidal rivers. Inland flooding also occurs along the main stem and tributaries of Sawmill Brook and Bennett's Brook as well as numerous wetland areas throughout Town. Inadequate drainage after flood events is associated with poorly infiltrating soils and undersized stormwater conveyances including channelized streambeds and culverts that do not have adequate capacity to handle runoff from larger storm events. Areas located where both coastal and inland flooding occur are especially impacted when storm surge, high tides and stream discharge coincide in the same storm and high tides result in backups of water in the inland drainage networks.

Areas at risk of flooding are mapped by the Federal Emergency Management Agency (FEMA) as part of the National Flood Insurance Program (NFIP). The Flood Insurance Rate Maps (FIRMs) include areas impacted by 100-year, 500-year flood events, and storm surge and wave action. Floodplains and areas subject to coastal storm surge are shown as high-risk areas or Special Flood Hazard Areas. Manchester participates in the NFIP, and is in the process of working with FEMA to finalize requested amendments to the current FEMA (July 2014) FIRMs. The Town has contested three areas of the these FIRMs including Manchester Harbor and Downtown areas. A letter of map revision has been submitted to FEMA requesting the FIRM should be lower in these areas.

The bridge on School Street was washed out in May 2006; there was up to 6 feet of water on sections of Brook Street, School Street, Norwood Avenue, and Putnam Court; approximately 150 single family houses were damaged; and flooding occurred as far north as the Essex County Club. Flooding on Route 127 and School Street is a major concern for the town, as these roadways serve as major arteries in and out of Manchester-by-the-Sea. In the case of an emergency, blockage of these roadways becomes a major public safety hazard as emergency response is hindered.

To gain a more local perspective on the current flooding areas of concern, residents and Town officials were surveyed. A summary chart of the areas of local flooding concern is provided below in Table 3-1.

TABLE 3-1
Summary of Local Observations of Areas Prone to Flooding in the Sawmill Brook Watershed

Location & Observations	Cause of Flooding: Rising groundwater (subsurface water) levels in the springtime	Extreme rain events (heavy rain or long duration storms)	High Tide	Storm Surge	Stream bank overflow	Catch basin overflow	Culvert back-up	Swamp/wetland overflow	Other
School Street north of 128, culvert washed out in 2012 and replaced.	✓	✓					✓		
Atwater Ave, culvert rebuilt in 2005.	✓	✓					✓		
Blue Heron Lane, neighborhood flooding.	✓	✓			✓		✓	✓	
Lincoln Street, junction of Causeway and Sawmill Brooks, flooding and culvert damage.	✓	✓			✓		✓		
Brook Street, playing Fields flood often.	✓	✓			✓				
School Street, Sawmill Brook north of School St culvert, wall, and vegetation reestablished under 5-Star grant.							✓		
School Street, roadway and culvert collapsed in 2006 Mother's Day storm.		✓			✓		✓		
Neighborhood flooding.		✓			✓				
Central Street parking lot near Town Hall floods.		✓	✓	✓					

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Brook Street, flooded basement and garage during times of high tide AND heavy rain.	✓	✓	✓						
School Street, culvert backup.		✓			✓		✓		
Norwood Ave, basement flooding, and brook stone wall collapse.	✓	✓			✓		✓		
Knight Circle, lowest portion of yard floods frequently, adjacent to brook. Flooding from rainstorm when neighbors drains sump pump into only catch basin on the road.	✓	✓			✓	✓			
Forest Lane, backup of Cat Brook along the Route 128 edge of property, backup related to trash accumulation at a culvert.		✓			✓				Debris
Old Essex Rd/ Pleasant Street/ Pine Street, runoff from DPW yard flows toward residence on Old Essex.		✓				✓			Sheet-flow
Old Essex Rd/ Pleasant St/ Blue Heron Lane From south side of Pleasant St (foot of Powder House Hill), across Old Essex Rd, following behind the residence on Old Essex Rd all the way up to Blue Heron Lane and beyond floods during heavy rains. Ditch dug by the WLA in the 30's collects water but needs clearing.		✓			✓				Debris

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Knight's Circle & Friend Street Flooding from Sawmill Brook, consistent when there is a rain event of the Brook is high. Sometimes the entire area behind Knight's Circle and 16 Friend St (and neighboring lots) is flooded.		✓			✓				
Vine & Lincoln, after storms, catch basin at the corner doesn't drain.		✓				✓			
Sawmill Brook, debris has built up and had not been addressed in several years. Numerous trees and debris in the Brook accumulated over the last 50+ years and never been cleaned. In hard rain it impedes water flow.									Debrs
20 Forest Lane, rear of property parallels Route 128 with Cat Brook which flows along our boundary with Route 128. We are on the hill above the brook with a wetland around us which controls water flow well. Our issue is with solid debris that collects at a culvert at the rear of the property to a degree where Cat Brook flow is partially impeded causing a wetland ponding effect.								✓	Debris
44 Norwood Ave, the culvert, & property floods on the Brook side lined with granite versus the soft low banks elsewhere. During Mother Day Storm 44 Norwood Ave reported flooding from across the street and down the driveway.		✓			✓				
7 Knight Rd, house at the end of Millet Brook, where 3 storm drains enter Millet Brook, has been flooded out 3 times since 1996.	✓	✓			✓		✓	✓	

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Summary of Local Observations of Areas Prone to Flooding in the Sawmill Brook Watershed

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14 Ancient County Way, basement floods from snow melt and 1-2 inches of rain even with sump pumping.	✓	✓							
12 School Street, Central Pond overtops the granite curb flooding the Fire Department Basement, notably when a lunar high tide and rainfall event coincide.		✓	✓		✓				

Section 4 Watershed Assessment

Three tasks were completed to evaluate the watershed of Sawmill Brook. A stream crossing survey was completed as part of Task 2 to inventory culvert and stream physical attributes. A Geographic Information System (GIS) “desktop” analysis was conducted as part of Task 3 to preliminarily screen the Town to identify suitable locations for flood mitigation, including culverts, green infrastructure, and other flood storage projects. Task 3 also included visits to sites identified as potentially suitable based on the “desktop” analysis. Finally, Task 4 included a hydrologic and hydraulic model evaluation to simulate how the watershed responds to inland and coastal flooding, both with and without potential flood practices. This section provides a brief overview of the highlights of the physical watershed assessment.

4.1 Stream Crossing Survey

The Sawmill Brook and associated tributaries provides drainage for the central portion of the Town of Manchester-by-the-Sea. Stream crossing infrastructure along the Brook and tributaries includes the Central Street tidal dam, culverts, and bridges. These structures, many of which are over 100 years old, include arches, bridges, and pipes constructed from a wide variety of materials including granite block, stone, aluminum, iron, and concrete.

The Town Department of Public Works (DPW) and Highway Department crews report dozens of culverts that appear to be undersized, in poor condition, or impacted by beaver dams. Deterioration, blocked culverts, and undersized structures frequently create flood water that backs up onto roadways and adjacent land, resulting in roadway closures and property damage. Culverts that have collapsed in the recent years due to flooding include two locations on School Street (one at Brook Street and one near Route 128) and the culvert at Atwater Avenue.

Task 2 of the CZM grant project provides an in-depth evaluation of all municipally owned stream crossing structures in the Sawmill Brook Watershed. The information obtained as part of Task 2 provides baseline observations of current conditions and physical characteristics required to calibrate the watershed model completed in Task 4. This section summarizes the culvert evaluation protocol, data collection, culvert evaluation results, and the tide gate evaluation. A summary of the data on culverts is provided in Appendix A. Culverts located in Essex, and along Route 128 were not included in the evaluation.

4.1.1 Stream Crossing Evaluation Protocol

A standardized stream crossing evaluation protocol, modified after the *Oyster River Culvert Analysis Project* (University of New Hampshire, 2010), was used to evaluate all municipally owned stream crossing structures (i.e. culverts and bridges) including the Central Street culvert, seawall, and tide gate. The protocol includes obtaining photo documentation of the exposed and above water portions of the structure both upstream and downstream, field measurements of critical dimensions, and observations on physical and environmental attributes. A sample blank worksheet is provided in Appendix A.

4.1.2 Stream Crossing Data Collection

The stream crossing data collection involved three separate components. Volunteers were recruited to assist with a one-day field data collection event on May 30, 2015. A separate culvert evaluation was completed on June 11, 2015 for the Central Street tide gate and associated structures by Tighe & Bond’s coastal engineer. Finally, a survey crew was deployed the week of July 20, 2015 to obtain culvert inlet/outlet elevations at specific locations along Sawmill and Cat Books. Utilizing different levels of expertise to gather the stream crossing evaluation data resulted in efficient use of resources and budget savings.

4.1.3 Stream Crossing Results

Twenty four (24) culverts were inventoried in June 2015. The majority were open bottom arch construction, and about half of the culverts were observed to have condition issues. The majority of the culvert locations had sediment buildup upstream and about half of the locations also had sediment buildup downstream. Blockages that might impede flow included concrete pipe, detritus, woody vegetation, metal, and beaver dams. Table 4-1 below summarizes the culvert observations and a complete table is provided in Appendix A including survey elevations.

TABLE 4-1
Summary of Culvert Observations

Culvert	Location	Construction and Other Features	Observed Issue
1	Conservation	N/A	Does not exist or was unable to be located
2	School St	Old, dry stone box culvert construction, beaver deceiver	Beavers
3	School St	New, metal open bottom arch construction	None
4	Atwater Ave	Old, metal open bottom arch construction	Upstream erosion and beaver dam
5	Conservation	Metal open bottom arch construction	Rust, upstream scour
6	School St	New concrete round culvert	
7	Forrest Ln	Old, stone open bottom arch construction	Collapsing, upstream backup and sediment buildup, downstream erosion
8	Loading Place Road	New, plastic round culverts (3)	Sediment buildup up and downstream, beaver dam upstream
9	Pine St	Old, metal round culverts (2)	Upstream sediment buildup, downstream clogged with sand
10	Rockwood Heights	Old, concrete and stone embedded round culverts (2)	Up and downstream sediment buildup, downstream clogged with mud
11	Mill St	Concrete open bottom arch construction	Up and downstream sediment buildup
12	Millet Ln	Metal embedded elliptical culvert	Rusty outlet, organic debris, up and downstream sediment buildup, erosion along headwall
13	The Plains	New, metal open bottom arch construction	Up and downstream sediment buildup

TABLE 4-1
Summary of Culvert Observations

Culvert	Location	Construction and Other Features	Observed Issue
14	Old Essex Rd	N/A	Does not exist or was unable to be located
15	Blue Heron Ln	New, concrete open bottom arch construction	Up and downstream sediment buildup, downstream erosion and headwall needs patching
16	Golf Course	Metal bridge with stone abutments	Natural gravel and stone bottom. *
17	Lincoln St	Old, stone open bottom arch construction	Up and downstream bank erosion, downstream sediment buildup
18	Lincoln St	Old, stone open bottom arch construction	Branches blocking outlet
19	School St- Golf	Old, metal open bottom arch construction	Wood debris blocking inlet, sediment buildup and detritus downgradient
20	Summer St	Old, metal open bottom arch construction	Concrete channel
21	Summer St	Old, concrete box culvert construction	Upstream sediment buildup and obstructions
22	Norwood Ave	Old, metal/stone bridge with abutments	Upstream erosion sediment buildup, downstream erosion, metal falling off
23	School St	Old, concrete/stone open bottom arch construction with 2 culverts	Upstream sediment buildup
24	Summer St	Old, concrete/plastic culverts underneath bridge with abutments	Rusted and upstream sediment buildup
25	Central St	Old, stone/concrete open bottom arch construction	Erosion, collapsing support walls, overlay repair
27	Mill St	Old, stone open bottom arch construction	Branches blocking outlet

4.2 Tide Gate/ Culvert/ Seawall Evaluation

The mouth of Sawmill Brook drains through a narrow culvert and tide gate under Central Street, shown below in **Figure 3**. This location was the site of several sawmills and other historic hydro powered industries, documented as early as 1790. The seawall actually serves as the road bed for Central Street, along a Town controlled section of Route 127. The tide gate was added around 1900 to dam the Brook for a fire reservoir and to provide a winter skating pond. Installation of the tide gate resulted in the creation of Central Pond. The tide gate and culvert are currently not functioning properly, creating a hydraulic restriction during storm events and impeding the passage of diadromous fish.

Figure 3: Tide Gate, Seawall, and Culvert Structures at Central Street

On June 11, 2015, the Massachusetts Division of Marine Fisheries (DMF), Tighe & Bond's coastal engineer and other staff, and Town staff completed a site visit together. The purpose of the visit was to discuss concerns about present tide gate fish passage restrictions and related issues prior to completing an in-water tide gate evaluation. A memorandum summarizing the DMF site visit is included in Appendix A. Following the DMF site visit, the Town DPW director authorized the opening of the tide gate to lower the impoundment surface water level and provide full access to observe the tide gate/culvert/seawall structures. Observations by the project coastal engineer of immediate structural safety concerns were summarized in a June 18, 2015 memorandum to the Town DPW director and Town Administrator. A copy of the memorandum and the full tide gate/culvert/dam evaluation and recommended next steps are included in Appendix A.

4.3 Desktop Assessment

Opportunities to reduce runoff, both rate and volume, and to store floodwaters were identified in a two-step process consisting of a desktop evaluation and field work to verify site conditions. The desktop screening was completed using GIS software and numerical ranking of watershed characteristics primarily looking at infiltration ability, environmental constraints, and parcel ownership. Parameters including depth to bedrock, surface topography, soil permeability, depth to bedrock and aquifer transmissivity were ranked to identify and prioritize potential locations for bioretention and infiltration practices. Based on discussions with the Town, only municipally owned parcels were considered for projects, although all types of property ownership were mapped.

Following a comprehensive review of the results of the desktop screening and ranking, site visits were conducted at each potential flood mitigation location to further evaluate feasibility, collect information, and identify other site conditions that would impact implementation including permitting and environmental concerns.

The approach was based on the U.S. Environmental Protection Agency's (EPA's) green infrastructure guidance documents,[1] EPA Region 1's current 2003 and, at the time of the assessment, draft 2014 General Permits for Stormwater Discharges from Small MS4s, discussions with the Town to identify areas of particular concern, and best professional judgment. The desktop screening GIS mapping based process, along with the resulting maps, are provided in Appendix B.

Flood mitigation practices evaluated as part of the desktop assessment included GSI practices that can capture and infiltrate rain where it falls, reducing stormwater runoff and improving the health of surrounding waterways.[2] Due to the large amount of impervious surfaces and poor soils frequently encountered within the Sawmill Brook Watershed, this study focused on practices best suited for urbanized areas including: disconnection, rain harvesting, rain gardens (bioretention), infiltration, street planters, underground storage, and porous/permeable pavement.

In addition to GSI, large areas that could be converted to flood plain or a flood storage areas (e.g. open low-lying land abutting the stream channel or wetlands) were identified. In these locations, traditional flood control structures and above-ground flood detention ponds or swales were considered to control the stream during high flow events.

4.4 Preliminary Site Assessment

Seventeen sites were initially identified after the watershed wide GIS desktop evaluation. Based on results of the desk-top screening, field observations, and further discussion with the Town, sites 1, 4, 5, 6, 7, 8, 9, and 15 have the most opportunity for management of stormwater runoff or flooding within the Sawmill Brook Watershed. Table 4-2 below provides a site description and summary of observations for all 17 sites. The preferred are discussed in more detail in Appendix B.

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[1] http://water.epa.gov/infrastructure/greeninfrastructure/

[2] Center for Neighborhood Technology (CNT) and American Rivers. *The Value of Green Infrastructure*. Available at http://www.cnt.org/repository/gi-values-guide.pdf.

TABLE 4-2
Summary of All Sites Assessed

Site Name	Site Description	Summary of Observations
Site 1: Parking lot abutting Town Fire Station at 12 School Street	Parking lot is heavily used by fitness club located at 6 School Street. Parking lot abuts stream channel and Central Pond.	There may be opportunities to install a LID BMP. Flood mitigation (such as subsurface storage) would be cost prohibitive given subsurface conditions related to bedrock and groundwater.
Site 2: Knight Circle	Narrow residential roadway with private property conflicts within the right of way and no municipally owned land abutting street.	Installation of a LID BMP or flood control on municipally owned property or right of would be challenging given the narrow roadway and extensive private property. It would be feasible to install rain gardens on private property, however, maintenance agreements, deed restrictions, and potentially easements would be needed.
Site 3: Access to Open Space off Friend Street	The access path to the open space/hiking area off Friend Street experiences heavy erosion and causes extensive runoff to be discharged to Friend Street during precipitation events, due to the steep slope that is mostly bedrock.	Given the slope and subsurface conditions, there is limited opportunity to install a LID BMP or flood control device.
Site 4: Municipal Land upstream of School Street Culvert 23	The small parcel upstream of the School Street culvert (23), just to the east of School Street and north of Brook Street, is vegetated but otherwise largely open.	The vegetated cover and elevation of the parcel in relation to the stream likely provides an opportunity to create a small flood storage area abutting the Sawmill Brook stream channel. Further information about historic stone wall construction restrictions is needed.
Site 5: Gravel Parking Lot for Turf Field at intersection of Norwood Avenue and Brook Street	Parking lot for turf field is gravel. Sediment migrates off site to Norwood Avenue during precipitation events.	May be an opportunity to replace gravel with porous asphalt, or repave parking lot and install other LID BMPs.
Site 6: Municipal Land Abutting Stream	Sawmill Brook flows through lightly vegetated (with some large diameter trees) municipal land in the area just upstream of Culvert 22 and downstream of the Elementary and High Schools.	May be an opportunity to create flood storage areas on either side of stream channel based on slope and vegetation.
Site 7: Manchester-Essex Regional High School	Extensive parking and driveway areas on school property.	Although site was recently redeveloped, may be an opportunity to install surface LID BMPs such as bioretention or tree box filters. Need to obtain existing drainage design to confirm presence of existing stormwater BMPs.

TABLE 4-2
Summary of All Sites Assessed

Site Name	Site Description	Summary of Observations
Site 8: Manchester-by-the-Sea Elementary School	Extensive parking and driveway areas on school property. Site also appears to have a rain garden next to tennis courts.	Consider future opportunity to re-pave parking lot and install porous asphalt for parking stalls, tree box filters, and other bioretention cells in parking lot.
Site 9: Golf Course	Sawmill Brook flows through municipally owned land on golf course that is open with limited vegetation.	May be opportunities to create flood storage given extensive open space bordering stream channel.
Site 10: Town Conservation land at the intersection of Forest Street and Summer Street	Site is heavily vegetated with no impervious cover. Unknown where existing drainage system discharges.	Based on lack of impervious cover abutting parcel, slope of roadways, and existing drainage system, limited opportunity to install LID BMPs or flood control devices was observed.
Site 11: Town Land off Forest Street north of Culvert 8	Side is naturally vegetated area north of Forest Street.	Site is north of Forest street and is naturally vegetated with no impervious cover, limited opportunity to install LID BMPs or flood control devices was observed.
Site 12: Town Land off Forest Street downstream of Culvert 11	Land owned by Town downstream of Culvert 11 has natural channel that provides flood storage on banks.	Site is downstream of Culvert 11 and already provides natural flood attenuation, limited opportunity for LID BMPs or flood control was observed.
Site 13: Culvert 4 at the end of Atwater Avenue	This culvert was rebuilt recently and appears to be sized appropriately to allow stream passage.	Would be cost-prohibitive to install flood management structure on upstream side.
Site 14: Town Land north of Culvert 6 (to the east of School Street)	Land owned by Town upstream of Culvert 6 is natural channel that provides flood storage on banks.	Limited opportunity for LID BMP or flood mitigation was observed.
Site 15: Culvert 2 on Old School Street	Roadway is old and has surrounding wetland area has potential to provide flood storage.	May be opportunity to raise elevation of abandoned road and resize culvert including installation of flood control device (e.g. weir) to detain upstream water for flood reduction.
Site 16: Culverts 12,13,15 on The Plains, Millets Lane, and Blue Heron Lane	Three residential areas with two-lane roads and a small municipally-owned parcel located between.	Area is too low gradient and Town land too small for LID BMP or flood control structure to be cost effective. Culvert sizes can be further evaluated during modeling phase.
Site 17: Land Upstream from Culvert 9 off Pine Street	Land includes naturally good wetlands areas with recent stream restoration completed due to excavation project (21e site)	Limited opportunity to install LID BMPs or flood control devices observed due to recently completed stream restoration and contaminated soils (now buried) at the location.

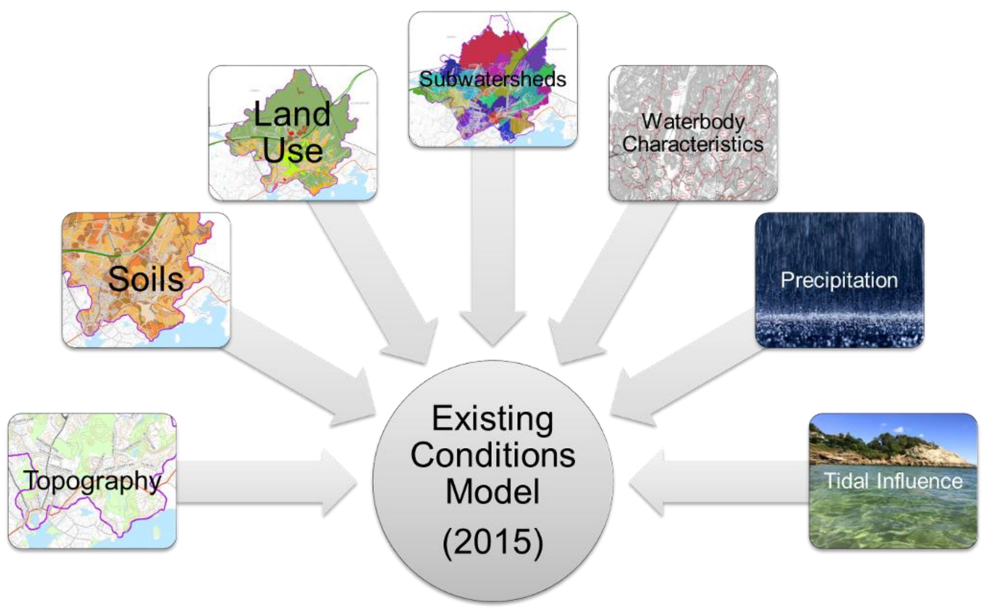
4.5 Watershed Modeling

4.5.1 Methodology

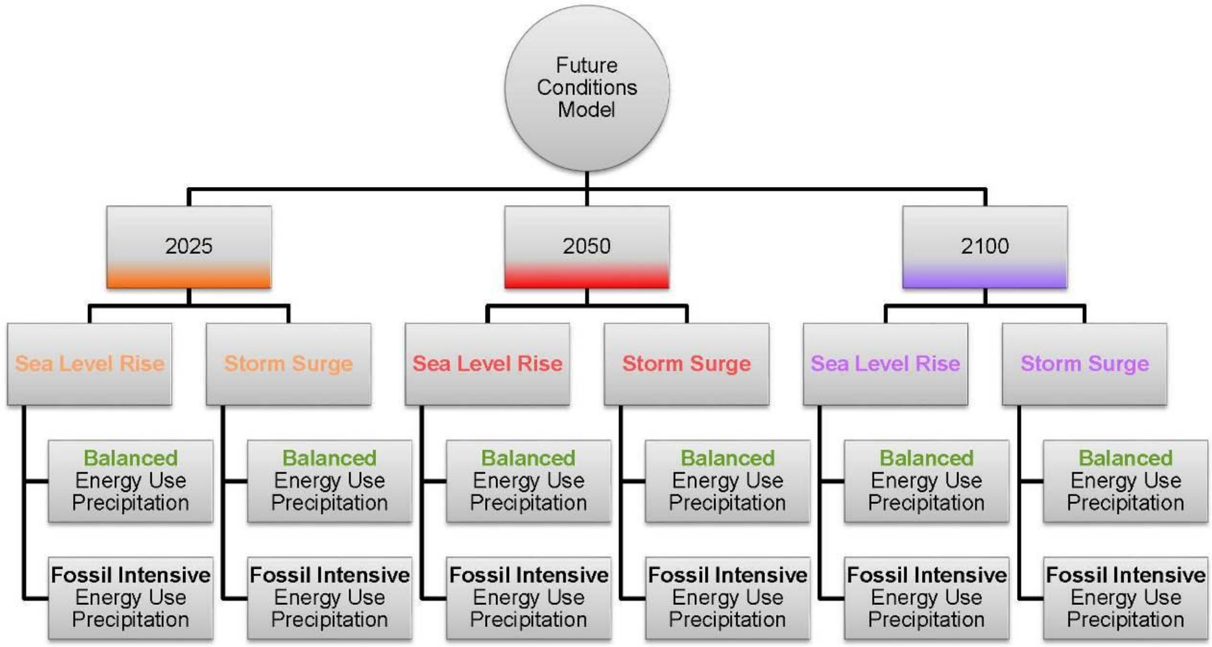
Task 4 included watershed modeling for the Sawmill Brook Watershed. Existing conditions within the Sawmill Brook Watershed were modeled and flooding impacts due to climate change were evaluated including increased levels of precipitation in combination with corresponding projections for sea level rise and storm surge.

The modeling provides the data to evaluate adequacy of culvert sizing within the Sawmill Brook Watershed under climate change conditions and the mitigation value of proposed flood reduction and stormwater best management practices at specific locations, including green stormwater infrastructure, conveyance projects, and flood storage. Additionally, the model will help determine projected flooding impacts upon important community assets identified as part of the Hazard Mitigation Plan enhancement completed under a FEMA Pre-disaster Mitigation Grant.

Existing watershed conditions were modeled with HydroCAD and HEC-HMS (US Army Corps of Engineers, 2015) using information about soils, topography, ground cover (impervious cover and land uses), existing wetlands and waterbodies, water travel times, and existing structures that control discharges (e.g. Central Street tide gate, culverts, etc.). Existing conditions considered rainfall depths developed by the Cornell University Northeast Regional Climate Center and tidal influences using data from Flood Insurance Study for Essex County (July 2014). The existing conditions model was calibrated against the May 2006 "Mother's Day" storm that represent 25-year single day and 100-year consecutive day storm conditions.



Building off the existing conditions model, **future watershed conditions** were predicted considering anticipated impacts from climate change and sea level rise in years 2025, 2050, and 2100. For this model, precipitation estimates in the existing conditions scenario were replaced with estimates of future rainfall depths for 2025, 2050, and 2100 from the *Oyster River Culvert Analysis Project* completed in Durham, New Hampshire. In addition, sea level rise and storm surge was incorporated into the model using data from the Inundation Risk Model (IRM) outputs developed by Keil Schmid (Geoscience, 2015).



Using the future conditions model, the **potential impacts on existing infrastructure** (e.g. tide gate at Central Street, culverts, crossings) from storm surge, sea level rise, and future precipitation conditions in 2025, 2050, and 2100 were identified. The future condition model was also used to evaluate culvert sizes and needed upgrades, and the mitigation value of proposed stormwater best management practices including green stormwater infrastructure, conveyance projects, and flood storage.

4.5.2 Existing Conditions Modeling Results

After calibrating the model, existing conditions were simulated for the 25-year, 50-year, and 100-year storm events. **Figure 4** shows the existing conditions model results, where culvert overtopping may occur. For the 2015 25-year storm, the existing conditions models indicate that 48% of the culverts overtop the roadway. For the 50-year storm, this number increases to 52%, and with a 100-year storm, 59% of culverts overtop.

Comparing the model existing conditions to the historic experience of culvert overtopping gives the reader an idea of where the model may be conservative. The model is consistently predicting the areas of historic flooding from the intersection of Sawmill Brook and Causeway Brook to the outlet at the Harbor, but may be conservative for culverts along Route 128 (culverts 31 and 33) and in the area of Old School Street at the Cedar Swamp, and Conservation Area on Manchester Road There are additional areas outside of Sawmill Brook that flood, so it is important to realize there are limitations of the model extent and accuracy. The model can continue to be refined with additional observed flood elevations and refined stream and drainage topography. It is an excellent screening tool to evaluate the impact of future flood conditions and feasibility of mitigation projects.

Another way of examining the model output is to look at flood profiles created by the HEC-RAS model. The profiles across the Sawmill Brook Watershed are shown in **Figure 5** for existing conditions. The chart shows the graphic output directly from the HEC-RAS model including the elevation profile of the land surface, the water table elevation resulting from a 100 year storm event in 2015, and the location of the 27 culverts that were included in the model. Locations are highlighted for Central Street, School Street, Norwood Avenue, and Lincoln Street where culvert projects are proposed. The Essex County Golf Course and Old School Street are highlighted where flood storage projects are proposed. These mitigation projects are further described in Section 5, Opportunities for Potential Flood Mitigation.

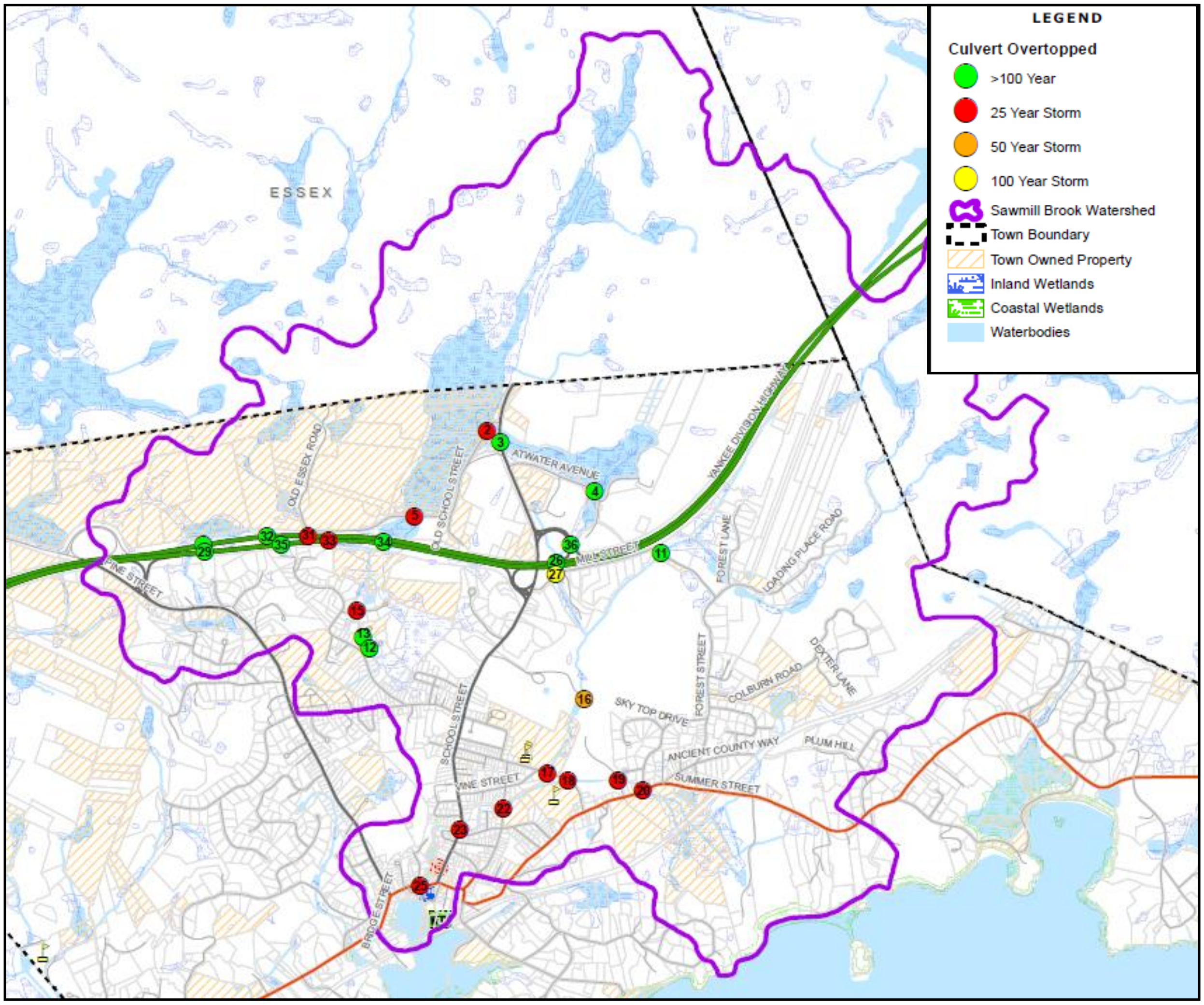
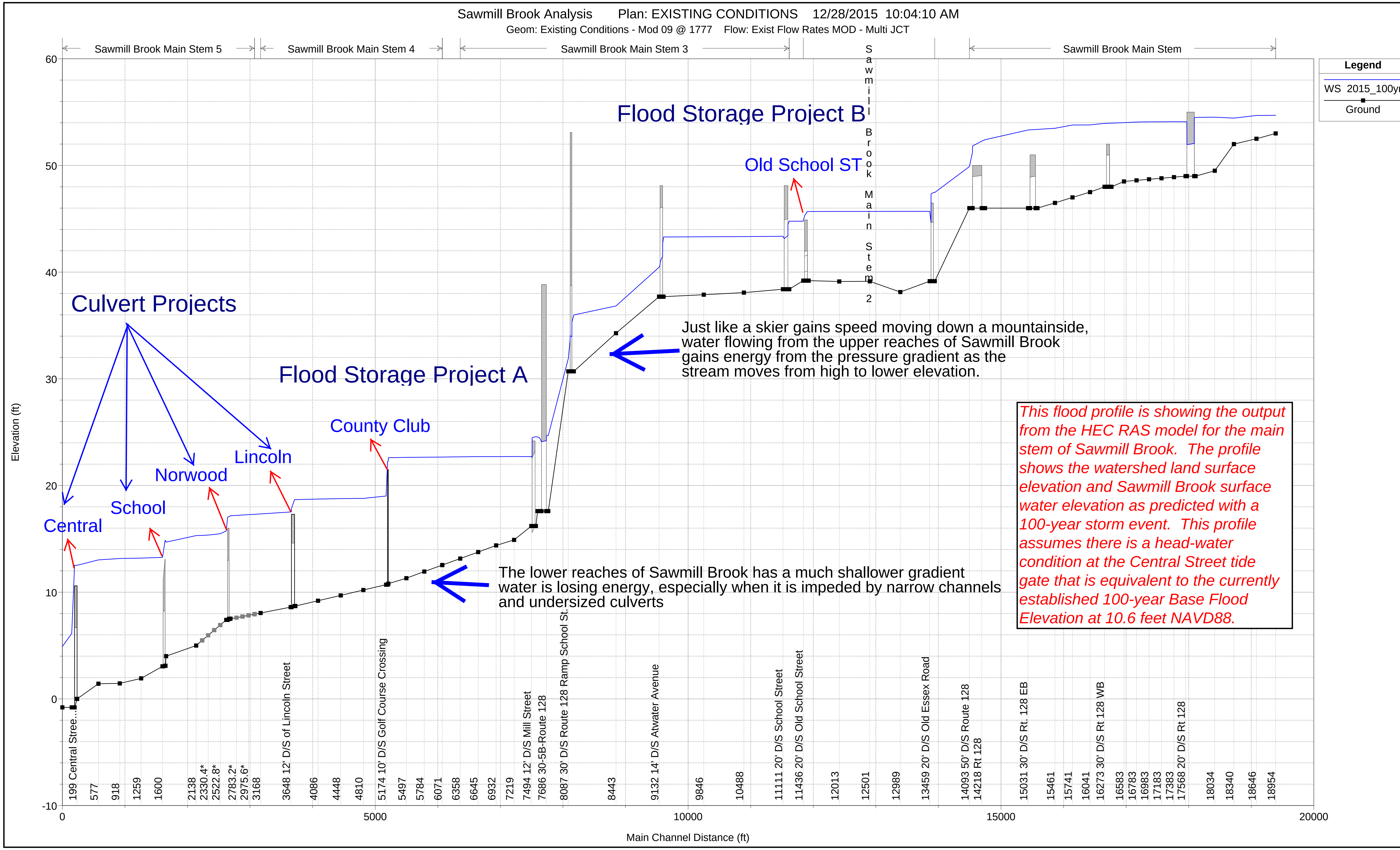


Figure 4: 2015 Storm frequency causing overtopping from existing conditions model

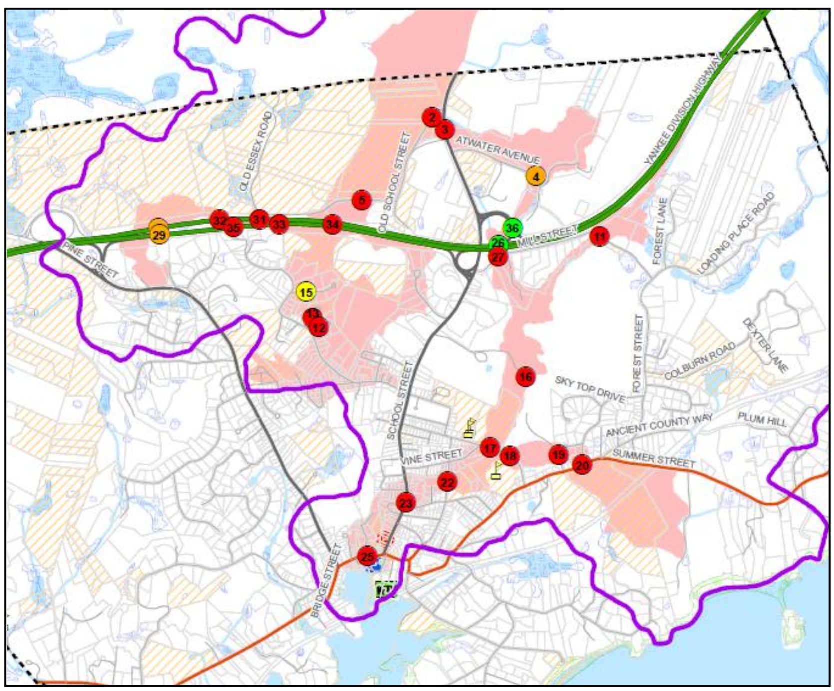
FIGURE 5 FLOOD PROFILE FOR EXISTING CONDITIONS SAWMILL BROOK MAIN STEM 2015 100-YEAR FLOOD



Based on model results, a number of sites were identified as exceeding capacity during flooding, either due to stream bank overflow or culvert overtopping. A map showing these locations is included in Appendix C. These correlate with known locations of flooding, but also include some areas that indicate where the model may be overly conservative based on input data. Appendix C summarizes model results with the flood elevations and discharge at each culvert or stream crossing location for both existing conditions.

4.5.3 Future Conditions Modeling Results

The future conditions HEC-RAS model was used to assess the impact on the culverts and bridges in the watershed based on the 50% probability for both stillwater (annual storm surge) and sea level rise at three different points in the future: years 2025, 2050 and 2100. By year 2100, almost all of the culverts in the watershed will be overtopped for storms more frequent than the 100-year event (see inset below). **Table 4-3** shows where, when and how culverts in the Sawmill Watershed will be impacted with climate change conditions. For example, using the Balanced Energy Use projection, the culvert at Mill Street on Sawmill Brook will overtop under the Balanced Energy Use in the years 2025 and 2050 during a 50-year storm. Under both Balanced and Fossil Intense Energy Use, it will overtop in the year 2100 during a 25-year storm. Overtopping results with sea level rise tailwater conditions alone versus storm surge conditions does have overall lower surface elevations. For project specific applications, the data provided in Appendix C should be referenced.



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Shown above are culverts that will overtop during specific flood events in the year 2100 with a fossil intensive precipitation scenario and storm surge. Culverts shown in red will overtop during a 25 year storm, orange will over top during a 50 year storm, yellow overtops during a 100 year event. Culverts in green will not overtop even with a 100 year storm

Table 4-3
Storm Frequency at which Hydraulic Structures Overtop
Storm Surge or Sea Level Rise

Precipitation Storm Event Frequency	
25-year	red
50-year	orange
100-year	yellow
>100-year	green

Stream	Culvert Crossing Location	Culvert Crossing Number	Balanced Energy Use 2025	Balanced Energy Use 2050	Balanced Energy Use 2100	Fossil Intense Energy Use 2025	Fossil Intense Energy Use 2050	Fossil Intense Energy Use 2100
Sawmill Brook	Central Street	25	25-year	25-year	25-year	25-year	25-year	25-year
	School Street	23	25-year	25-year	25-year	25-year	25-year	25-year
	Norwood Avenue	22	25-year	25-year	25-year	25-year	25-year	25-year
	Lincoln Street	17	25-year	25-year	25-year	25-year	25-year	25-year
	Golf Course Driveway	16	50-year	50-year	25-year	50-year	25-year	25-year
	Mill Street	27	50-year	50-year	25-year	50-year	25-year	25-year
	Route 128	26	>100-year	>100-year	>100-year	>100-year	>100-year	>100-year
	Route 128 Ramp	36	>100-year	>100-year	>100-year	>100-year	>100-year	>100-year
	Atwater Avenue	4	>100-year	>100-year	>100-year	>100-year	100-year	50-year
	School Street	3	>100-year	>100-year	100-year	100-year	100-year	25-year
	Old School Street	2	25-year	25-year	25-year	25-year	25-year	25-year
	Old Essex Road	5	25-year	25-year	25-year	25-year	25-year	25-year
	Route 128	34	100-year	100-year	100-year	50-year	25-year	25-year
	Route 128	31, 33	25-year	25-year	25-year	25-year	25-year	25-year
	Route 128	32, 35	>100-year	100-year	100-year	100-year	50-year	25-year
	Route 128	28, 29	>100-year	>100-year	>100-year	>100-year	>100-year	50-year
Causeway Brook	Lincoln Street	18	25-year	25-year	25-year	25-year	25-year	25-year
	Golf Course Driveway	19	25-year	25-year	25-year	25-year	25-year	25-year
	Summer Street	20	25-year	25-year	25-year	25-year	25-year	25-year
Cat Brook	Mill Street	11	>100-year	>100-year	100-year	100-year	50-year	25-year
Millet Brook	Millet Lane	12	25-year	25-year	25-year	25-year	25-year	25-year
	The Plains	13	>100-year	>100-year	>100-year	>100-year	>100-year	25-year
	Blue Heron Lane	15	>100-year	>100-year	>100-year	>100-year	>100-year	100-year

Section 5 Opportunities for Potential Flood Mitigation

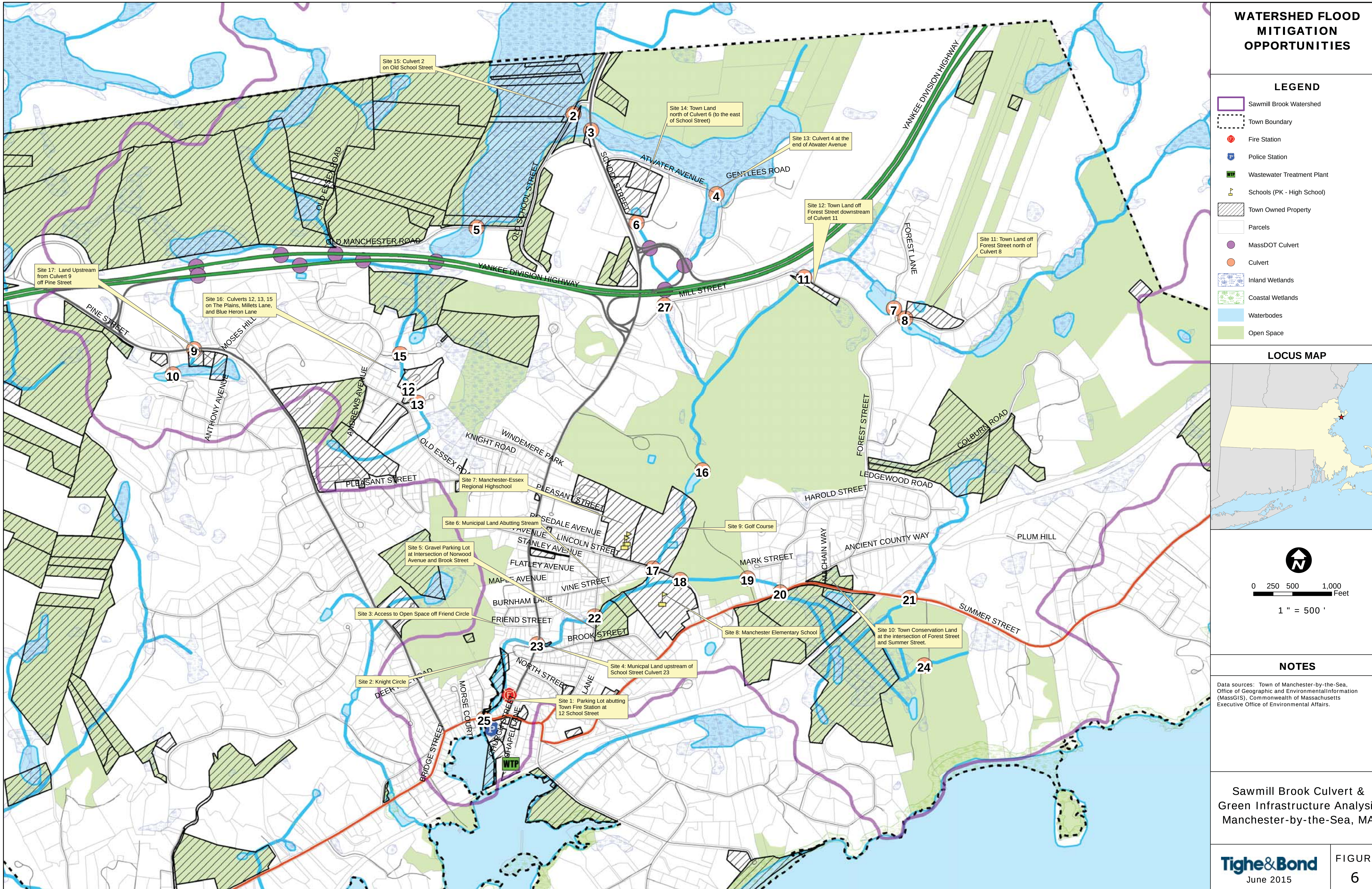
The results of the GIS desktop analysis, field work, and watershed modeling identified a number of opportunities to reduce flooding and increase conveyance of the waterbodies throughout the Sawmill Brook. **Figure 6** indicates the location and the type of potential flood mitigation that were recommended for further consideration. To narrow down this list, the Town primarily relied on the modeling results, where the greatest flood reduction benefits were identified, but other factors influenced the selection of projects. The most common themes that were discussed with the Town and CRAG included:

- Is the proposed location of the practice within a known flood-prone area? Does this area contribute to flooding problems downstream in the watershed?
- Will the project improve wildlife habitat?
- What pollutants will the project remove (e.g. solids, nutrients, etc.)?
- Will the project cultivate educational opportunities?
- Will the project improve aesthetics for the area?
- Will this installation of the practice enhance or preserve existing natural vegetation?
- What is the level of community support for the practice, both community-wide and in the neighborhood?
- Does this project overlap with another planned improvement to a building, parking area, or infrastructure on the site?

5.1 Identification of Potential Projects

Based on a preliminary evaluation of project benefits, further evaluation through modeling completed in Task 4, discussions with Town staff at the October 26, 2015 meeting, and input by the CRAG at the January 13, 2016 meeting, the following nine projects were selected for further evaluation through iterative modeling and a more robust assessment of permitting and regulatory review processes:

1. Removing channel restrictions at Central Street (Option 1) consists of removing the tide gate and keeping the configuration of the culvert, potentially with a rock riffle to keep Central Pond full of water
2. Removing channel restrictions at Central Street (Option 2) consists of removing the tide gate, opening the culvert, removing the dam, and changing the entire crossing to be a bridge, and restoring the historic stream channel
3. Increasing the dimensions of the School Street culvert (23) with modifications to the channel of Sawmill Brook to account for increased culvert sizing
4. Increasing the dimensions of the Norwood Avenue culvert (22) with modifications to the Sawmill Brook channel to account for the increased culvert dimensions
5. Increasing the dimensions of the Lincoln Avenue culvert (17)
6. Flood storage in the Essex County Club Golf Course.
7. Flood storage upstream of Old School Street culvert (2)
8. Development of a hurricane barrier located in Manchester Harbor to manage overtopping from storm surge and hurricanes
9. Installation of a green infrastructure practice, porous pavement, at the Coach Field parking lot



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5.2 Refinement of Potential Projects with Modeling Iterations

The watershed modeling was expanded to look at potential reductions to flooding by relieving channel restrictions at Central Street, providing additional flood storage north of Route 128, managing flooding through culvert rightsizing, and utilizing green infrastructure best management practices at a variety of pre-screened locations. Modeling for the flood mitigation scenarios was based on conditions in the year 2050, assuming precipitation based on a balanced energy use and the 50 year storm event.

Based on the modeling results looking at individual projects, the scenario with resizing the culvert at Central Street has by far the largest improvement in the watercourse's flood carrying capacity.

To achieve optimal flood reduction benefits, a combination of culvert resizing projects and flood storage is desirable. HEC-RAS modeling runs were completed for a series of combined projects as shown below in Table 5-1.

TABLE 5-1
Summary Table of Combined Flood Mitigation Projects

	Modeling Iterations												
Project Elements	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Culvert Improvements													
Central Street	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓
School Street	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓
Norwood	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓
Lincoln						✓	✓	✓	✓				
Channel Improvements													
School –Norwood Widen	✓		✓			✓					✓	✓	✓
School-Norwood Widen and Deepen												✓	✓
Flood Storage													
Essex County Golf Course				✓	✓								
Old School Street		✓	✓		✓	✓		✓					

5.3 Probable Permitting Requirements

Numerous local, state, and federal permits and regulatory review processes will be required to implement the proposed projects as documented in the memorandum titled "Identification and Assessment of Permits Needed for Sawmill Brook Culvert, Flood Mitigation, and Green Infrastructure Projects" included on the enclosed CD. As part of this evaluation, the following regulatory requirements were reviewed for applicability to the proposed projects:

- Massachusetts Wetlands Protection Act Notice of Intent and Stormwater Management Standards
- Massachusetts Environmental Policy Act (MEPA) Environmental Notification Form (ENF) and/or Environmental Impact Report (EIR)
- EPA National Pollutant Discharge Elimination System (NPDES) Construction General Permit
- EPA NPDES Dewatering General Permit
- Massachusetts Department of Transportation (MassDOT) Permits
- Massachusetts Department of Environmental Protection (MassDEP) Section 401 Water Quality Certification
- MGL Chapter 91, The Massachusetts Public Waterfront Act - Waterways License
- United States Army Corps of Engineers (USACE) Massachusetts General Permit Review/Permitting (Section 10/Section 404)
- Massachusetts Historical Commission Project Notification and Review
- Massachusetts Endangered Species Act (MESA) Project Review through the Natural Heritage and Endangered Species Program (NHESP)
- Division of Marine Fisheries Consultation
- Massachusetts Office of Coastal Zone Management Federal Consistency Review
- Local permits (Historical Commission, Planning Board, Street Opening, Trench Permit, tree removal)

Table 5-2 shows the likely applicability of these requirements to each project. Once projects move into final design, permits and review processes need to be further evaluated to confirm requirements based on the preferred design. Obtaining required permits for the proposed flood mitigation projects will be costly, time consuming, and require extensive planning and coordination. One method to reduce the effort is to apply for permits for multiple projects in the same application. For example, the Central Street, School Street, Norwood Avenue, and Lincoln Street culvert improvement projects will all require filing a Notice of Intent with the Manchester-by-the-Sea Conservation Commission and obtaining an Order of Conditions. Along with design, these sites will require wetlands flagging, survey, and other pre-permitting coordination with abutting property owners. Depending on the final schedule and budget for these project, it would reduce costs overall to combine the projects into a single Notice of Intent. Orders of Conditions are valid for up to three years after issuance, therefore, the projects would need to be completed within three years or extended. In addition, as of January 2016, regulatory amendments to 310 CMR 9.00 and 314 CMR 9.00 allow combined review and permitting of projects subject to certain dredging, excavation and fill activities under Chapter 91 and the 401 Water Quality Certification Regulations. There is also a process for combining 310 CMR 9.00 and 314 CMR 9.00. An application for combined Licenses/Permits for Waterways & Water Quality Certification (BRP WW 26) is available on MassDEP's website.[3]

[3] http://www.mass.gov/eea/agencies/massdep/water/regulations/314-cmr-9-00-401-water-quality-certifications.html

TABLE 5-2
Probable Permits

Permit/Review	Central Street Tide Gate and Culvert Improvements – Option 1 Repair	Central Street Tide Gate and Culvert Improvements – Option 2 Replace	Culvert Improvement at School Street	Culvert Improvement at Norwood Avenue	Culvert Improvement at Lincoln Street	Porous Asphalt Parking Area at Coach Field Playground	Flood Storage Improvements at Essex County Club	Old School Street Flood Mitigation	Storm Surge Barrier
Massachusetts Wetlands Protection Act, Regulations, and Stormwater Management Handbook	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Massachusetts Environmental Policy Act (MEPA) Environmental Notification Form and/or Environmental Impact Report	Yes, due to Pond	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
United States Environmental Protection Agency (US EPA) Construction General Permit	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Yes	No	No
US EPA Dewatering General Permit	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	No	Unlikley	Unlikely	No
Massachusetts Department of Transportation (MassDOT) Permits / Reviews	Likely	Yes	Yes	Yes	Yes	No	No	Yes	No
Massachusetts Department of Environmental Protection (MassDEP) 401 Water Quality Certification	Likely	Yes	Yes	Yes	Likely	No	Likely	Likely	Yes
MGL Chapter 91, The Massachusetts Public Waterfront Act - Waterways License	Yes	Yes	Yes	Yes	Likely	No	No	No	Yes
United States of America Army Corps of Engineers (ACOE) Review / Permitting	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Massachusetts Historical Commission (MHC) Determination	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Massachusetts Endangered Species Act (MESA) Project Review through the Natural Heritage and Endangered Species Program (NHESP)	No	No	No	No	No	No	No	Possible	No
Manchester-by-the-Sea, MA Local Permits	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Likely

Section 6 Recommendations

Maintaining a comprehensive watershed approach for flood control that simultaneously considers coastal climate change impacts, inland flooding, water quality, and species habitat is challenging, but ultimately should result in carefully planned projects that will meet multiple goals and perform well for many years to come. To identify and refine potential projects within the Sawmill Brook Watershed, a methodology was followed that included iterative assessment and refinement of projects that can be realistically and cost-effectively implemented. This section summarizes the process that was followed to select and refine green infrastructure and flood mitigation projects, and ultimately prioritize projects for implementation

6.1 Project Prioritization

The process to identify possible projects began with the watershed wide assessment of historic flooding (see Section 3), culvert conditions (see Sections 4.1 and 4.2), the "desktop" evaluation of subsurface conditions and surface conditions (see Section 4.3), and development of a watershed model (see Section 4.5). Out of the many potential culverts, flood storage locations, and green stormwater infrastructure locations, projects with the greatest opportunity for flood mitigation were selected for further evaluation and discussion. Based on further modeling completed in Task 4, identification of probable permitting requirements, discussions with Town staff at the October 26, 2015 meeting, and input by the CRAG at the January 13, 2016 meeting, preliminary designs were developed for the following nine projects:

1. Central St. Tide Gate/Culvert and Sawmill Brook Improvements – Option 1 Repair
2. Central St. Tide Gate/Culvert and Sawmill Brook Improvements – Option 2 Replace
3. Culvert Improvement at School St.
4. Culvert Improvement at Norwood Ave.
5. Culvert Improvement at Lincoln St.
6. Porous Asphalt Parking Area at Coach Field Playground
7. Flood Storage Improvements at Essex County Club
8. Old School St. Flood Mitigation
9. Storm Surge Barrier

The project conceptual design summary sheets are provided in Appendix D. These projects are described in detail in Section 6.2.

These nine conceptual designs were further reviewed to help prioritize which projects to choose for developing the three planning level designs. As part of developing the opinion of probable cost for each conceptual design, impacts to existing utilities and infrastructure, erosion and sediment control requirements, traffic control, permitting needs, and general constructability were considered and included in the estimates. To further examine the project benefits and costs, a pairwise comparison was used. The pairwise comparison is a multi-step process that consists of:

1. Selecting ranking criteria (e.g. health and safety, flood mitigation, utility conflicts, permitting needs, habitat impacts, operation and maintenance needs, etc.);
2. Ranking each criteria against one another using a matrix;
3. Assigning rankings to each project; and
4. Comparing the final pro/con ranking to the project cost.

Table 6-1 presents the screening criteria that were selected for the Manchester-by-the-Sea flood control projects.

TABLE 6-1
Selected Screening Criteria for Pairwise Comparison

Screening Criteria	Definition of Criteria - Ability of Alternative to…	Scoring Criteria (1 worst through 5 best)
Flood Mitigation / Health & Safety	…reduce potential for flooding that causes health and safety issues	5 = Maximum flood reduction benefit 3 = Moderate flood reduction benefit 1 = No flood reduction benefit
Coordination with Other Town Project	…coordinate with a planned water, sewer, drainage, or paving project.	5 = Other project budgeted within project area 3 = Other project planned in project area 1 = No projects planned or discussed in project area
Habitat Improvement	…protect or preserve rainbow smelt or other habitat.	5 = Maximum habitat benefit (i.e. total area and benefit)
Additional Community Benefit	…show the public the benefits of ongoing flood management, including visibility and education, provide trails and accessibility to water.	5 = Obvious and tangible social impact (visibility, education and recreation)
Water Quality Improvement	…improve water quality.	5 = Maximum water quality improvement 3 = Moderate water quality improvement 1 = No water quality improvement
Permitting Difficulty	…requires the least difficult permitting	5 = Project will require the least amount of and lease difficult permitting 1 = Project will require the most amount of and most difficult permitting
Long-term Maintenance	…requires the least long-term maintenance effort and cost	5 = Project will reduce annual operations and maintenance

The next step in the pair-wise comparison was to determine the relative importance of each screening criteria that results in a normalized weighting factor. Table 6-2 shows the weighting factors for the seven screening criteria against one another. The normalized percentage shows that flood mitigation/ health and safety were identified as the most important criteria, followed by habitat and water quality improvements. The factor that had the least importance in the screening criteria was long-term maintenance.

TABLE 6-2
Development of the Weighting Factor for Screening Criteria

Pair-Wise Comparison	Flood Mitigation / Health & Safety	Coordination with Other Town Project	Habitat Improvement	Additional Community Benefit	Water Quality Improvement	Permitting Difficulty	Long-term Maintenance	Sum	Weighting Factor	Normalized (%)
Flood Mitigation / Health & Safety		5	4	6	4	6	6	31	0.21	21.1%
Coordination with Other Town Project	2		1	4	2	3	5	17	0.12	11.6%
Habitat Improvement	3	6		6	3.5	6	6	30.5	0.21	20.7%
Additional Community Benefit	1	3	1		2	3	5	15	0.10	10.2%
Water Quality Improvement	3	5	3.5	5		6	6	28.5	0.19	19.4%
Permitting Difficulty	1	4	1	4	1		3.5	14.5	0.10	9.9%
Long-term Maintenance	1	2	1	2	1	3.5		10.5	0.07	7.1%
								147	1.00	100.0%

Each of the nine conceptual projects was then assigned a "score" for each screening criteria listed in Table 6-1. A value of 5 is best and 1 is worst. These scores combine with the weighting factors from Table 6-2 to inform an overall weighted score and rank as shown in Table 6-3. Based on the weighted evaluation, the Tide Gate Option 1 and 2 had the highest rating overall, followed by School Street culvert, Norwood Avenue culvert, and Coach Field Parking Lot. Table 6-4 presents the final ranked order of the projects along with the Opinion of Probable Costs.

TABLE 6-3
Weighted Evaluation of Conceptual Projects

PROJECT:		Lincoln Street Culvert	School Street Culvert	Coach Field Parking Lot	Norwood Avenue Culvert	Central Street Tide Gate (#1)	Central Street Tide Gate (#2)	Golf Course	Old School Street	Hurricane Barrier
Screening Criteria	Weight	Score	Score	Score	Score	Score	Score	Score	Score	Score
Flood Mitigation / Health & Safety	21.1%	4	4	1	3	4	5	1	2	4
Coordination with Other Town Project	11.6%	1	5	3	1	5	5	1	1	1
Habitat Improvement	20.7%	4	4	1	4	5	5	1	1	1
Additional Community Benefit	10.2%	3	4	5	3	5	5	4	1	5
Water Quality Improvement	19.4%	4	4	4	2	5	5	1	1	1
Permitting Difficulty	9.9%	3	3	5	3	2	2	3	3	1
Long-term Maintenance	7.1%	1	1	5	1	3	3	2	1	5
Weighted Score		**3.24**	**3.80**	**2.90**	**2.64**	**4.35**	**4.56**	**1.57**	**1.41**	**2.33**
Rank		**4**	**3**	**5**	**6**	**2**	**1**	**8**	**9**	**7**

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TABLE 6-4 **Final Ranking and Opinion of Probably Cost for Conceptual Projects**		
Project	**Ranking**	**Opinion of Probable Cost**
Central Street Tide Gate (Option #2)	1	$ 1,910,000
Central Street Tide Gate (Option #1)	2	$ 860,000
School Street Culvert	3	$ 1,040,000
Norwood Avenue Culvert	4	$ 910,000
Coach Field Parking Lot	5	$ 430,000
Lincoln Street Culvert	6	$ 400,000
Hurricane Barrier	7	$ 26,000,000
Golf Course	8	$ 1,180,000
Old School Street	9	$ 220,000

The pairwise comparison was used to help systematically rank the nine conceptual designs using criteria that were deemed the most important to the town. Based on the results, three projects were chosen to advance to planning level design including:

- Central Street Culvert and Sawmill Brook Restoration (Option #2);
- School Street Culvert and Channel Improvements; and
- Norwood Avenue Culvert and Channel Improvements.

These three projects are described in detail in Section 6.3, including the planning level drawings. The projects all have the benefits of improving hydraulic capacity, reducing upstream flooding, restoring habitat, and improving water quality and aesthetics. Costs range from $910,000 for the Norwood Avenue project, to $1,910,000 for the Central Street Culvert and Pond Restoration. The projects were presented at the February 2016 public forum in Manchester-by-the-Sea for public comment. Replacement of the parking lot at Coach Field was not advanced to a planning design level, but was highly recommend by Town staff as a desirable project to complete. This project has the fewest permitting requirements and lowest cost. It did not rank higher due to the comparatively low flood mitigation benefits.

6.2 Preliminary Designs

Preliminary designs were prepared for the following nine projects:

1. Removing channel restrictions at Central Street (Option 1) consists of removing the tide gate and keeping the configuration of the culvert, potentially with a rock riffle to keep Central Pond full of water
2. Removing channel restrictions at Central Street (Option 2) consist of removing the tide gate, opening the culvert, removing the dam, and changing the entire crossing to be a bridge, and restoring the historic stream channel
3. Increasing the dimensions of the School Street culvert (23) with modifications to the channel of Sawmill Brook to account for increased culvert sizing
4. Increasing the dimensions of the Norwood Avenue culvert (22) with modifications to the Sawmill Brook channel to account for the increased culvert dimensions
5. Increasing the dimensions of the Lincoln Avenue culvert (17)
6. Flood storage in the Essex County Club Golf Course
7. Flood storage upstream of Old School Street culvert (2)
8. Development of a hurricane barrier located in Manchester Harbor to manage overtopping from storm surge and hurricanes
9. Installation of a green infrastructure practice, porous pavement, at the Coach Field parking lot

Removing Channel Restrictions at Central Street & Installation of a Hurricane Barrier

- When only sea level rise is taken into account, the Central Street improvements have the largest impact on reducing water surface elevations upstream. Due to the locations of a business on the east bank of the river, and the roadway on the west bank, any widening of the stream would be difficult, but eliminating the tide gate would result in reductions in water surface elevation. Culvert enlargements would also result in significant reductions in water surface elevation upstream, and would restore the stream crossing to historic conditions. Both improvement alternatives will improve smelt passage and spawning potential.
- Under worst case future storm conditions, even with modifications to the Central Street Bridge, the roadway would still overtop because the surge elevation exceeds the roadway centerline elevation for 2050 and beyond. This may be addressed with use of a hurricane barrier or raising the elevation of Central Street. A hurricane barrier might be located at the mouth of Manchester Harbor.

Removing Channel Restrictions at Culverts

- Improving conveyance of Sawmill Brook in the "downtown" area of Manchester (i.e. culverts at School Street, Norwood Avenue, and Lincoln Street) will reduce the overall watershed flooding.

Increasing Flood Storage at the Golf Course

- The golf course is located at approximately the halfway point in the watershed, includes some areas of Town-owned land, and has a large area for flood management before Sawmill Brook flows into Manchester's downtown area. These reasons make the golf course an excellent candidate for managing floodwaters with limited impacts to abutters.

Improving Flood Storage upstream of Old School Street

- Increasing the storage upstream of Old School Street (north of Route 128) reduces the flow rate for the stretch of stream channel between School Street and the confluence of Causeway Brook at Lincoln Street for large storm events. Most improvement would be between School Street and Mill Street. Further downstream, flows from other areas in the watershed combine, increasing flow in the watershed, so the contribution of the storage decreases until it disappears by the time the brook meets Causeway Brook.

Installation of Green Infrastructure at the Coach Field Playground Parking Area

- The Coach Field Playground parking area was identified as a priority over the Elementary School parking area due to proximity to Sawmill Brook and planned improvements at the Elementary School. While installation of porous pavement at the Coach Field Playground parking area does not reduce flood elevations in Sawmill Brook, it does have an excellent opportunity to improve water quality and result in localized reductions in discharge from the parking lot. This is also an excellent location for public education.

Summary sheets for each planning level design are included in Appendix D.

6.3 Planning Level Designs

Central Street Culvert and Sawmill Brook Restoration

<u>Project Need</u>

The Central Street tide gate, dam, and related structures are in need of modification to provide better functionality with respect to drainage and fish passage (**Figure 7**). The tide gate and culvert at Central Street impedes drainage from Sawmill Brook, especially during coastal storm events, resulting in localized flooding. The tide gate structure also overtops on spring high tides and storm surge tides. Discussions with the Massachusetts Division of Marine Fisheries indicate a preference to remove or modify the tide gate to improve fish passage conditions for rainbow smelt.

Figure 7: Sawmill Brook Culvert at Central Street, looking south

The Sawmill Brook culvert under Central Street was observed on June 11, 2015 as part of an in-water walk-through to view existing conditions of the seawall, tide gate structure, culvert, and stream bed/weirs. The inspection report noted corrosion/erosion on the tide gate tracts and safety concerns due to the separation and settlement of culvert arch stones. Significant seepage was observed from the stone dam/sidewall supporting the south side of Central Street, particularly when the tide gate was closed. The seepage can cause a loss of soils under the street. Repairs made to the wall using pneumatically applied concrete and non-shrink grout repointing have failed, particularly in the tidal zone.

The current design of the bottom opening tide gate impedes fish passage. The gate is typically set with a partial opening, which is not conducive for rainbow smelt migration due to the head pressure and high velocity of water exiting the gate. Even when the tide gate is fully open, smelt encounter two more weirs inside the stone arch culverts. Since smelt are not able to jump up weirs, the tide needs to rise to at least 2/3 of mean high tide to allow smelt to swim upstream.

Results from the HEC-RAS watershed modeling demonstrates that removal of the tide gate results in significant upstream reduction in water levels. During an extreme storm event, Sawmill Brook would be lowered as much as 3 feet at Central Street by eliminating the hydraulic barrier at the tide gate.

Planning Level Design

Figure 8: Graphic rendering of Central Street Culvert

The planning level design includes removing the existing tide gate and replacing the existing stone arch culvert with a concrete box culvert at the full stream width of the existing stream channel. Restoration of Central Pond from an open water area to a stream channel and tidally influenced wetland system is included as part of the design. This may include sediment and organic debris removal, wetland plantings, stream bank stabilization and adding a rock riffle within the stream channel to improve aeration. Repairing and restoring the existing seawall including the guard rail is also part of the project (road widening is not included in project costs). This project should be coordinated with intersection and street improvements, including widening Central Street to improve sidewalks, parking, travel lanes, and crosswalks.

Project Benefit

Removal of the tide gate and enlargement of the culvert will improve fish passage and increase the hydraulic capacity of Sawmill Brook reducing upstream flooding. Removing the tide gate will also limit the hydraulic pressure behind the seawall and reduce safety concerns (**Figure 8**). Restoration of the seawall and guard rail will improve traffic safety. Stream restoration will improve habitat and aesthetics in the downtown area. The public location is also ideal for educational signage about Sawmill Brook's natural history.

Project plans for the Central Street Tide Gate Culvert and Central Pond improvements are provided in Appendix E.

School Street Culvert and Channel Improvements

Project Need

Figure 9: Sawmill Brook Culvert at School Street, looking south

The culvert under School Street is one of many hydraulic restrictions along Sawmill Brook. This culvert is currently undersized and creates a flow impediment, resulting in maintenance concerns and safety hazards under flood conditions. Drainage in Sawmill Brook is also impeded by the undersized culvert combined with the low-gradient stream (Figure 9).

Tighe & Bond modeled existing and future conditions within the Sawmill Brook Watershed based on anticipated climate change scenarios that considered impacts of increased precipitation, sea level rise, and storm surge in 2025, 2050, and 2100. This culvert was re-sized to accommodate the 50 year storm for the year 2050 under balanced energy use precipitation scenario and sea level rise.

Planning Level Design

- Remove existing School Street culvert and replace with 6.6 foot tall by 16 foot wide box culvert
- Emulate historic stone work in replacement facing
- Shore stone wall under existing building

- Full-depth roadway reconstruction including guardrail replacement
- Widen and lower limited segments of Sawmill Brook. At School Street, lower stream channel by approximately 1.2 feet. Downstream of School Street, widen by approximately 4 feet until Central Pond. Upstream of School Street to Norwood Avenue, widen by approximately 4 to 8 feet depending on location and conflicts with private property.
- Project should be coordinated with intersection and street improvements, including widening School Street to accommodate a full width sidewalk along the east side of the road, from Brook Street to the existing sidewalk north of the culvert on School Street, and adding a crosswalk to Brook Street.

<u>Project Impact</u>

Enlargement of the School Street culvert and limited widening of Sawmill Brook stream channel will improve hydraulic capacity of the stream channel and limit backwater flooding to alleviate flooding of private properties adjacent to Sawmill Brook. Improvements to stormwater drainage will also benefit water quality. Sediment removal and stabilization of the streambank as part of the stream widening will improve rainbow smelt habitat.

Based on the HEC-RAS modeling completed, increasing the size of this culvert along with widening and lowering of limited segments of Sawmill Brook, along with improving the downstream Central Street Culvert and upstream Norwood Avenue culvert, will decrease water surface elevations in flood conditions by approximately 5% upstream of School Street and approximately 13% downstream of School Street. Without making channel improvements, the downstream water surface elevations will only be reduced by approximately 8%. In addition, some channel improvements are necessary for culvert widening.

Project plans for the School Street culvert and stream improvements are provided in Appendix E.

Norwood Avenue Culvert and Channel Improvements

<u>Project Need</u>

The culvert under Norwood Avenue is one of many hydraulic restrictions within Sawmill Brook. This culvert is made of metal girders and stone bridge abutments. This culvert is currently undersized and creates a flow impediment, resulting in maintenance concerns and safety hazards under flood conditions. The location of adjacent properties immediately abutting the stream channel presents additional concerns with flooding (**Figure 10**).

Figure 10: Private property abutting Sawmill Brook at Norwood Avenue culvert

<u>Planning Level Design</u>

- Remove existing Norwood Avenue culvert and replace with 7’ tall by 20’ wide box culvert
- Widen Sawmill Brook stream channel downstream of Norwood Avenue by approximately 4 to 8 feet depending on location and conflicts with private property.
- Lower Sawmill Brook channel by approximately 3.1 feet at Norwood Avenue Culvert
- Full-depth roadway reconstruction including guardrail replacement

Project Impact

Enlargement of the Norwood Avenue culvert and limited widening of Sawmill Brook stream channel will improve hydraulic capacity of the stream channel and limit backwater flooding to alleviate flooding of private properties and municipal facilities adjacent to Sawmill Brook.

Based on the HEC-RAS modeling completed, increasing the size of this culvert along with widening and lowering of limited segments of Sawmill Brook, along with improving the downstream School Street and Central Street culverts, will decrease water surface elevations in flood conditions by approximately 6% downstream before School Street and approximately 13% downstream of School Street. In addition, some channel improvements are necessary for culvert widening.

Project plans for the Norwood Avenue culvert and stream improvements are provided in Appendix E.

Section 7 Conclusions

7.1 Next Steps

7.1.1 Permitting Considerations

Obtaining required permits for the proposed flood mitigation projects will be costly, time consuming, and require extensive planning and coordination. A detailed discussion of the permitting process is provided in Section 5.3 of the final report. One method to reduce the effort is to apply for permits for multiple projects in the same application. For example, the Central Street, School Street, Norwood Avenue, and Lincoln Street culvert improvement projects will all require filing a Notice of Intent with the Manchester-by-the-Sea Conservation Commission and obtaining an Order of Conditions. Along with design, these sites will require wetlands flagging, survey, and other pre-permitting coordination with state and federal agencies, abutting property owners and other Town departments. Depending on the final schedule and budget for these projects, it would reduce costs overall to combine the projects into a single Notice of Intent. Orders of Conditions are valid for up to three years after issuance, therefore, the projects would need to be completed within three years or extended.

7.1.2 Coordination with Town Projects

The three planning level projects tie in with ongoing Town Projects. The Central Street Culvert project should be coordinated with Central Street intersection and street improvements, including widening Central Street to improve sidewalks, parking, travel lanes, and crosswalks. The School Street and Lincoln Avenue projects should be coordinated with stormwater and sidewalk improvements.

7.1.3 Grant Opportunities

Now that much of groundwork has been completed with baseline analysis, project selection, and preliminary design, Manchester-by-the-Sea is in an excellent position to apply for additional funding opportunities. The projects have been closely coordinated with State and Federal agencies and environmental groups including Massachusetts DMF, MEMA, CZM, and Salem Sound Coastwatch. With this support as a basis, the Town should begin pursing implementation grants from agencies including EPA, NOAA, CZM MassDOT, US Army Corps of Engineers, Massachusetts Environmental Trust, and others.

Specific grant opportunities that would help complete the studies, final design, permitting and construction for the three planning level designs include:

- CZM- Coastal Resiliency Grant Program
- CZM- Coastal Pollution Remediation Grant Program
- FEMA- Hazard Mitigation and Pre-disaster Mitigation Grant Programs
- MA Division of Marine Fisheries- Technical Assistance Grant
- NOAA- Habitat Restoration Grants
- DCR- Parks and Recreation Grant
- MA EEA, Section 319 Grant
- MA EEA Dam Removal and Coastal Foreshore Protection Funding

In addition to the three planning level design projects, the Town should consider applying for a grant for low impact development (LID) projects identified for downtown improvements and a grant to help provide matching costs for residential low impact development projects such as raingardens. CZM's Coastal Pollution Remediation Grant Program would be a good match for these projects.

7.2 Lessons Learned

7.2.1 Climate Change Modeling

- **Expectations**

  Successful completion of the CZM grant tasks was made possible in part due to the availability of data generated from climate change models that were more advanced compared to previously available information such as FEMA flood mapping and the Town evaluation of potential expansion of the FEMA 100 year flood zone due to sea level rise (Tighe & Bond, December 4, 2014).

  The CZM grant scope relied on utilizing the climate change models that were selected as part of ongoing hazard mitigation planning under a FEMA Pre-disaster Mitigation Grant. This was accomplished by using future rainfall estimates from the *Oyster River Culvert Analysis Project* and sea level rise and storm surge data from the Inundation Risk Model (IRM) outputs developed by Keil Schmid (Geoscience, 2015). The models are summarized in Section 4.5 of this final report. Model results for three planning horizons-2025, 2050, and 2100 were obtained for the purpose of informing risk and adaptation plans. The 2025 time frame was intended to identify high priority needs that could be accomplished near term. The 2050 time frame was used to define design criteria for infrastructure projects with a 30 year design life such as stormwater infrastructure, culverts, drainage projects, etc. Looking at flooding scenarios for 2100 provides a snapshot of future "worst case" conditions. This will be helpful for long term planning for expensive capital improvements, such as building relocations, hurricane barriers, etc.

- **Challenges**

  Combining the HEC-RAS modeling and IRM outputs provided to be more difficult than anticipated. The HEC-RAS model requires elevation inputs to account for the sea level rise and storm surge at the mouth of the watershed, and the IRM model output was presented in probabilities. Therefore the IRM data had to be extrapolated from risk to elevation, which resulted in more modeling iterations and discussions with the model developer than expected. Combining the two was an improvement over the first order approximation of food zone expansion previously completed, but will need to be revisited over time as climate science improves.

7.2.2 Watershed Model

- **Expectations**

  Metcalf and Eddy had previously developed a hydrologic model of the Sawmill Brook Watershed using EPA's Stormwater Management Model (SWMM), as documented in the report titled "Hydrologic Study Millets Brook and Sawmill Brook Watersheds" (February 2008). Originally, we intended to utilize and enhance this model with climate change variables (increased precipitation, sea level rise, and coastal surge).

- **Challenges**

  As the project moved into the modeling phase, the Town staff and consulting engineer came to a mutual agreement to change from using the EPA model SWMM to US Army Corps of Engineers model HEC-RAS. There are several similarities and differences between the two. Both models are public domain and both incorporate culvert and channel dimension and either is capable of evaluating variable flow conditions in Sawmill Brook. HEC-RAS is a riverine hydraulics model, intended for flood plain studies and floodway encroachment evaluations. SWMM is a rainfall-runoff and water quality simulator primarily intended for use with urban stormwater drainage systems with lots of continuous closed pipes. SWMM cannot properly analyze open channel flows around inline and lateral structures such as dams, bridges, gates, etc. HEC-RAS is more labor intensive to use, and modeling hydraulics and hydrology are two separate components of the model. HEC-RAS allows for a better understanding of riverine hydraulics, including more robust culvert modeling routines, and also allows for unsteady flow analysis to determine the water surface elevation at a particular moment in time along the watercourse in addition to the resultant maximum water surface elevation for the storm. HEC-RAS is typically more user-friendly than SWMM, and provides users an easier method to analyze of multiple scenarios and potential channel/culvert improvements.

The output of HEC-RAS is largely numerical, with a few graphics within the program itself, and therefore there was substantial work to translate the results into maps and summary tables that reflected the results.

7.2.3 Mitigation Planning

- **Expectations**

  The grant scope assumed over 15 locations to mitigate flooding in the form of GSI and flood storage would be identified. In addition, the grant scope assumed there would be numerous culverts that required rightsizing to reduce watershed flooding.

- **Challenges & Successes**

  Because of limitations due to property ownership, protected open space constraints, impervious cover locations, and sub-surface conditions, far fewer opportunities to install flood storage and GSI were found than anticipated. In addition, based on the modeling iterations, less culverts were identified as needing "rightsizing" than expected. Enlarging culverts in the upstream watershed often assisted with localized flooding but increased downstream flooding. Overall, fewer alternatives were available to select from as part of the prioritization process. However, because it was quicker to arrive at priority projects given there were fewer to select from, and the design processes moved faster than expected.

7.2.4 Public Outreach

- **Expectations**

  Outreach events including Town, CRAG, and Public Forums were planned to overlap with FEMA grant to save time for participants and budget for town. Multiple media sources were planned for use to reach a wide audience.

- **Challenges & Successes**

  - Website: The Grants Administrator created and maintained a website featuring the Sawmill Brook Culvert and Green Infrastructure Analysis project including project overviews, maps, survey results, and task deliverables.

  - Public surveys: The first survey on known locations of flooding had less than optimum return rate, but the quality of information was excellent. This online survey was supplemented with in person survey at the public forum. The second survey on climate change awareness had a better return rate, likely due to exposure of the project through Cricket article series and more residents being aware of the project over the prior 18 months.

  - Meetings: A total of 13 meetings were held for this project and involved Town Staff, the Coastal Resiliency Advisory Group, and town residents and businesses at the Public Forums. Extensive material was reviewed at each meeting. Information was conveyed through uploads to the project website, handouts, poster boards, and PowerPoint slide presentations. The graphic presentations were important to convey the material, and preparation took more budget than planned. The staff and CRAG were very invested in the project and took the time to provide thoughtful comments, questions and respond to requests for assistance.

  - Volunteer Opportunities: Volunteers from the community including the Manchester Coastal Stream Team, Manchester Essex Regional High School Green Team, and others participated in several events including a day long culvert field study, and interactive sessions at the public forums. Coordination of volunteers was challenging, and results of data inventory needed to be reviewed and vetted to understand minor differences in data collection between individuals.

  - Media: Multiple methods of media were used to educate the Town residents, including a series of press releases and articles, website content, direct distribution (with town meeting warrant hand delivered), and cable TV broadcast of the forums. The website and articles in the Cricket local paper were the most effective sources for outreach reaching the greatest number of Manchester residents, however, word of mouth was also effective though not quantifiable.

7.3 Transferability

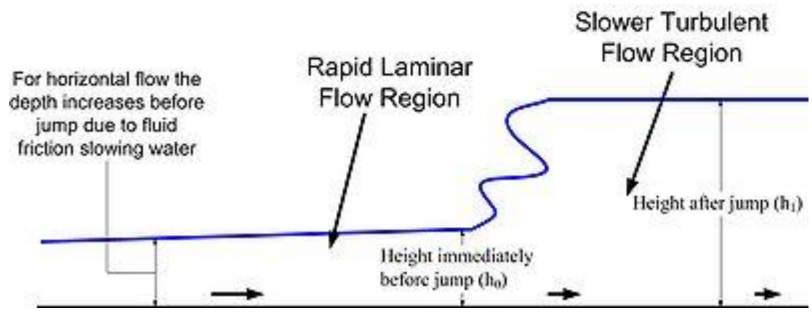
There are multiple aspects of this grant project that have been and will be of great interest to other coastal communities experiencing similar inland and coastal flooding issues. The Town has already participated in a number of community resilience workshops, highlighting the accomplishments of the CZM FY15 grant including two Coastal Resiliency workshops in Peabody and Plymouth (11/15 and 5/16), a Salem Sound Coastwatch Anniversary Symposium (3/15) and a NH Environmental Business Community Workshop in Greenland, NH (3/16). The unique approach to addressing flood mitigation with a watershed approach and lessons learned were highlighted in the presentations. Areas that stood out as interesting and unique examples included the modeling strategies to achieve results for both inland and coastal flooding with climate change, tools used to support the project, and methodologies for optimization of feasible projects, and the use of a multi-faceted stakeholder advisory group to oversee multiple grants. Specifically, the following components of the project are transferrable to other communities:

- The methods and results of the *Oyster River Culvert Analysis Project a*re transferrable to communities throughout Massachusetts that have an interest in evaluating their watershed connectivity and culverts.
- The IRM model outputs can be utilized by communities within Salem Sound.
- Written Procedures for the Culvert Observations, Desktop BMP Evaluation, and Pair Wise Comparison.
- The templates developed for Mitigation Project conceptual designs can be followed by others and is a good tool to educate the public and decision makers as it highlights the important decision making process.
- The final Presentation PowerPoint slides are a simplified project summary suitable for a wide range of audiences and presenters.
- The Final Report is posted on the Town project website, which allows other interested parties to following the procedures, methods, and approach used in this grant project.

Glossary of Terms

GIS: acronym for Geographic Information Systems; a system designed to store, analyze, manage, and present all types of geographical data

Hydraulic Jump is a phenomenon in the science of hydraulics which is frequently observed in open channel flow such as rivers and spillways. When water at high velocity discharges into a zone of lower velocity water, a rather abrupt rise occurs in the water surface. The rapidly flowing water is abruptly slowed and increases in height, converting some of the flow's initial kinetic energy into an increase in potential energy, with some energy irreversibly lost through turbulence to heat. In open channel flow, this manifests as the fast flow rapidly slowing and piling up on top of itself similar to how a shockwave forms. The following figure illustrates the behavior in a hydraulic jump.



A hydraulic jump is a region of rapidly varied flow and is formed in a channel when a **supercritical flow** transitions into a **subcritical flow**. In general, supercritical flows are shallow and fast and subcritical flows are deep and slow.[1]

Hydrologic Soil Group is a designation by the Natural Resource Conservation Service (NRCS). The NRCS publishes a soil survey for most counties in the United States that classifies the soils into one of four hydrologic soil groups based upon how quickly the soil drains. Soils classified as "A" are the fastest draining (and have the smallest runoff potential) and soils classified as "D" are the slowest draining (and have the greatest runoff potential).

Hydrograph is a graph that shows the relationship of flow vs. time for a particular location within the watershed.

Hyetograph: A plot of cumulative rainfall or rainfall intensity versus time for a particular precipitation event

Inundation: to be covered with water

Lag time is the time between when the peak of a precipitation event occurs, and when that runoff makes it to the outlet of the watershed.

LiDAR: Light Detection and Ranging, is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. It is a state-of-the-art method for collecting accurate elevation information for large areas.

[1] Source: Wikipedia.org

NAVD88: North American Vertical Datum of 1988 is the vertical control datum established in 1991 for vertical control surveying. NAVD88 consists of a leveling network on the North American Continent, affixed to a single origin point. NAVD88 replaced NGVD29 as the official vertical datum.

Return Frequency: likelihood, or probability that a rainfall event (specific to the magnitude and duration) will be equaled or exceeded in any given year.

Riverine: Associated with a river

Sea Level Rise: An increase in sea level caused by a change in the volume of the world's oceans due to temperature increase, deglaciation (uncovering of glaciated land because of melting of the glacier), and ice melt (Source: NOAA).

Stage Storage Discharge Curves: define the relationship between the depth of water and the discharge or outflow for the flood storage areas behind a culvert or impoundment.

Stillwater Elevation: The projected elevation of floodwaters in the absence of waves resulting from wind or seismic effects. In coastal areas, stillwater elevations are determined when modeling coastal storm surge: the results of overland wave modeling are used in conjunction with the stillwater elevations to develop Base Flood Elevations (Source: FEMA).

Storm Surge: Storm surge is the water, combined with normal tides that push toward the shore by strong winds during a storm. This rise in water level can cause severe flooding in coastal areas, particularly when the storm coincides with the normal high tides. The height of the storm surge is affected by many variables, including storm intensity, storm track and speed, the presence of waves, offshore depths, and shoreline configuration (Source: FEMA).

Tributary: a stream or channel that joins with a larger stream

Tailwater: The elevation of the water surface downstream from a dam or culvert. In coastal areas, such as Manchester-by-the-Sea, the tailwater elevation downstream of a dam is affected by tides, storm surge and sea level rise.

Time of Travel: The time interval required for water to travel from one point to another through a part (reach) of a watershed

Weighted Runoff Curve Number (CN): is a parameter used for predicting direct runoff or infiltration. The CN characterizes the runoff properties for each particular soil and groundcover in modeling applications. The CN method was developed by the USDA Natural Resource Conservation Services, formerly the Soil Conservation Service or SCS.

10-year Storm: A storm event having a 10% probability of occurring in any given year

25-year Storm: A storm event having a 4% probability of occurring in any given year

50-year Storm: A storm event having a 2% probability of occurring in any given year

100-year Storm: A storm event having a 1% probability of occurring in any given year

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