Johnson Creek Watershed Flood Resiliency Project

Final Report

Municipal Vulnerability Preparedness (MVP) Program Grant 2021, RFR ENV 22 MVP 02

Prepared for:

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MVP

Municipal Vulnerability Preparedness

Table of Contents

List of Tables

List of Figures

List of Appendices

Executive Summary

The Johnson Creek Watershed has several areas of flooding concern. Flooding at some locations has historically occurred on an annual basis. The Town was awarded a grant from the Massachusetts Municipal Vulnerability Program to perform a detailed watershed-wide vulnerability study relative to potential future climate change conditions. Project objectives were as follows:

- Perform field data collection to evaluate high priority / high flood-risk locations throughout the watershed.
- Develop and calibrate a hydrologic and hydraulic model of the watershed to identify and quantify areas of flooding concern relative to current and future climate conditions.
- Develop a list of recommendations and a prioritized action plan to increase resiliency to climate change throughout the watershed, with a focus on **Nature-Based Solutions (NBS)**.
- Perform targeted public involvement and community engagement activities throughout the Project.

A detailed list of 15 prioritized recommendations was developed based on findings from field data collection and flood modeling. It is recommended that “High Priority” recommendations be implemented first. The primary goal of recommendations was to provide flood mitigation and increased flood resiliency throughout the watershed while incorporating nature based components and environmental co-benefits. The resulting recommendations can be split into the following categories:

- Perform stream continuity improvements and restoration.
- Repair/retrofit dam outlets and modify operations to mimic natural floodplain function.
- Install green infrastructure.
- Purchase parcel to protect from development and maintain floodplain function.

Because of the influence of the Merrimack River on flooding within the watershed, it is not possible to entirely eliminate flooding throughout the watershed; however, flood simulation findings indicate that implementation of recommendations has the potential to greatly reduce flood duration and occurrence at all simulated locations. Simulation results also indicate that minimal unanticipated consequences to roadway flooding are expected based on the sequence of implementation of proposed improvements (i.e., if a particular upstream culvert is replaced before a downstream culvert).

This project included a comprehensive stakeholder engagement strategy which included digital, print, and in-person engagement activities.

1 Introduction

1.1 Background

There are several areas in the Johnson Creek Watershed that have potential flood risk as indicated by the Federal Emergency Management Agency's National Flood Hazard Layer (see **Figure 1-1**). For example, flooding has historically occurred multiple times per year in the vicinity at Lower Center Street at the inlet to Johnsons Pond near Lakeshore Road and can result in road closures that last for several days. Flood risk areas are located along school bus routes and important local transportation corridors used for travel between Haverhill and Georgetown. Many homes and businesses are located within the current 100-year FEMA floodplain at the lower reaches of the watershed near the intersection of Main Street and Washington Street, and along the mainstem of Johnson Creek.

The observed frequency and severity of flooding has been increasing and there is concern that the problem will continue to worsen as the intensity and magnitude of precipitation continues to increase. According to the Massachusetts Climate Change Clearinghouse (MA CCC), extreme precipitation and future flooding are expected to worsen from climate change. For example, the total amount of annual precipitation in Essex County is expected to increase 14% from an average of 47 inches per year under current conditions to 53.7 inches per year in 2100.

Workshop participants at the Town of Groveland's (Groveland) Municipal Vulnerability Program (MVP) workshop held on 12/5/2019 concluded that it is a top priority to perform a detailed watershed-wide vulnerability study to assess the problem, quantify potential future impacts, and develop prioritized recommendations to address flooding vulnerabilities associated with future climate change impacts.

1.2 Project Purpose

Following the workshop, the Town was awarded a grant from the MVP Program to perform a detailed watershed-wide vulnerability study relative to potential future climate change conditions. Project objectives were as follows:

- Perform field data collection to evaluate high priority / high flood-risk locations throughout the watershed.
- Develop and calibrate a hydrologic and hydraulic model of the watershed to identify and quantify areas of flooding concern relative to current and future climate conditions.
- Develop a list of recommendations and a prioritized action plan to increase resiliency to climate change throughout the watershed, with a focus on Nature-Based Solutions.
- Perform targeted public involvement and community engagement activities throughout the Project.

The remainder of this report summarizes the outcome of each of these objectives.

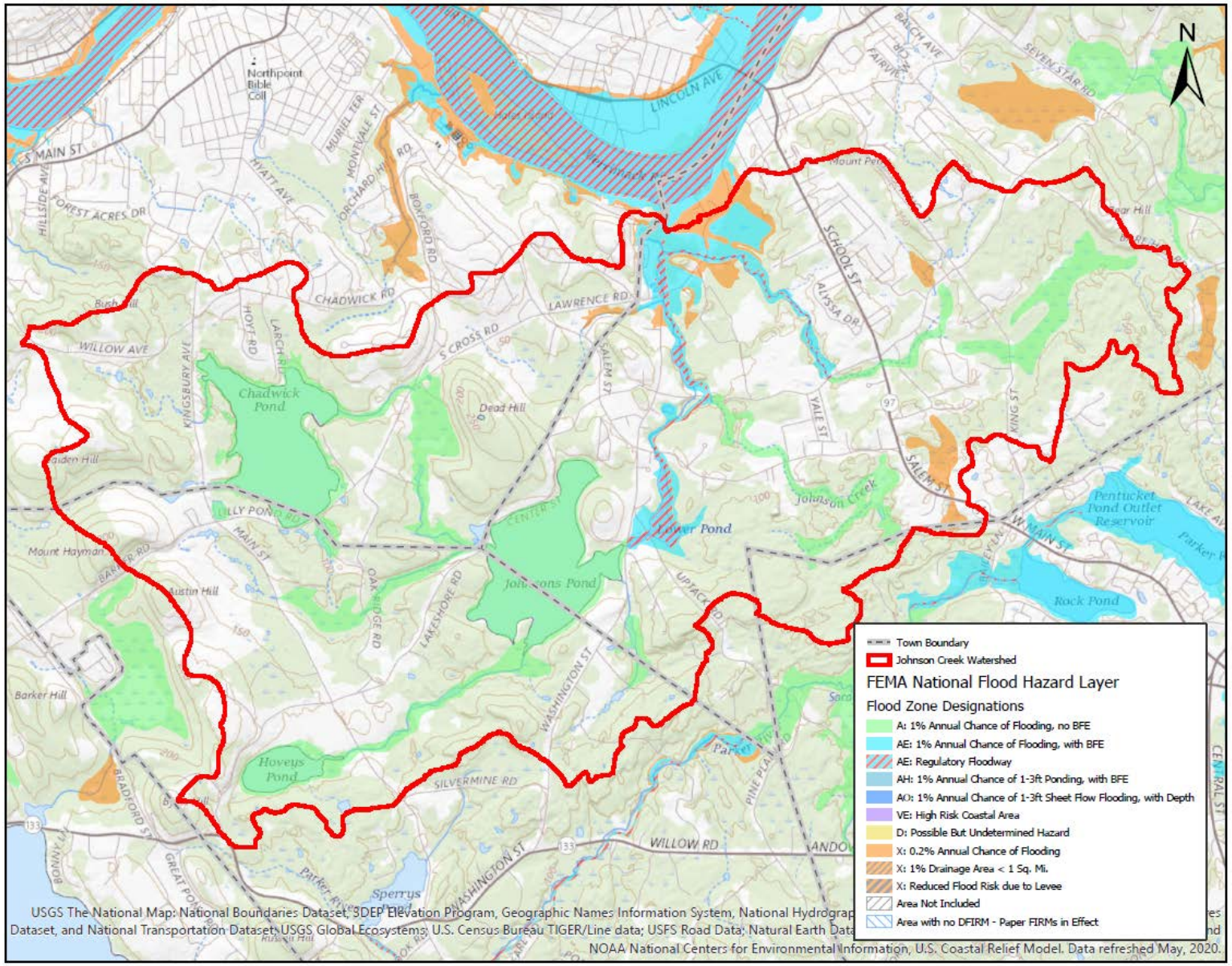

Figure 1-1. Johnson Creek Watershed Overview

2 Field Data Collection

2.1 Methods

The purpose of this task was to collect detailed field data collection at key road crossings and dams throughout the mainstem of the Johnson Creek Watershed. Field data collection was performed as follows.

- An electronic field data collection form was developed using Survey123, an application of ArcGIS Online.
- The field data collection forms included space to collect attribute information (e.g., size, material, etc.), condition observations, sedimentation observations, channel observations, and photos.
- The field data collection form was designed to output results from each visited located into a standardized PDF template, including photos (see **Appendix A** for results).
- The Town used the field data collection forms to perform in-kind field inspections at 27 locations as summarized by **Figure 2-1**.
- Field inspections were performed in November and December of 2021.

2.2 Summary of Findings

Findings were reviewed and tabulated following in-kind Town field data collection as follows:

- Field data was summarized for each collected feature (e.g., size, material, etc.) (**Table 2-1**).
- Field observations were summarized for each collected feature (e.g., condition, sedimentation, channel issues) (**Table 2-2**).
- A series of maps was created for visual depiction of observed issues - **Figure 2-2** (Condition), **Figure 2-3** (Sedimentation), **Figure 2-4** (Channels).

Findings are summarized as follows:

- Condition: Qualitative condition for assessed locations ranged from “Good” to “Poor”. Typical reasons for observed “Poor” conditions were structural damage (e.g., deterioration, collapsing, etc.) potentially caused by age, stream instability, beaver activity, or other factors.
- Sedimentation: As is typical of most New England towns, sedimentation of drainage features (i.e., culverts, channels) was observed throughout the watershed. Sediment buildup was typically less than 10% relative to culvert or channel capacity, but approached 25% at some locations (e.g., RC014). The primary cause of sedimentation is likely eroded material (or material from roadways) that settle upstream of in-stream hydraulic structures (e.g., culverts or dams) that create depositional backwater conditions.
- Channels: Most visited channels had some observed issues. Commonly observed issues included sedimentation, debris blockage, beaver activity, and channel instability (i.e., erosion). The primary cause of erosion is likely high velocity flows in erodible channels caused by upstream impervious surfaces, inadequate riparian buffers, or reduced natural floodplain.

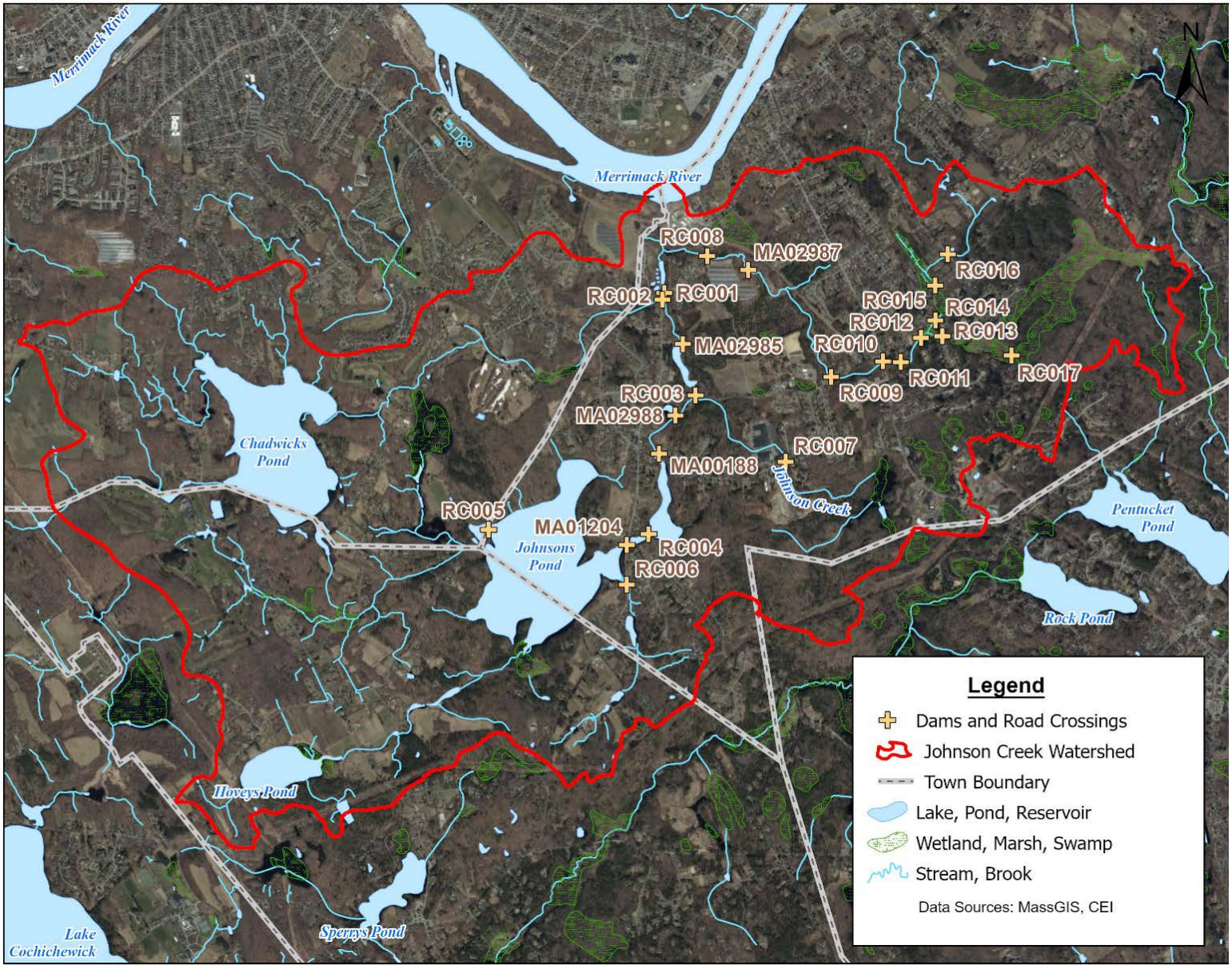

Figure 2-1. Field Evaluation Sites

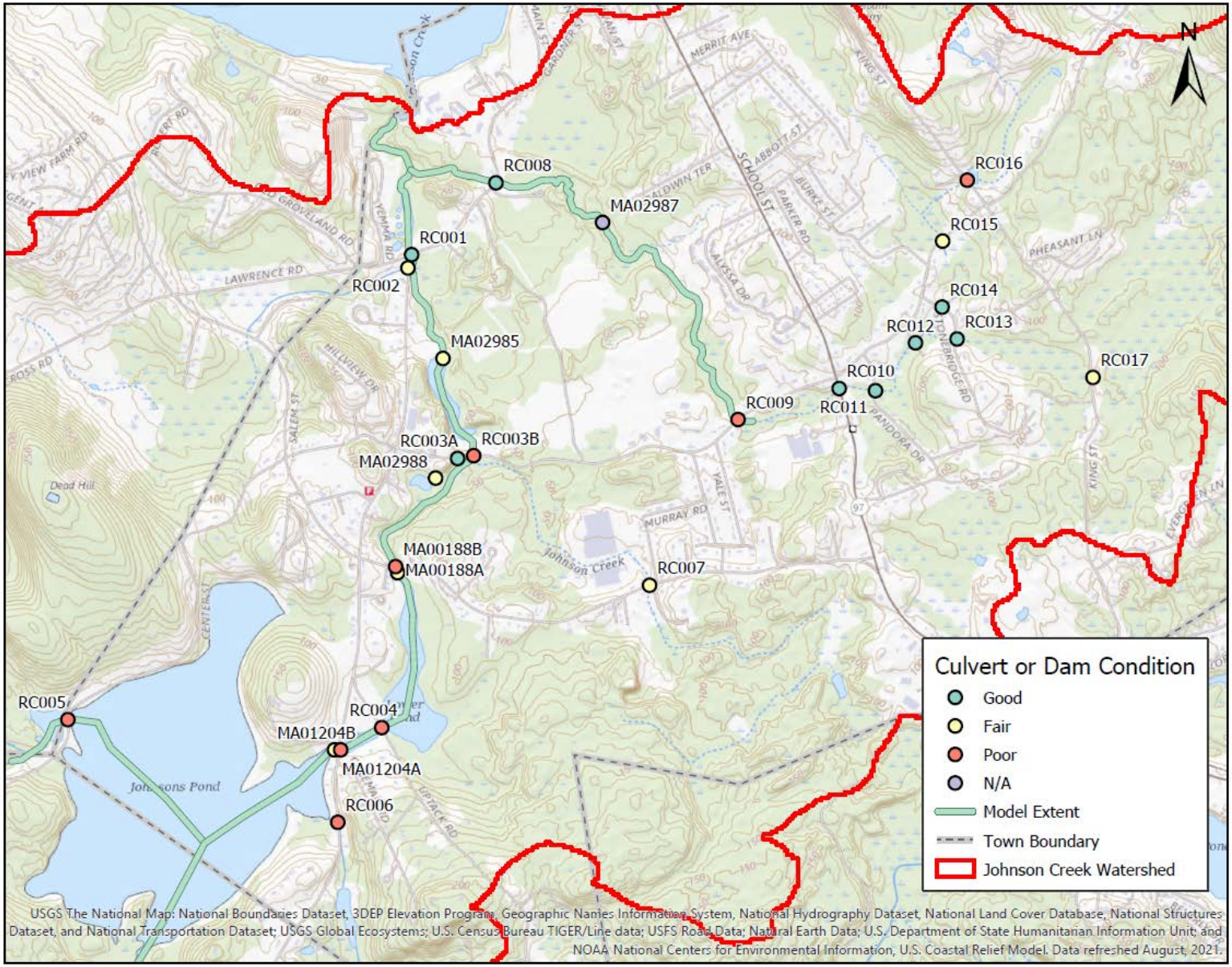

Figure 2-2. Condition Observations

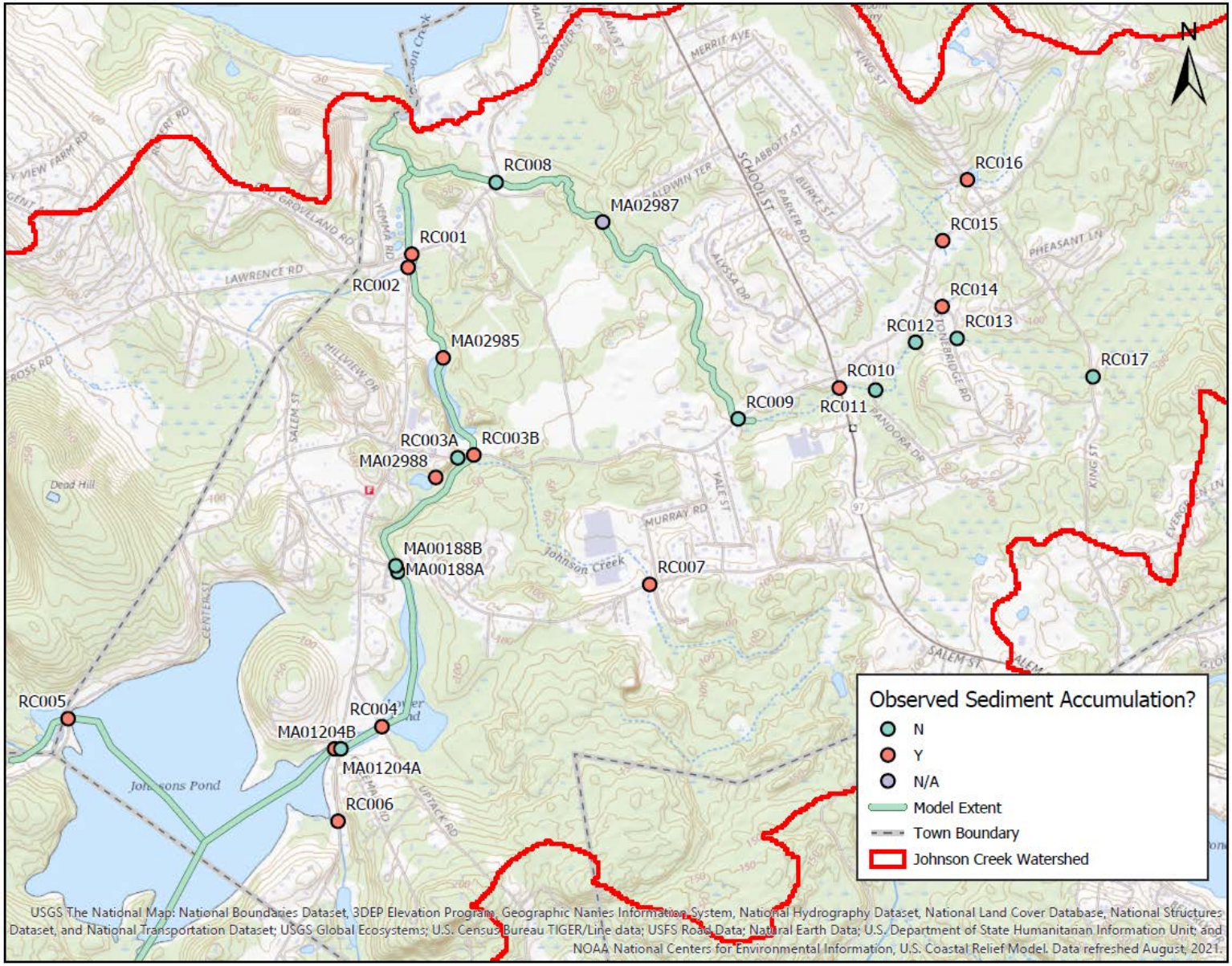

Figure 2-3. Sedimentation Observations

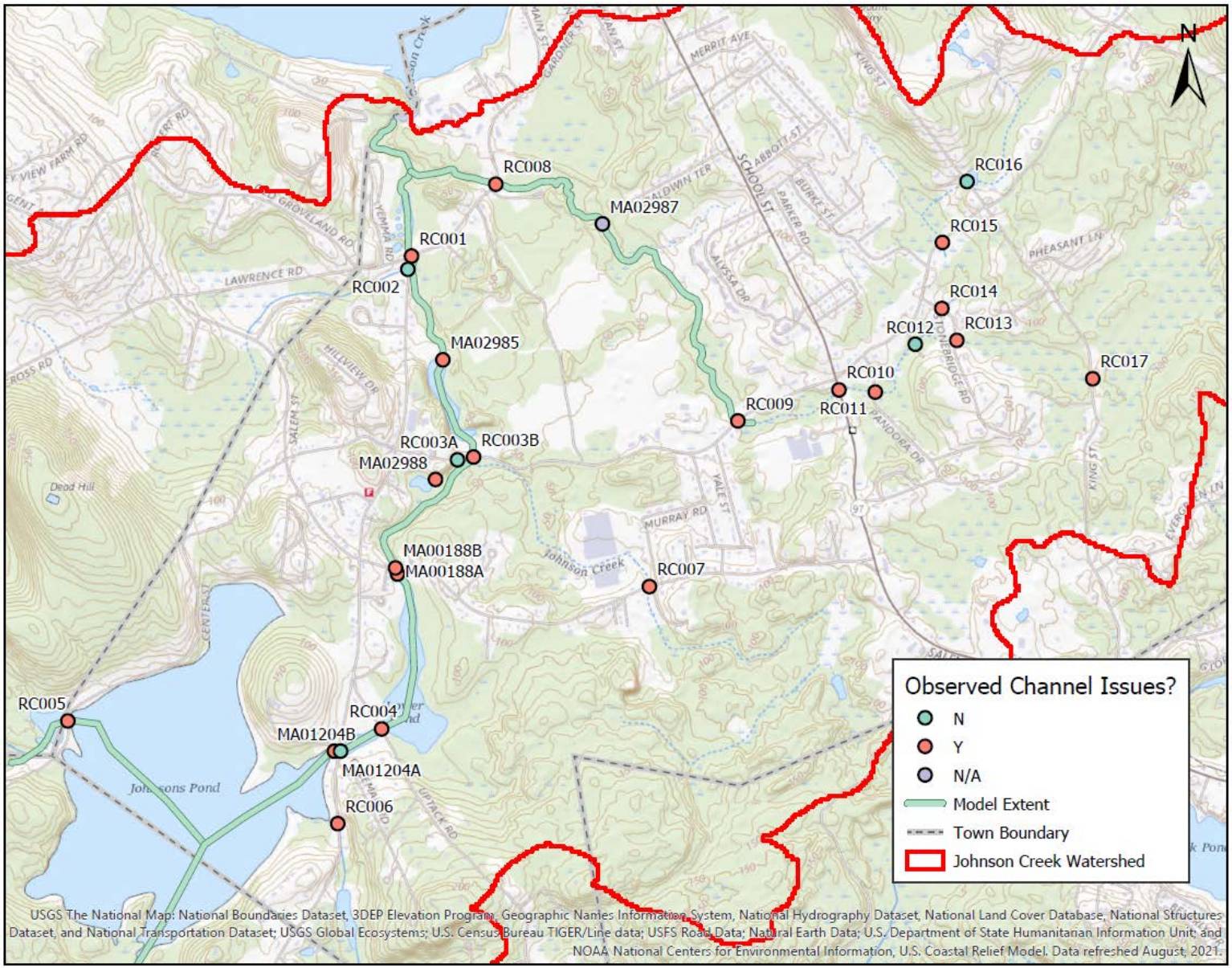

Figure 2-4. Channel Observations

Table 2-1. Summary of Field Data Collected from Field Inspections

General Site Information			Location Data	Elevation Data (NAVD88)			Existing Structure Data										Existing Channel Data							
							Culvert Characteristics						Dam Characteristics				Upstream Channel Characteristics				Downstream Channel Characteristics			
Eval. ID	Location Reference	Site Type	Approximate Coordinates (Lat, Long)	Inlet Invert (ft)	Outlet Invert (ft)	Roadway Elev. (ft)	Culvert Material	Culvert Geometry	Number of Barrels	Height (ft)	Span (ft)	Length (ft)	Dam Material	Span (ft)	Height (ft)	Controls	Bottom Width	Bankfull Width	Bankfull Depth	Depth of Headwater	Bottom Width	Bankfull Width	Bankfull Depth	Depth of Tail Water
RC005	Lower Center St.	Culvert	42.7336, -71.0581	72.663	72.270	77.637	RCP/CMP	Circular	2	2.5	2.5	50	---	---	---	---	6	7	3	3	5	10	4	2
RC006	Washington St.	Culvert	42.7301, -71.0456	---	---	---	HDPE	Circular	1	3	3	35	---	---	---	---	4	10	2	2	3	5	2	1
MA01204A	Washington St.	Dam	42.7325, -71.0457	73.989	---	77.762	---	---	---	---	---	---	Concrete	6	2	Stoplogs	---	---	5	2	10	12	12	3
MA01204B	Washington St.	Culvert	42.7325, -71.0457	71.009	70.209	77.762	CMP	Arch	1	4	6	40	---	---	---	---	---	---	---	1.5	---	---	---	2
RC004	Uptack Rd.	Culvert	42.7333, -71.0435	68.549	67.999	76.878	Masonry	Box	1	8	6	24	---	---	---	---	---	---	4	4	---	---	3	3
MA00188A	Salem St.	Dam	42.7386, -71.0428	70.859	---	76.506	---	---	---	---	---	---	Masonry	4.5	2	Stoplogs	---	---	4	2	20	25	3	3
MA00188B	Salem St.	Culvert	42.7386, -71.0428	65.663	64.163	76.506	CMP	Circular	1	4.5	4.5	75	---	---	---	---	---	---	---	2.5	25	---	---	1.5
BEAVERDAM	Mill Street Ext.	Dam	42.7418, -71.0410	51.216	---	61.692	---	---	---	---	---	---	Beaver	6	2	None	---	---	---	---	---	---	---	---
MA02988	Mill Street Ext.	Culvert	42.7418, -71.0410	46.103	43.703	61.692	RCP	Circular	1	6	6	120	---	---	---	---	12	---	---	2	18	20	2	2
RC003A	Center St.	Culvert	42.7425, -71.0399	35.527	34.802	43.828	RCP	Box	1	3	6	60	---	---	---	---	8	15	4	0.67	10	20	5	0.83
RC003B	Center St.	Culvert	42.7426, -71.0392	35.527	34.802	43.828	RCP	Box	1	4	8	30	---	---	---	---	3	7	4	1	5	8	---	2
RC007	Salem St.	Culvert	42.7381, -71.0310	---	---	---	RCP	Circular	1	3	3	40	---	---	---	---	4	5	1	1	3	5	1	1
MA02985A	E. of Washington St.	Dam	42.7459, -71.0406	24.297	---	35.527	---	---	---	---	---	---	Earthen	6	3	Stoplogs	---	---	---	3	20	40	2	2
MA02985B	E. of Washington St.	Culvert	42.7459, -71.0406	24.297	22.827	35.527	RCP	Circular	1	5	5	75	---	---	---	---	---	---	---	---	---	---	---	---
RC002	Washington St.	Culvert	42.7490, -71.0422	10.557	8.835	17.394	RCP	Circular	1	4	4	45	---	---	---	---	4	6	2	2	1	3	2	1
RC001	Main St.	Culvert	42.7495, -71.0420	7.983	7.853	16.509	RCP	Box	1	3	8	35	---	---	---	---	8	12	3	3	10	12	3	3
RC008	Main St.	Culvert	42.7519, -71.0381	10.058	9.416	19.724	Masonry	Box	1	6	8	40	---	---	---	---	---	---	---	2	---	---	---	2
MA02987	Baldwin Terr.	Dam	42.7505, -71.0331	---	---	---	---	---	---	---	---	---	Masonry	N/A	N/A	N/A	---	---	8	1	---	---	---	1
RC009	Center St.	Culvert	42.7438, -71.0269	46.341	45.416	50.193	CMP	Circular	1	3	3	35	---	---	---	---	4	10	2	1	7	13	2	1
RC010	School St.	Culvert	42.7448, -71.0222	---	---	---	RCP	Circular	1	4	4	65	---	---	---	---	1	5	1	1	5	8	3	1
RC011	Pandora Dr.	Culvert	42.7447, -71.0205	---	---	---	RCP	Circular	1	4	4	50	---	---	---	---	2	5	5	1	---	---	---	1
RC012	Center St.	Culvert	42.7463, -71.0186	---	---	---	RCP	Circular	1	1	1	40	---	---	---	---	---	---	---	1	---	---	---	1
RC013	Stonebridge Rd.	Culvert	42.7465, -71.0167	---	---	---	RCP	Box	1	3	10	40	---	---	---	---	6	---	---	1	1	---	---	1
RC014	Stonebridge Rd.	Culvert	42.7476, -71.0174	---	---	---	RCP	Circular	1	3	10	40	---	---	---	---	8	14	4	1	10	14	---	1
RC015	Center St.	Culvert	42.7498, -71.0174	---	---	---	RCP	Circular	1	2	2	35	---	---	---	---	---	---	---	1	---	---	---	1
RC016	King St.	Culvert	42.7519, -71.0162	---	---	---	CMP	Circular	1	2	2	40	---	---	---	---	---	---	---	1	---	---	---	1
RC017	King St.	Culvert	42.7451, -71.0104	---	---	---	Clay	Circular	1	1	1	30	---	---	---	---	1	---	---	10	---	---	---	1

Table 2-2. Summary of Field Observations Collected from Field Inspections

General Site Information			Existing Site Conditions																
				Structure Condition Summary						Upstream Channel Condition Summary					Downstream Channel Condition Summary					
Eval. ID	Location Reference	Site Type	Condition	Structural Damage	Sediment Buildup	Channel / Bank Instability	Vegetation / Debris	Beaver Activity	Prev. Surcharge / Overtop	Sediment Buildup	Channel / Bank Instability	Vegetation / Debris	Beaver Activity	Prev. Surcharge / Overtop	Sediment Buildup	Channel / Bank Instability	Vegetation / Debris	Beaver Activity	Prev. Surcharge / Overtop	Issue Summary
RC005	Lower Center St.	Culvert	Poor	Y	N	Y	Y	Y	Y	<_10%	Y	Y	Y	N	N	Y	Y	Y	N	Undersized culverts and upgradient beavers cause road flooding and upstream scour and bank erosion.
RC006	Washington St.	Culvert	Poor	Y	N	Y	Y	N	N	N	Y	Y	N	N	<_10%	Y	N	N	Y	Culvert is deformed and collapsing; upstream debris buildup; downstream channel erosion.
MA01204A	Washington St.	Dam	Fair	Y	N	N	N	N	N	25_50%	Y	Y	Y	Y	<_10%	Y	Y	Y	N	Outlet structure is deteriorating; controls are limited; beaver activity increases flood risk.
MA01204B	Washington St.	Culvert	Poor	Y	N	N	N	N	N	N	Y	Y	Y	Y	N	Y	Y	Y	N	Downstream portion of culvert is deteriorating.
RC004	Uptack Rd.	Culvert	Poor	Y	N	Y	N	Y	N	<_10%	Y	Y	Y	Y	<_10%	Y	Y	Y	N	Culvert is failing; sinkhole on roadway; beaver activity increases flood risk.
MA00188A	Salem St.	Dam	Fair	N	N	N	Y	N	N	N	N	Y	Y	Y	N	Y	Y	N	Y	Outlet grate is deformed and is periodically clogged.
MA00188B	Salem St.	Culvert	Poor	Y	N	N	N	N	N	N	N	Y	Y	Y	N	Y	Y	N	Y	Downstream culvert bottom is corroded and headwall is undermined; downstream channel bank is eroded.
BEAVERDAM	Mill Street Ext.	Dam	Poor	N	N/A	N	N	Y	N	N/A	N	Y	Y	N	N/A	Y	Y	Y	Y	Dam is a beaverdam, blocking downstream culvert
MA02988	Mill Street Ext.	Culvert	Fair	Y	10_25%	Y	Y	Y	N	10_25%	N	Y	Y	N	<_10%	Y	Y	Y	Y	Culvert is failing; upgradient beaver dam is blocking culvert inlet and is a flood risk.
RC003A	Center St.	Culvert	Good	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	No observed issues.
RC003B	Center St.	Culvert	Poor	Y	<_10%	Y	N	N	N	10_25%	Y	N	N	N	10_25%	Y	Y	N	N	Culvert is undermining and has exposed footings; upstream / downstream bank erosion.
RC007	Salem St.	Culvert	Fair	Y	10_25%	N	N	Y	Y	10_25%	Y	Y	Y	Y	10_25%	Y	Y	Y	Y	Upstream and downstream headwalls are cracking; culvert is corroded.
MA02985A	E. of Washington St.	Dam	Fair	Y	N	Y	N	N	N	<_10%	N	N	N	N	10_25%	Y	N	N	N	The spillway concrete is spalling
MA02985B	E. of Washington St.	Culvert	Fair	Y	N	Y	N	N	N	<_10%	N	N	N	N	10_25%	Y	N	N	N	Concrete at outlet structure is spalling; sinkhole observed near top of dam embankment.
RC002	Washington St.	Culvert	Fair	N	<_10%	Y	N	N	Y	10_25%	N	N	N	N	10_25%	N	N	N	N	Upstream wingwall is undermining; culvert surcharges during large storm events, likely undersized.
RC001	Main St.	Culvert	Good	N	25_50%	N	N	N	N	10_25%	Y	Y	N	Y	10_25%	N	N	N	N	Severe bank erosion and frequent debris accumulation at upstream channel.
RC008	Main St.	Culvert	Good	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	Debris frequently observed at upstream channel.
MA02987	Baldwin Terr.	Dam	N/A	Y	N/A	Y	N	N	Y	<_10%	Y	Y	Y	N	<_10%	Y	Y	N	Y	Dam fell apart nearly 20 years ago; streamflow is unimpeded.
RC009	Center St.	Culvert	Poor	Y	N	Y	Y	N	Y	N	Y	Y	N	N	N	N	N	N	N	Culvert appears to be collapsing or deforming.
RC010	School St.	Culvert	Good	N	N	N	N	N	N	10_25%	Y	Y	N	Y	N	N	N	N	N	Upstream channel is eroding and shows signs of instability (e.g., toppled tree)
RC011	Pandora Dr.	Culvert	Good	N	N	N	Y	N	N	N	N	Y	N	N	N	Y	N	N	N	Debris frequently observed at upstream channel.
RC012	Center St.	Culvert	Good	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	No observed issues.
RC013	Stonebridge Rd.	Culvert	Good	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	N	N	Debris / blockage at downstream channel (i.e., toppled tree).
RC014	Stonebridge Rd.	Culvert	Good	N	<_10%	N	Y	N	N	<_10%	N	Y	N	Y	10_25%	Y	Y	N	N	Upstream and downstream channel shows signs of instability (i.e., bank erosion) and blockages.
RC015	Center St.	Culvert	Fair	Y	N	N	N	N	Y	<_10%	Y	N	N	N	<_10%	N	Y	N	Y	Culvert headwall is failing; culvert appears undersized; channel erosion and debris blockage.
RC016	King St.	Culvert	Poor	Y	N	Y	N	N	N	N	N	N	N	N	10_25%	N	N	N	N	Perched culvert is undermining; downstream embankment appears to be eroding.
RC017	King St.	Culvert	Fair	N	N	N	N	N	Y	N	N	Y	N	Y	N	N	Y	N	Y	Culvert appears undersized and not set at the right elevation to properly drain upstream areas.

3 Model Development

The purpose of this task was to develop a hydrologic and hydraulic model of the mainstem of the Johnson Creek Watershed to quantify existing and future areas of flooding concern relative to potential climate change. See **Figure 3-2** for the model extent.

The model was developed using EPAs Stormwater Management Model (SWMM). SWMM is a dynamic rainfall-runoff and routing simulation model used to quantify single event or long-term (continuous) runoff. The hydrologic / rainfall-runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff. The hydraulic / routing component of SWMM transports runoff through a system of pipes, channels, storage units, culverts, weirs, and other features. SWMM tracks the quantity of runoff generated within each subcatchment, and the corresponding flow rate and flow depth that is routed in each conduit during a simulation period. SWMM was chosen for use in this study for its ability to run single event simulations and implement operational logic and rules.

The hydrologic basis of the model included: 1) Development of rainfall depth and distributions to simulate existing and future conditions; and 2) Characterization of subcatchments for all major tributary inputs along 9.5 square mile watershed. The hydraulic basis of the model included characterization of flow routing and cross-sectional information, including culvert, weir, storage unit, and channel geometry, throughout the model extent. This section describes how the hydrologic and hydraulic model inputs were compiled.

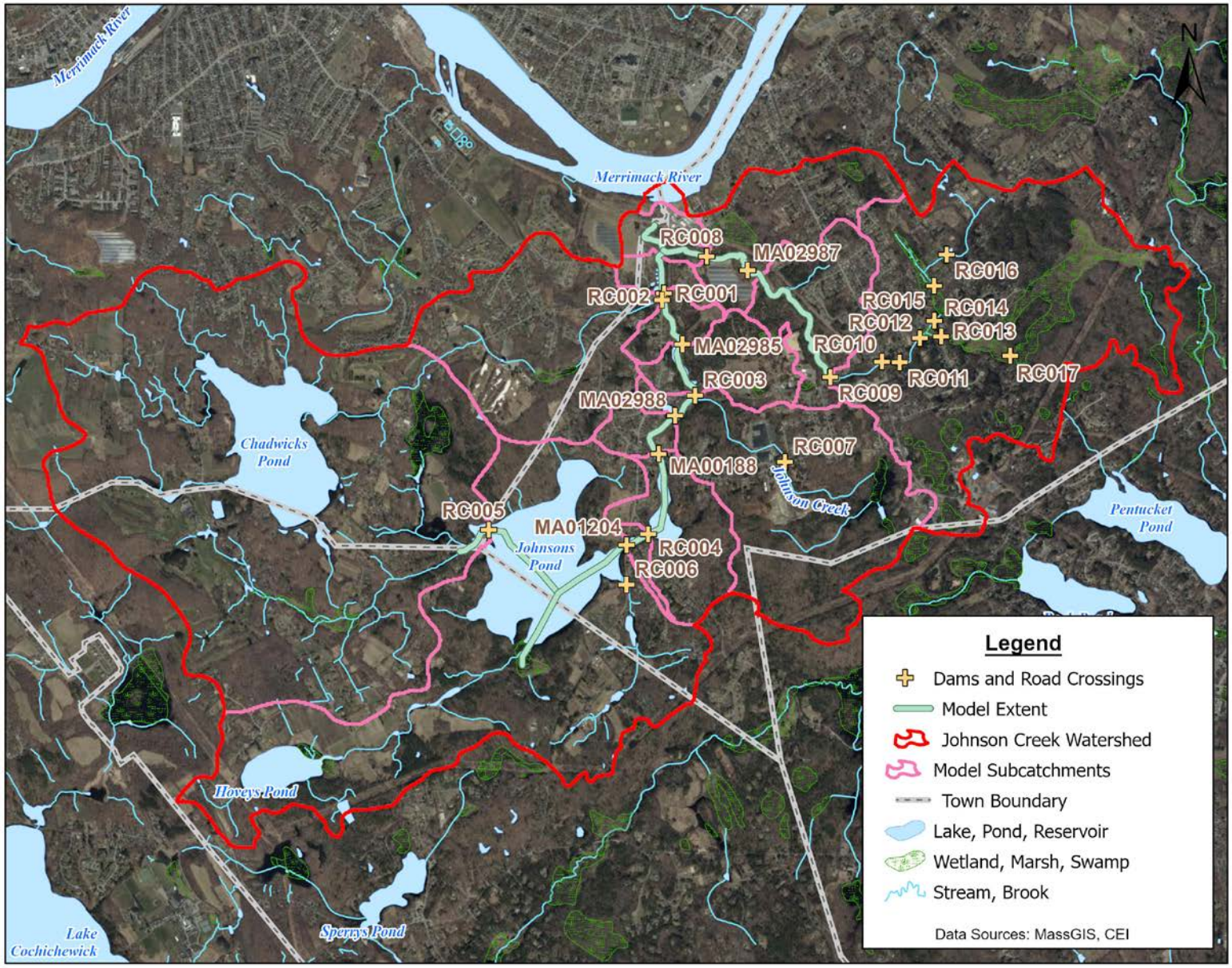

Figure 3-1. Model Simulation Extent Relative to Field Visit Locations

3.1 Hydrologic Inputs

The hydrological component of SWMM is used to generate runoff from contributing drainage areas (i.e., subcatchments) to the conveyance system. Hydrologic inputs were developed as described below.

3.1.1 Rain Gauges

Engineering analysis and designs have traditionally been based on the NRCS TR 55 method which relies on outdated rainfall depths and intensity distributions from U.S. Weather Bureau Technical Paper 40 published in 1961. Design storm depths and intensity distributions have since been updated based on analysis of more current precipitation data by the National Oceanic and Atmospheric Administration (NOAA) (i.e., NOAA Atlas 14). NOAA Atlas 14 design storm depths are presented as a range (i.e., lower 90th percent confidence interval to upper 90th percent confidence interval). Six different 24-hour duration design storm types, or rain gauges, were developed and analyzed for the model simulations:

- 5-year existing and future storms
- 25-year existing and future storms
- 100-year existing and future storms

Existing conditions simulations were based on median precipitation depth values from NOAA Atlas 14 at the centroid of Groveland. Potential future conditions simulations were based on the upper 90th percent confidence interval precipitation depth values from NOAA Atlas 14. Refer to **Table 3-1** below for a comparison of the 24-hour rainfall depths for traditional methods (i.e., TP 40) vs. updated methods (i.e., NOAA Atlas 14). Existing and future conditions were both based on a dimensionless 24-hour Massachusetts NOAA Type rainfall distribution developed by the NRCS for the June 2016 Massachusetts Supplement to Chapter 2 of the Engineering Field Handbook. This type of distribution results in higher intensity over a 24-hour period than the traditional NRCS Type III storm.

Table 3-1. Precipitation Depth Comparisons

Return Period	**24-Hour Rainfall Amount Comparison**		
	TP 40 (in) – Not Used	NOAA Atlas 14: Median (in) – **Existing Conditions**	NOAA Atlas 14: 90th Percentile (in) - **Future Conditions**
5-yr	4	4.22	5.10
25-yr	5	6.23	7.97
100-yr	6.5	8.02	11.40

3.1.2 Subcatchments

Subcatchments within the Johnson Creek Watershed were delineated based on the USGS StreamStats application. StreamStats determines subcatchment boundaries with digital elevation data obtained from the USGS 3D Elevation Program (3DEP). Elevation data is processed within StreamStats so that the elevation data conforms to the digital stream channels depicted in the high-resolution version of the National Hydrography Dataset (NHD) and to the drainage-basin boundaries of the Watershed Boundary Dataset (WBD) (USGS, 2018).

For this model, the 9.5-square mile Johnson Creek Watershed was divided into 14 subcatchments representing the confluence of significant tributaries (**Figure 3-1**). Subcatchments ranged in size from approximately 50 acres to 2,000 acres Relevant subcatchment parameters were developed for the model as follows:

- Area: Subcatchment areas were calculated from the USGS StreamStats delineations.
- Width: The subcatchment width is the physical width of overland flow. Subcatchment widths were calculated by dividing the area by the maximum length of overland flow, which was approximated using MassGIS LiDAR contour data.
- Slope: The subcatchment slope is the average slope of overland flow. Subcatchment slopes were determined using Spatial Analysis, an extension of ArcGIS.
- Impervious Area: The subcatchment impervious areas were determined using the impervious surface layer data from MassGIS.
- Manning's n for Overland Flow: Subcatchment Manning's n values were assigned for pervious and impervious areas of the subcatchment based on the SWMM 5.1 Manual, Table A.6 guidelines. A default Manning's n was used for impervious areas. An area weighted approach was used to determine Manning's n for pervious areas based on MassGIS land use data.
- Curve Number (CN): Infiltration was estimated for each subcatchment based on the SCS Curve Number method. Subcatchment CNs were assigned for pervious areas of the subcatchment based on the Hydrologic Soil Group (HSG). An area weighted approach was used to determine the CN for pervious areas based on the land use/HSG layer obtained from MassGIS and Web Soil Survey.

3.2 Hydraulic Inputs

The hydraulic component of SWMM is used to route runoff and other inflows through the conveyance system. Hydraulic inputs for this study were primarily developed based on field survey and available data from the FEMA Flood Insurance Study (FIS) of Essex County effective in 2012. This data was supplemented by GIS data (i.e., LiDAR) and data collected from the field inspections (summarized in **Section 2)**. Hydrologic inputs were developed as described below.

3.2.1 Junctions

For this model, junctions were used to represent the confluence of natural surface water channels and major infrastructure features (e.g., culvert inlets and outlets and weir inlets and outlets). Relevant junction input parameters used for this project are as follows:

- Invert Elevation: The invert elevation for each junction corresponds to: (1) the associated culvert/weir inlet or outlet inverts, which was obtained from field survey; or (2) the associated channel invert, which was obtained from the FIS where field survey data was not available.

3.2.2 Outfalls

Outfalls represent the downstream end of the conveyance system. For this model, one outfall was modeled to represent the confluence of Johnson Creek and Merrimack River. Relevant outfall input parameters used for this project are as follows:

- Invert Elevation: The invert elevation for the outfall corresponds to the channel invert at the confluence of Johnson Creek and Merrimack River, which was obtained from the FIS.

- Outfall Type: The downstream influence of the Merrimack River on flooding within Johnson Creek Watershed was conservatively assumed based on the maximum potential elevation of the Merrimack River during a given storm simulation. A "FIXED" stage outfall type was therefore selected.

- Fixed Stage: The fixed stage for the outfall corresponds to the flood elevations at the confluence of Johnson Creek and Merrimack River. Fixed stage elevations were obtained from the FIS as summarized by **Table 3-2**. The FIS did not provide a flood elevation for the 5-yr and 25-yr return period rainfall events. FIS flood elevations for the 10-yr and 50-yr return periods were used as the model's flood elevations for the 5-yr and 25-yr return periods, respectively. The same fixed outfall stages were used for both existing and future rain gauges.

Table 3-2. Fixed Stages at the Outfall

Return Period		**Fixed Stage** (NAVD88, ft)
FIS Storm	SWMM Model Storm	
10-yr	5-yr	13.8
50-yr	25-yr	17.9
100-yr	100-yr	20.6

3.2.3 Storage Nodes

Storage units are conveyance system nodes that provide storage volume. For this model, four storage nodes were modeled – i.e., one preceding every impoundment/dam: Johnsons Pond (MA01204), Storage Node 2 (RC004), Lower Pond (MA00188), Storage Node 4 (Beaverdam/MA02988), Storage Node 5 (MA02985). Relevant storage node input parameters used for this project are as follows.

- Invert Elevation: The invert elevation for each storage node corresponds to the associated downstream culvert/weir inlet invert, which was obtained from field survey. (This study was focused on simulated flooding events, so the actual bottom of the storage unit is not relevant.)

- Max Depth: The max depth for the storage nodes correspond to the distance between the storage node invert elevation and the maximum elevation of the storage node. The maximum elevation for the storage nodes correspond to the associated downstream roadway elevation, which was obtained from field survey (i.e., if the water exceeds the maximum depth, it would flow over the roadway via weir flow).

- Initial Depth: The initial depth for the storage nodes correspond to the distance between the storage node invert elevation and the outlet control device (weir or stop log) height, which was obtained from field survey.

- Storage Curve: The storage volume of the storage node, for the purposes of the model, is the volume between the invert elevation (downstream culvert/weir inlet) to the maximum elevation (downstream roadway). The volumetric properties of the storage node are entered into SWMM as a table of surface area versus height (i.e., stage-area relationship or storage curve). The storage curve data, from the invert elevation to the maximum elevation, of each storage node was obtained using a combination of field survey data and MassGIS LiDAR contour data.

3.2.4 Weirs

Weirs represent the outlet structures of the dams in the conveyance system or roadway flooding. For this model, four outlet structure weirs were modeled: MA01204A, MA00188A, Beaverdam, and MA02985A). The other 10 weirs modeled were roadway weirs to simulate roadway flooding and not actual structures inspected during field survey: RC005A, MA01204C, RC004A, MA00188C, MA02985C, RC002A, RC001A, RC008A, RC009A. Relevant weir input parameters for this project are as follows:

- Weir Type: The weir type is based on the geometric shape of the weir cross-section. The weir type was determined based on field survey and observations (transverse, side flow, v-notch, trapezoidal, or roadway). All weirs in the model are transverse or roadway. Roadway weirs were input at most road crossings (weirs and culverts) to simulate roadway flooding and ensure that all the runoff generated from the subcatchments was transported downstream and not artificially "ponded" during peak flow conditions.
- Dimensions: Dimensions (i.e., length, height, width) were approximated based on available field data and GIS measurements.

  Discharge Coefficient: The default discharge coefficient of 3.33 was used for all weirs. These values correspond to the SWMM 5.1 Manual guidelines.

3.2.5 Conduits

Conduits represent linear features that convey water between junctions and storage nodes. For this model, conduits are either culverts or streams. The 11 culverts modeled include the following: RC005B, MA01204B, RC004B, MA00188B, RC003A, RC003B, MA02985B, RC002B, RC001B, RC008B, and RC009B. Relevant conduit input parameters used for this project are as follows:

- Transects: Transects are only applicable to stream conduits. The stream transects, for the purposes of the model, is the cross-sectional area of the stream from the invert elevation (downstream culvert/weir inlet) to the maximum elevation (downstream roadway). The cross-sectional geometry of the stream transects is entered into SWMM as a table of stream bottom elevation versus the horizontal distance over the cross-section of the stream. The geometric data, from the invert elevation to the maximum elevation, of each stream conduit was obtained using a combination of field survey data and MassGIS LiDAR contour data. This data was supplemented by the FIS.
- Conduit Shape: The conduit shape is the geometric shape of the conduit cross-section. For streams, the shape is irregular and a stream transect table is assigned. For culverts, the shape was determined based on field survey and observations (circular, arch, rectangular, etc.).
- Max Depth: The conduit max depth is the physical depth of the culvert or stream (e.g., culvert diameter). For streams, the max depth automatically populates when it is assigned a stream transect table. For culverts, the max depth is based on measurements taken during field survey.
- Conduit Span: The conduit span is the physical width of the culvert or stream. For streams, the span automatically populates when it is assigned a stream transect table. For culverts, the conduit span is based on measurements taken during field survey.
- Conduit Length: The conduit length is the physical length of the stream or culvert. For streams, the length was approximated using the MassGIS wetlands/hydrography layer and aerial orthophotography. For culverts, the conduit length is based on measurements taken during field survey.

- Manning's Roughness: Conduit Manning's Roughness coefficients were assigned for culverts and streams based on the SWMM 5.1 Manual, Table A.7 (closed conduit values) and Table A.8 (open channel values) guidelines, respectively. The Manning's Roughness for culverts are based on culvert material, which was obtained during field survey and observations (RCP, CMP, Masonry, etc.). The Manning's Roughness for streams are based on stream bottom material, which was obtained during field survey and observations.

- Inlet/Outlet Offset: The inlet/outlet elevations for culverts and streams were obtained from field survey. The inlet/outlet elevations for some streams were obtained from the FIS where survey data was not available.

- Entry and Exit Loss Coefficient: The default entry loss coefficient of 0.5 and default exit loss coefficient of 1.0 was used for all culverts. These values correspond to the SWMM 5.1 Manual, Table A.11 guidelines.

- Culvert Code: The culvert code number corresponds to the culvert material and geometric properties. The culvert code was determined using the SWMM 5.1 Manual, Table A10 guidelines, and based on field survey and observations.

3.2.6 Dynamic Routing

Flow routing within a conduit link in SWMM is governed by the conservation of mass and momentum equations for gradually varied, unsteady flow. The three routing options are: (i) Steady Flow Routing, (ii) Kinematic Wave Routing, and (iii) Dynamic Wave Routing. For this project, Dynamic Wave Routing was chosen as the routing methodology. Dynamic Wave Routing solves the complete one-dimensional Saint Venant flow equations and therefore produces the most theoretically accurate results. These equations consist of continuity and momentum in conduits and volume continuity at nodes. With this form of routing, it is also possible to represent pressurized flow (i.e., when a closed conduit becomes full) in which the actual flow in the conduit can exceed the full-flow Manning's equation value. In addition to pressurized flow, Dynamic Wave Routing can account for channel storage, backwater effects, entrance/exit losses, and flow reversal. Because it combines the solution for water levels in nodes and flows in conduits, it can be applied to any general network layout (USEPA, 2015).

3.3 Coarse Model Calibration

Once all inputs to the existing conditions model were developed, coarse calibration was performed. There was no available historical field measurement data for the watershed (i.e., pond levels, streamflow), so calibration was performed by comparing model simulation results to the FIS. The calibration process was performed as follows:

1) Set initial boundary conditions and run preliminary simulations.
2) Compare simulated outfall discharge to the FIS.
3) Adjust subcatchment and conduit parameters to more closely match the FIS.

3.3.1 Preliminary Simulations

To initiate the calibration process, model logic (i.e., initial boundary conditions) were configured to match existing operations of the outlet control structures at all of the impoundment locations. For the Johnson's Pond Dam (MA01204) and the Lower Pond Dam (MA00188), the weir elevation was set such that all stop logs were in place (approximately 3 feet high). The other impoundment locations were modeled to have fixed outlet elevations, since no operational weir controls were present.

Once initial boundary conditions were set, preliminary model simulations were run to compare model simulated discharge with FIS estimated discharge at the Merrimack River Outfall. The FIS did not provide peak flows for the 5-yr and 25-yr return period rainfall events. Therefore, calibration was only performed for the existing 100-year return period. Preliminary simulation results summarized by **Table 3-3** indicate that the model was dramatically over-simulating discharge by an order of magnitude – i.e., 100-year FIS value of 1,219 cfs vs. 100-year SWMM simulated value of in excess of 5,000 cfs.

3.3.2 Model Parameter Adjustments

Preliminary overestimation of peak modeled discharge was caused by unrealistic runoff being generated from model subcatchments and to a lesser extent, roughness values assigned to stream channel overbanks. Model parameter adjustments were made as follows:

- Subcatchments: Subcatchment parameters that had the greatest sensitivity to model results were subcatchment width, subarea routing, and percent routed. All subcatchment widths were decreased by approximately 33% which results in reductions in peak runoff. Subarea routing was initially defined as "outlet", meaning that all runoff generated by the subcatchment would be routed directly to the outlet with minimal attenuation. Given that most subcatchments have large areas of forest and green space, routing was changed to "pervious" such that 75% of runoff would be routed through pervious areas before reaching the outlet. These changes generally resulted in more realistic runoff hydrographs (i.e., smoother hydrograph peaks, slower response rates).

- Stream Conduits: As discussed in **Section 3.2.5**, a Manning's Roughness coefficient was initially estimated for all stream transects based on field survey and observation. After review, the overbank (i.e., the portion of the transect outside of the main low flow conveyance channel) value for Manning's Roughness coefficient was increased to 0.5 for all channels to increase roughness and simulate additional attenuation of flows associated with heavily vegetated wetland banks. This additional attenuation is important given the role that these overbank floodplains play in the study area.

3.3.3 Calibrated Simulation Results

Once model parameter adjustments were made, the SWMM model was estimating peak 100-year (existing conditions) outfall discharge at the Merrimack river as 1,332 cfs as compared to the FIS value of 1,219 cfs (**Table 3-3**). These results logically make sense because the FIS model was built in the 1980's when TR40 rainfall data were still being used – i.e., lower rainfall depths and less intensity as compared to the NOAA Atlas 14 data used for this modeling effort. As a final calibration step, peak water surface elevations (WSE) generated by the SWMM model were compared to FIS peak WSE's. Results of this comparison were generally within 1 foot (±) of one another and are indicative that model results are representative of order of magnitude flood conditions.

Table 3-3. Comparison of Peak Outfall Discharge Estimates

Return Period	**Peak Discharge Estimate (cfs)**		
	FIS	SWMM Model *(Preliminary)*	SWMM Model *(Calibrated)*
100-yr (Existing)	1,219	> 5,000	1,332

3.4 Model Limitations

- The hydrologic and hydraulic model developed for this study is suitable for planning level purposes.
- The intent of the model is to improve understanding of how the watershed functions as a whole and to compare relative differences between evaluated scenarios (i.e., baseline conditions vs. staged improvement evaluations).
- Model results are not intended to be used for engineering design or other related analysis – site specific improvements will require additional analysis.
- This model was developed on a regional (i.e., watershed) scale using the best available information. The model does not account for all potential features in the watershed such as beaver dams, stormwater pipes, and upstream culverts.
- Model inputs were developed based on field observations and available GIS data. The model was not developed based on detailed site survey data.
- Coarse calibration of the model was performed based on Flood Insurance Study data. Field data, including streamflow measurements or water levels were not available for calibration. Outputs from this model are therefore suitable to provide order of magnitude estimates, but have not been calibrated to any specific storms.

4 Baseline Flooding Evaluation

Once calibration was complete, a baseline evaluation was established to evaluate existing conditions and potential future conditions assuming that no improvements are made in the watershed.

Note: An electronic copy of all model versions with accompanying inputs used to simulate results is available electronically as **Appendix B**.

4.1 Discharge Results

As indicated by **Figure 4-1**, peak discharge at the outfall to the Merrimack River is expected to range from approximately 330 cfs (5-year existing condition) to up to 2,378 cfs (100-year potential future conditions) under baseline conditions. Results indicate that the existing 100-year storm is approximately equivalent to the future 25-year storm.

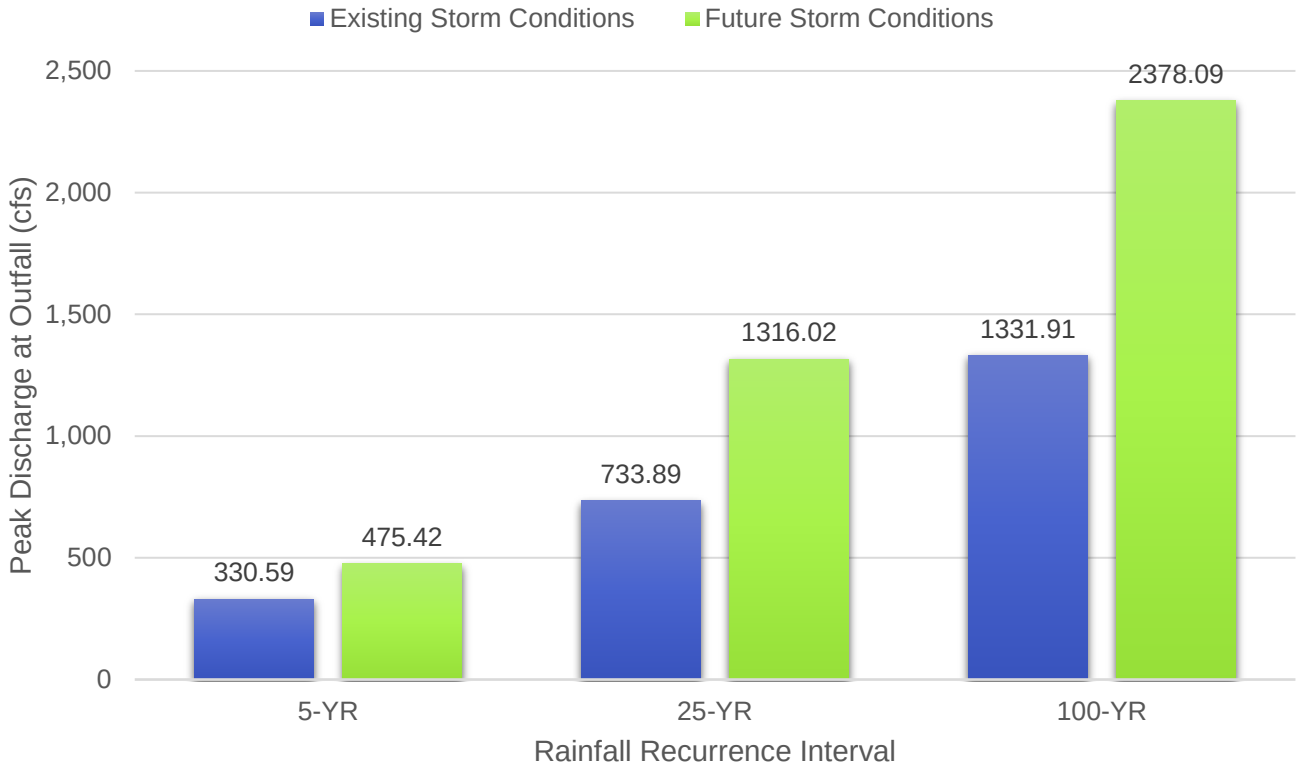

Figure 4-1. Peak Discharge Comparison (Baseline Conditions)

4.2 Roadway Flooding Results

Potential roadway flooding depths were simulated for each modeled design storm based on peak simulated water surface elevations. Results are presented by **Figure 4-2** through **Figure 4-7**. Areas of flooding concern can generally be split into four (4) areas.

- Area 1 (downstream portion of the watershed): Simulated flooding begins to occur during the 5-year future storm. Flood depths during the 5-year future storm are < 0.5 feet and are short duration (i.e., less than 2 hours). Flooding depths increase up to 3 feet for the 25-year existing storm and are simulated to be greater than 3 feet for the 100-year storms (existing and future). Flooding appears to be controlled by influence from the Merrimack River (i.e., elevated flood stage). If

Merrimack River influence is assumed to be a non-factor, flooding depths and duration are significantly less.

- Area 2 (Center Street near Argilla Brook): This area includes a small 36-inch corrugated metal outfall that appears to be partially crushed. There was standing water on either side of the outfall observed during the field data collection phase of the project. It appears that the outfall is undersized. Flooding occurs during the simulated 5-year existing conditions storm (< 0.5 feet). Simulated flooding increases to greater than 3 feet for the future 100-year storm. Simulated flooding at this location could be exacerbated because upstream culverts were not modeled – flooding issues could also extend to upstream culverts.
- Area 3 (Johnson Pond and Salem St. Dams): Flooding is simulated to occur in this area beginning with the future 25-year storm (and the existing 100-year storm). Simulated flooding for these storms is short duration (< 5 hours) with a depth of less than 0.5 feet. Flood duration increases to approximately 12 hours with depths approaching 1 foot during the simulated 100-year future storm.
- Area 4 (Primary Inlet to Johnsons Pond): Frequent flooding from undersized dual culverts is well documented at this location. Flooding at this area occurs during the simulated 5-year existing conditions storm (< 0.5 feet). Simulated flooding increases to up to 3 feet for the future 100-year storm. Note that simulated flooding at this location could be exacerbated because upstream restrictions were not modeled (e.g., culverts, Chadwick Pond outlet).

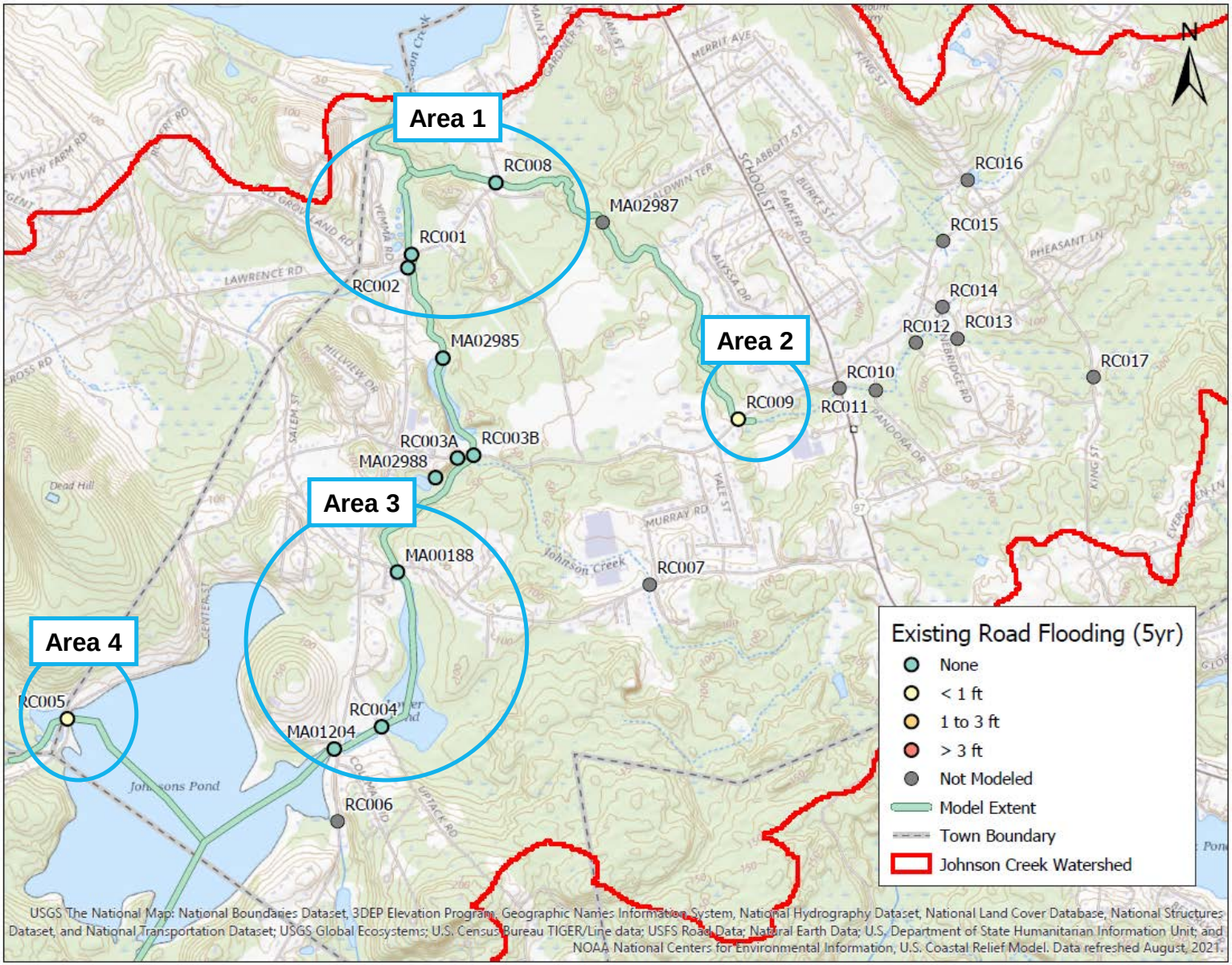

Figure 4-2. Simulated Baseline Flooding (5-Year Storm, Existing Conditions)

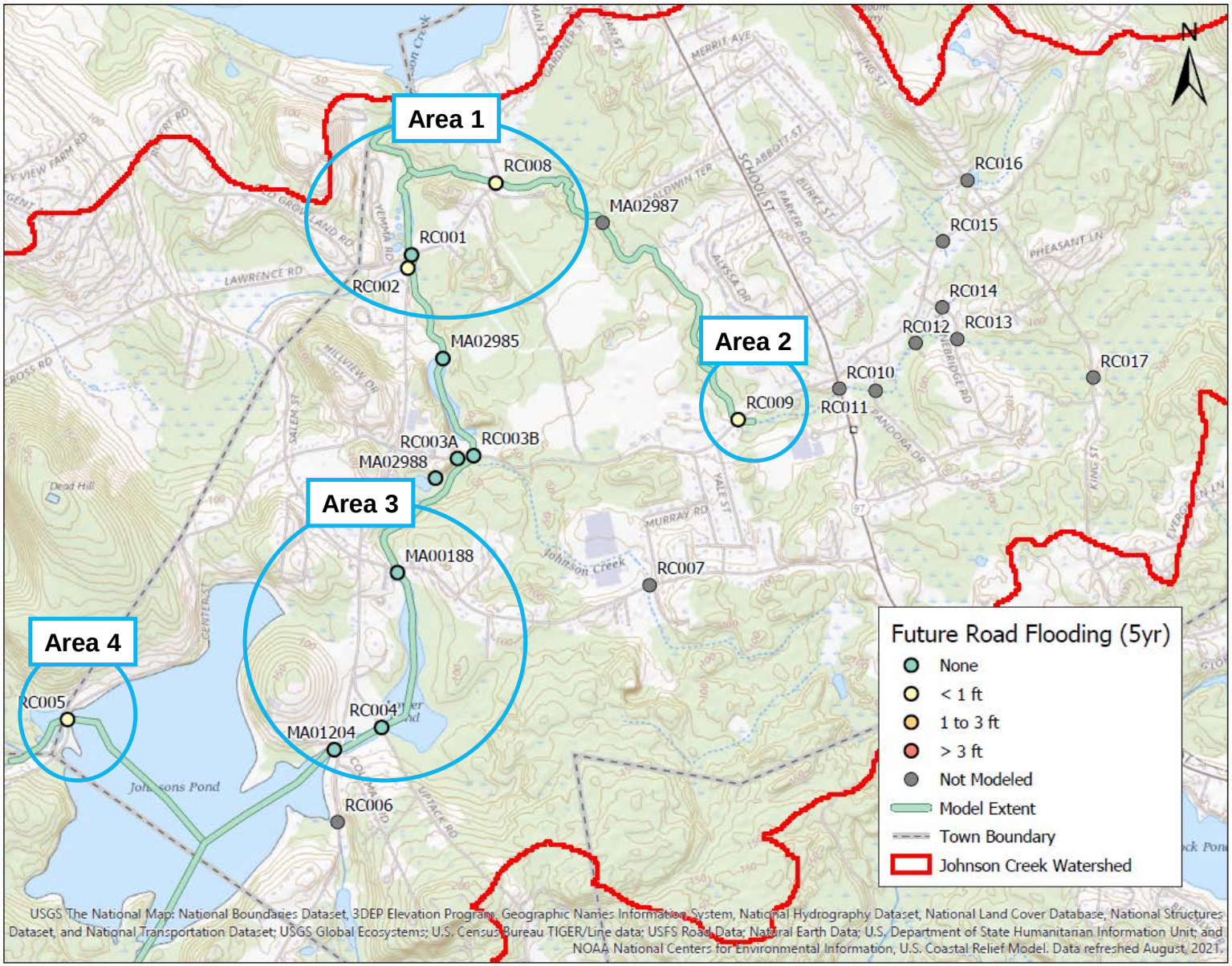

Figure 4-3. Simulated Baseline Flooding (5-Year Storm, Potential Future Conditions)

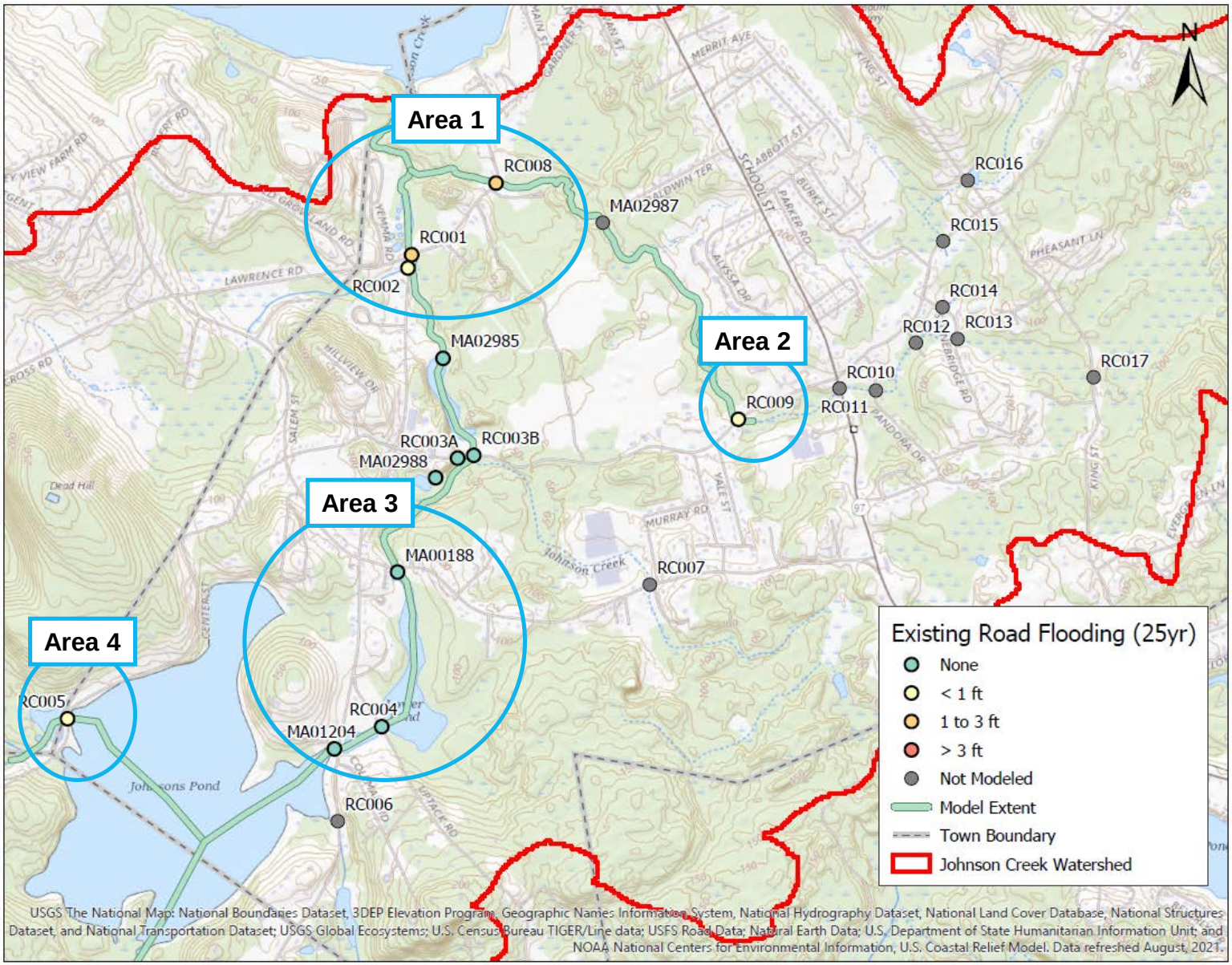

Figure 4-4. Simulated Baseline Flooding (25-Year Storm, Existing Conditions)

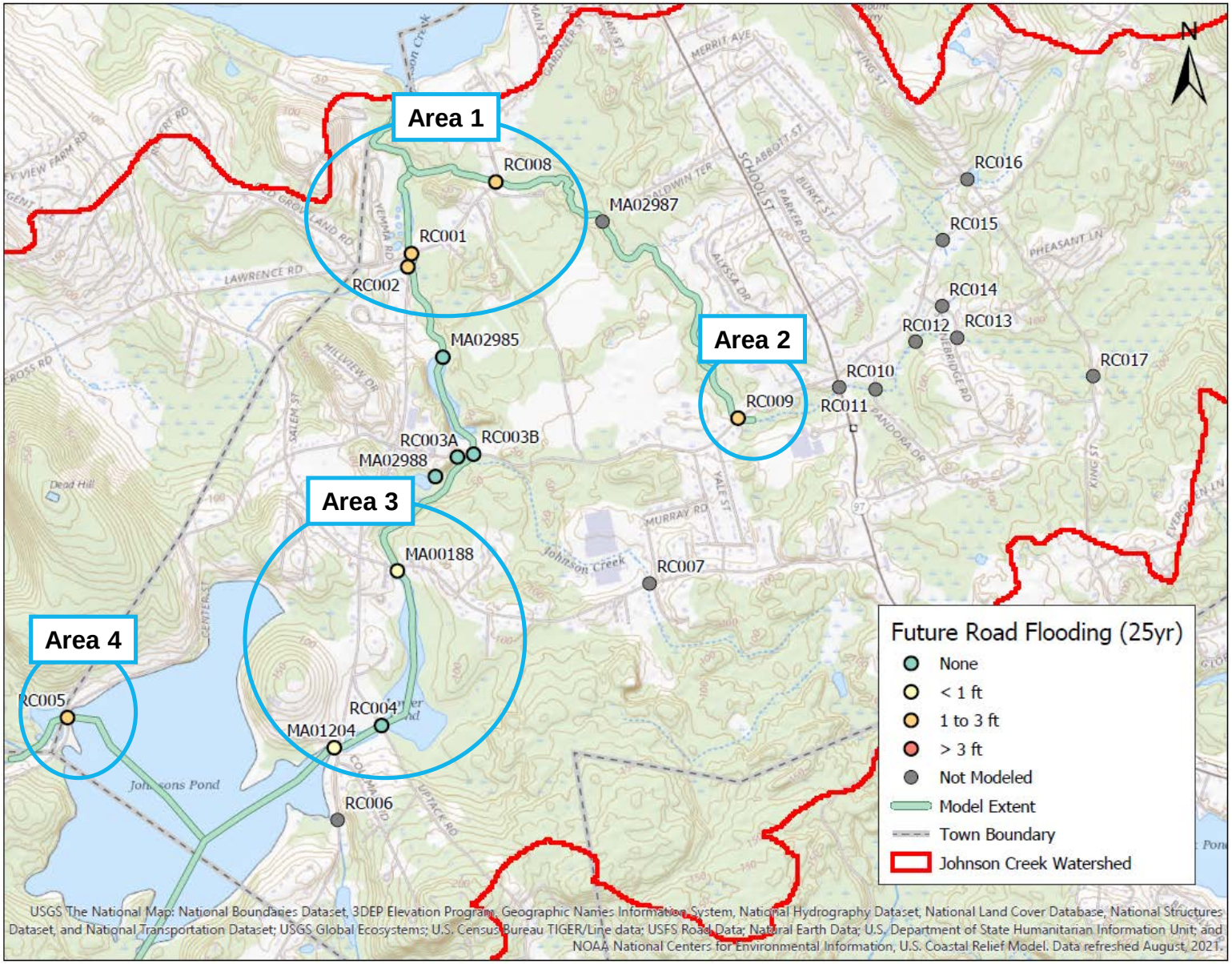

Figure 4-5. Simulated Baseline Flooding (5-Year Storm, Potential Future Conditions)

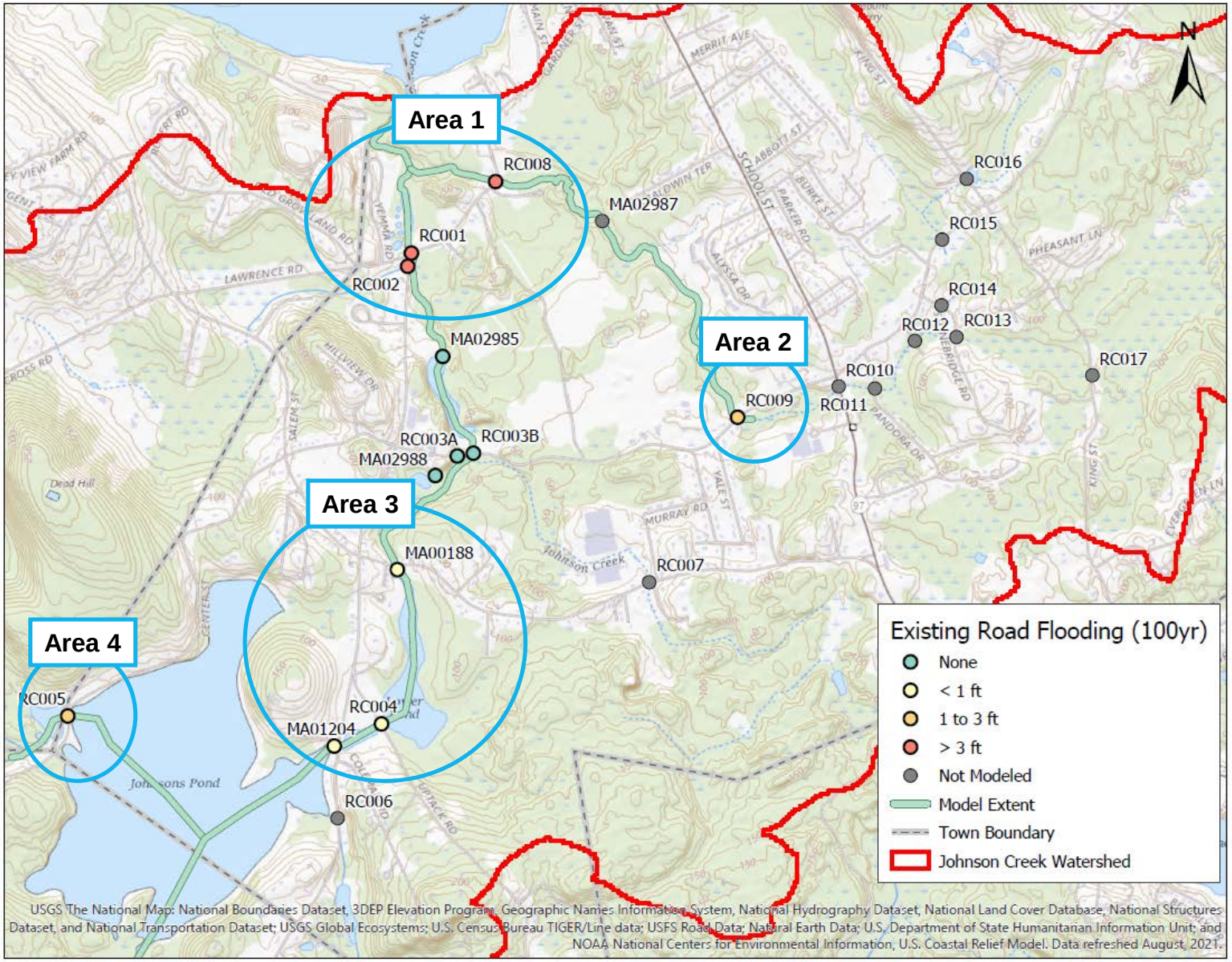

Figure 4-6. Simulated Baseline Flooding (100-Year Storm, Existing Conditions)

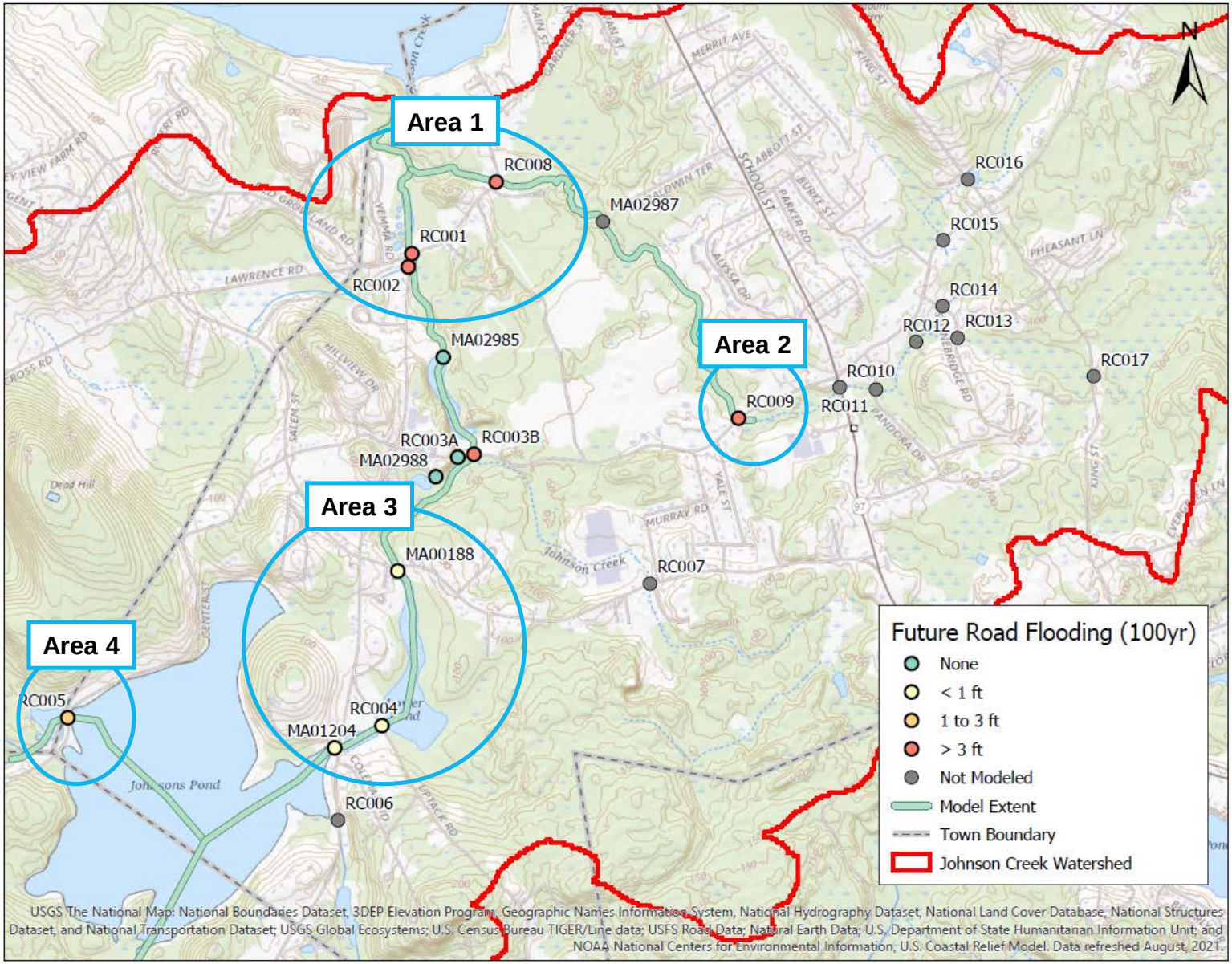

Figure 4-7. Simulated Baseline Flooding (5-Year Storm, Potential Future Conditions)

5 Potential Improvement Evaluation (Preliminary)

A list of 32 potential improvement recommendations were compiled based on the findings from the field assessment and baseline flooding analysis (see **Table 5-1**). Each potential recommendation was assigned an *issue magnitude* based on factors such as the severity of simulated flooding (if data was available), site condition, and other noted issues. From this list, 15 recommendations were selected for more detailed evaluation as presented in **Section 7** of this report. Detailed recommendations were selected for more detailed evaluation and prioritization based on issue magnitude, whether they were primarily **nature based solutions**, and based on discussion with the Town.

Although 15 of 32 potential recommendations were selected for more detailed evaluation, this preliminary list can still be used to plan for future lower priority improvement projects. See below for accompanying keys that can be used to interpret **Table 5-1**.

Simulated Flooding Key

	None
	< 1 foot
	1 to 3.5 feet
	> 3.5 feet

Issue Magnitude Key

H	Simulated Flooding > 3 ft; Poor Condition; Other
M	Simulated Flooding > 1 ft; Fair Condition; Other
L	Simulated Flooding < 1 ft; Other

Table 5-1. Preliminary List of Potential Improvement Projects

General Site Information			Existing Conditions						Potential Improvements	
Eval. ID	Location Reference	Site Type	Condition	Issue Summary	Simulated Flooding Results			Issue Magnitude	Brief Description of Improvements	Detailed Evaluation
					5-YR Future Storm	25-YR Future Storm	100-YR Future Storm			
RC005	Lower Center St.	Culvert	Poor	Undersized culverts and upgradient beavers cause road flooding and upstream scour and bank erosion.				H	Right-size and replace culvert; raise road elevation; improve stream continuity for fish and wildlife crossing; perform upstream and downstream streambank stabilization/restoration	Y
RC006	Washington St.	Culvert	Poor	Culvert is deformed and collapsing; upstream debris buildup; downstream channel erosion.	N/A	N/A	N/A	M	Repair culvert; address overgrown vegetation and upstream debris blockage; and perform downstream streambank stabilization/restoration	N
MA01204A	Washington St.	Dam	Fair	Outlet structure is deteriorating; controls are limited; beaver activity increases flood risk.				M	Repair or retrofit outlet structure to provide outlet control flexibility; enhance wildlife crossing at weir opening	Y
MA01204B	Washington St.	Culvert	Poor	Downstream portion of culvert is deteriorating.				H	Repair and replace culvert; enhance wildlife crossing	Y
RC004	Uptack Rd.	Culvert	Poor	Culvert is failing; sinkhole on roadway; beaver activity increases flood risk.				H	No recommendations; culvert is in the process of being replaced.	N
MA00188A	Salem St.	Dam	Fair	Outlet grate is deformed and is periodically clogged.				M	Repair or retrofit outlet structure to provide outlet control flexibility; enhance wildlife crossing at weir opening	Y
MA00188B	Salem St.	Culvert	Poor	Downstream culvert bottom is corroded and headwall is undermined; downstream channel bank is eroded.				H	Repair and replace culvert; enhance wildlife crossing; perform downstream streambank stabilization/restoration	Y
BEAVERDAM	Mill Street Ext.	Dam	Poor	Dam is a beaverdam, blocking downstream culvert				M	Remove beaverdam to improve stream continuity for fish and wildlife crossing purposes	N
MA02988	Mill Street Ext.	Culvert	Fair	Culvert is failing; upgradient beaver dam is blocking culvert inlet and is a flood risk.				M	Right-size and replace culvert; address beaver issues at the inflow; improve stream continuity for fish and wildlife crossing.	N
RC003A	Center St.	Culvert	Good	No observed issues.				L	No recommendations.	N
RC003B	Center St.	Culvert	Poor	Culvert is undermining and has exposed footings; upstream / downstream bank erosion.				H	Right-size and replace culvert; improve stream continuity for fish and wildlife crossing; perform upstream and downstream streambank stabilization/restoration	Y
RC007	Salem St.	Culvert	Fair	Upstream and downstream headwalls are cracking; culvert is corroded.	N/A	N/A	N/A	M	Replace collapsing headwall. Repair, or right-size and replace, culvert; improve stream continuity for fish and wildlife crossing.	N
MA02985A	E. of Washington St.	Dam	Fair	The spillway concrete is spalling				M	Assess and repair sinkhole/animal burrow on embankment. Consider creating an armored spillway to safely pass significant future storms.	N
MA02985B	E. of Washington St.	Culvert	Fair	Concrete at outlet structure is spalling; sinkhole observed near top of dam embankment.				M	No recommendations.	N
RC002	Washington St.	Culvert	Fair	Upstream wingwall is undermining; culvert surcharges during large storm events, likely undersized.				H	Right-size and replace culvert; repair undermining wingwall; raise road elevation; improve stream continuity for fish and wildlife crossing	Y
RC001	Main St.	Culvert	Good	Severe bank erosion and frequent debris accumulation at upstream channel.				H	Right-size and replace culvert; raise road elevation; improve stream continuity for fish and wildlife crossing; perform upstream streambank stabilization/restoration	Y
RC008	Main St.	Culvert	Good	Debris frequently observed at upstream channel.				H	Right-size and replace culvert; raise road elevation; address upstream debris blockage; improve stream continuity for fish and wildlife crossing	Y
MA02987	Baldwin Terr.	Dam	N/A	Dam fell apart nearly 20 years ago; streamflow is unimpeded.	N/A	N/A	N/A	L	Remove remnants of dam to improve stream continuity for fish and wildlife crossing purposes	N
RC009	Center St.	Culvert	Poor	Culvert appears to be collapsing or deforming.				H	Right-size and replace culvert; raise road elevation; improve stream continuity for fish and wildlife crossing	Y
RC010	School St.	Culvert	Good	Upstream channel is eroding and shows signs of instability (e.g., toppled tree)	N/A	N/A	N/A	L	Stabilize and restore upstream channel	N
RC011	Pandora Dr.	Culvert	Good	Debris frequently observed at upstream channel.	N/A	N/A	N/A	L	Address overgrown vegetation and upstream debris blockage	N
RC012	Center St.	Culvert	Good	No observed issues.	N/A	N/A	N/A	L	No recommendations	N
RC013	Stonebridge Rd.	Culvert	Good	Debris / blockage at downstream channel (i.e., toppled tree).	N/A	N/A	N/A	L	Stabilize and restore downstream channel and remove debris	N
RC014	Stonebridge Rd.	Culvert	Good	Upstream and downstream channel shows signs of instability (i.e., bank erosion) and blockages.	N/A	N/A	N/A	L	Stabilize and restore upstream channel and remove debris	N
RC015	Center St.	Culvert	Fair	Culvert headwall is failing; culvert appears undersized; channel erosion and debris blockage.	N/A	N/A	N/A	M	Right-size and replace culvert; reestablish stream continuity for fish and wildlife crossing; stabilize and restore upstream and downstream channel.	N
RC016	King St.	Culvert	Poor	Perched culvert is undermining; downstream embankment appears to be eroding.	N/A	N/A	N/A	M	Right-size and replace culvert; reestablish stream continuity for fish and wildlife crossing; stabilize and restore downstream embankment	N
RC017	King St.	Culvert	Fair	Culvert appears undersized and not set at the right elevation to properly drain upstream areas.	N/A	N/A	N/A	M	Right-size and replace culvert; reestablish stream continuity for fish and wildlife crossing	N
SC-MA01204	-	Subcatchment	N/A	N/A	N/A	N/A	N/A	L	Install bioretention area to collect parking lot runoff & waterbars to decrease road runoff velocity.	Y
SC-RC002	Groveland Park	Subcatchment	N/A	N/A	N/A	N/A	N/A	L	Install bioretention area to collect parking lot runoff.	Y
SC-RC009	Bagnall Elementary	Subcatchment	N/A	N/A	N/A	N/A	N/A	L	Install bioretention area to collect parking lot runoff and cistern to collect rooftop runoff.	Y
PARCEL1	Behind Groveland Gas	Parcel	N/A	N/A	N/A	N/A	N/A	L	Purchase parcel and protect from development to maintain floodplain function	Y
PARCEL 2	Lower Center St.	Parcel	N/A	N/A	N/A	N/A	N/A	L	Purchase parcel and protect from development to maintain floodplain function	Y

6 Flooding Evaluation for Proposed Improvements

6.1 Evaluation Methods

Applicable improvements were modeled in **Stages** to assess potential **incremental** benefits and unanticipated consequences (e.g., verify that proposed improvements don't exacerbate downstream flooding). Changes made to the base scenario for the Staged model simulations scenarios are as follows:

- Stage 1: Repair or retrofit existing outlet controls at MA01204 (Johnson Pond Dam) and MA00188 (Lower Pond Dam at Salem Street) to enable drawdown prior to forecast significant storm events. To simulate this Stage, the model was adjusted to decrease the initial water level of the Johnson Pond and Lower Pond impoundments and to decrease weir elevations to simulate lower stop log settings.
- Stage 2: Perform stream continuity improvements at RC005 (Lower Center Street), RC009 (Center Street), and RC002 (Main Street). These represent the primary modeled "upstream" culverts that appear to be undersized along the mainstem. The purpose of this Stage was to evaluate whether replacement of these culverts could cause adverse effects to "downstream" culverts – for example, evaluate whether replacing RC001 could increase flooding of downstream RC002. The size of applicable culverts in the model was increased in accordance with the Massachusetts Stream Crossing Standards as described in more detail in **Section 7**.
- Stage 3: Combination of Stage 1 and Stage 2.
- Stage 4: Combination of Stage 3 and stream continuity improvements at RC008 (Main Street), RC001 (Washington Street), and RC003B (Center Street). These represent the primary modeled "downstream" culverts that appear to be undersized along the mainstem. The purpose of this Stage was to evaluate whether overall improvements are more pronounced if these culverts are replaced – i.e., evaluate whether they are a bottleneck and are contributing to upstream flooding. The size of applicable culverts in the model was increased in accordance with the Massachusetts Stream Crossing Standards as described in more detail in **Section 7**.
- Stage 5: Combination of Stage 4 and implementation of green infrastructure at three (3) subcatchments. The purpose of this evaluation was to understand whether implementation of green infrastructure has the potential to decrease peak runoff rates and decrease subsequent downstream flooding. Green infrastructure was simulated using the LID module of SWMM. To evaluate the **upper limit** of potential improvements, five (5) bioretention areas with dimensions of approximately 50 feet by 50 feet and associated ponding storage were simulated in each of the three (3) evaluated subcatchments.

Note: As described in **Section 6.1.3**, it appears that will be little to no unanticipated consequences to roadway flooding based on the Stage (or sequence) of implementation. For brevity, the below mostly focuses on results from Stage 5 which assumes that all proposed improvements have been implemented.

6.2 Discharge Results

Simulated outfall discharge results comparing Baseline conditions (no improvements) to Stage 5 conditions (all proposed improvements) are presented by **Table 6-1**. Takeaways are as follows:

- It appears that peak discharge will remain relatively **unchanged** based upon completion of proposed Stage 5 improvements for all simulated storm events. For example, the predicted peak discharge for the 100-year future conditions Baseline simulation is 2,367 cfs as compared to 2,381 for the Stage 5 simulation.

- It appears that average discharge will **increase** based upon completion of proposed Stage 5 improvements for most simulated storm events. For example, the predicted average discharge for the 100-year existing conditions Baseline simulation is 580 cfs as compared to 594 for the Stage 5 simulation. This is likely from upsizing the culverts and increasing the flow capacity throughout the conveyance system.

Table 6-1. Discharge Comparison at the Outfall to the Merrimack River

Simulation Type	Return Period	Baseline Results		Stage 5 Results	
		Avg. Discharge (cfs)	Peak Discharge (cfs)	Avg. Discharge (cfs)	Peak Discharge (cfs)
Existing	5-yr	196	331	209	332
	25-yr	385	734	402	718
	100-yr	580	1332	594	1336
Future	5-yr	267	475	282	480
	25-yr	591	1316	591	1316
	100-yr	1062	2378	962	2381

6.3 Roadway Flooding Results

A Comparison of flood depth simulation results between Baseline conditions and proposed improvement Stages (i.e., Stage 1 through 5) for the 100 year existing storm is provided by **Table 6-2**. As indicated by the Table, there is minimal to no potential increase in downstream flooding based upon the implementation Stage of improvements (i.e., if upstream culverts are replaced before downstream culverts). The Table also indicates that it is possible to implement proposed improvements sequentially to provide incremental flooding benefits over time – for example, perform Stage 1 dam outlet modifications to eliminate or decrease flooding at the outlet of Johnsons Pond (MA01024) and Salem Street Dam (MA00188), then progress to stream continuity improvements to eliminate or decrease flooding at other locations. Assuming that all proposed improvements are implemented (Stage 5), simulated flooding is eliminated or significantly decreased at all locations. The Table also indicates that the addition of subcatchment green infrastructure (Stage 5) will likely not result in any noticeable flooding depth reductions.

Table 6-2. Comparison of Flood Depth Results for Model Stages (100-yr Existing Storm)

Evaluation Location	Simulated Road Flooding Depth (ft)					
	Baseline	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
RC005	1.3	1.3	0	0	0	0
MA01204	0.42	0	0.401	0	0	0
RC004	0.05	0	0.052	0	0	0
MA00188	0.24	0	0.24	0	0	0
MA02988	0	0	0	0	0	0
RC003A	0	0	0	0	0	0
RC003B	0	0	0	0	0	0
MA02985	0	0	0	0	0	0
RC002	4.07	4.07	1.06	1.07	1.08	1.08
RC001	4.84	4.84	4.84	4.84	1.84	1.84
RC008	3.42	3.42	3.41	3.41	0.92	0.92
RC009	2.01	2.01	0	0	0	0

Refer to **Figure 6-1** through **Figure 6-6** for a series of maps depicting simulated flooding depths for Stage 5 (i.e., implementation of all proposed improvements) for all simulated storms. Takeaways as compared to Baseline Conditions (**Figure 4-2** through **Figure 4-7**) for each of the four (4) primary areas of concern are as follows:

- Area 1 (downstream portion of the watershed): Under Baseline Conditions (no improvements), simulated flooding begins at the 5-year future storm. Under Stage 5 Conditions (all improvements implemented), roadway flooding of less than 1 foot is simulated to occur at RC008 (Main Street) during the future 25 year storm. Simulated flooding expands to RC001 (Main Street) and RC002 (Washington Street) during the existing 100-year and future 100-year storms where simulated depths could potentially exceed 3 feet. The Merrimack River stage has a large influence on potential flooding in these areas. Assuming no influence from the Merrimack River, the flood duration at all three locations in this area (RC001, RC002, and RC008) decreases to approximately 5 hours of less, with significantly reduced simulated road flooding depths.
- Area 2 (Center Street near Argilla Brook): Under Baseline Conditions (no improvements), simulated flooding begins during the 5-year future storm. Under Stage 5 Conditions (all improvements implemented), simulated roadway flooding of less than 3 feet is only simulated to occur at this location during the future 100-year storm.
- Area 3 (Johnson Pond and Salem St. Dams): Under Baseline Conditions (no improvements), simulated flooding begins during the 25-year future storm. Under Stage 5 Conditions (all improvements implemented), simulated roadway flooding of less than 1 foot is only simulated to occur at MA01204 (Johnson Pond Outlet) during the future 100-year storm.
- Area 4 (Primary Inlet to Johnsons Pond): Under Baseline Conditions (no improvements), simulated flooding begins during the existing 5-year storm. Under Stage 5 Conditions (all improvements implemented), simulated short duration (i.e., < 5 hours) roadway flooding of less than 1 foot is only simulated to occur at this location during the future 100-year storm.

Based on these observations, implementation of proposed improvements (Stage 5) have the potential to greatly improve flooding conditions throughout the mainstem of the watershed during all simulated storms.

6.4 Subcatchment Runoff Results

Finally, an evaluation of the potential impact on green infrastructure on potential runoff reduction and subsequent downstream flooding was performed – see **Appendix B** for a tabulation of results. Based on evaluation of these results, implementation of green infrastructure (Stage 5 improvements) has the potential to **slightly** decrease total subcatchment runoff, but will likely not have an impact on downstream flooding elevations (i.e., see **Table 6-1**). Although the effect of implementing green infrastructure will be minimal for large flooding events, the overall benefits that they provide, particularly during smaller events, is substantial. More discussion on the benefits of green infrastructure is provided in **Section 7**.

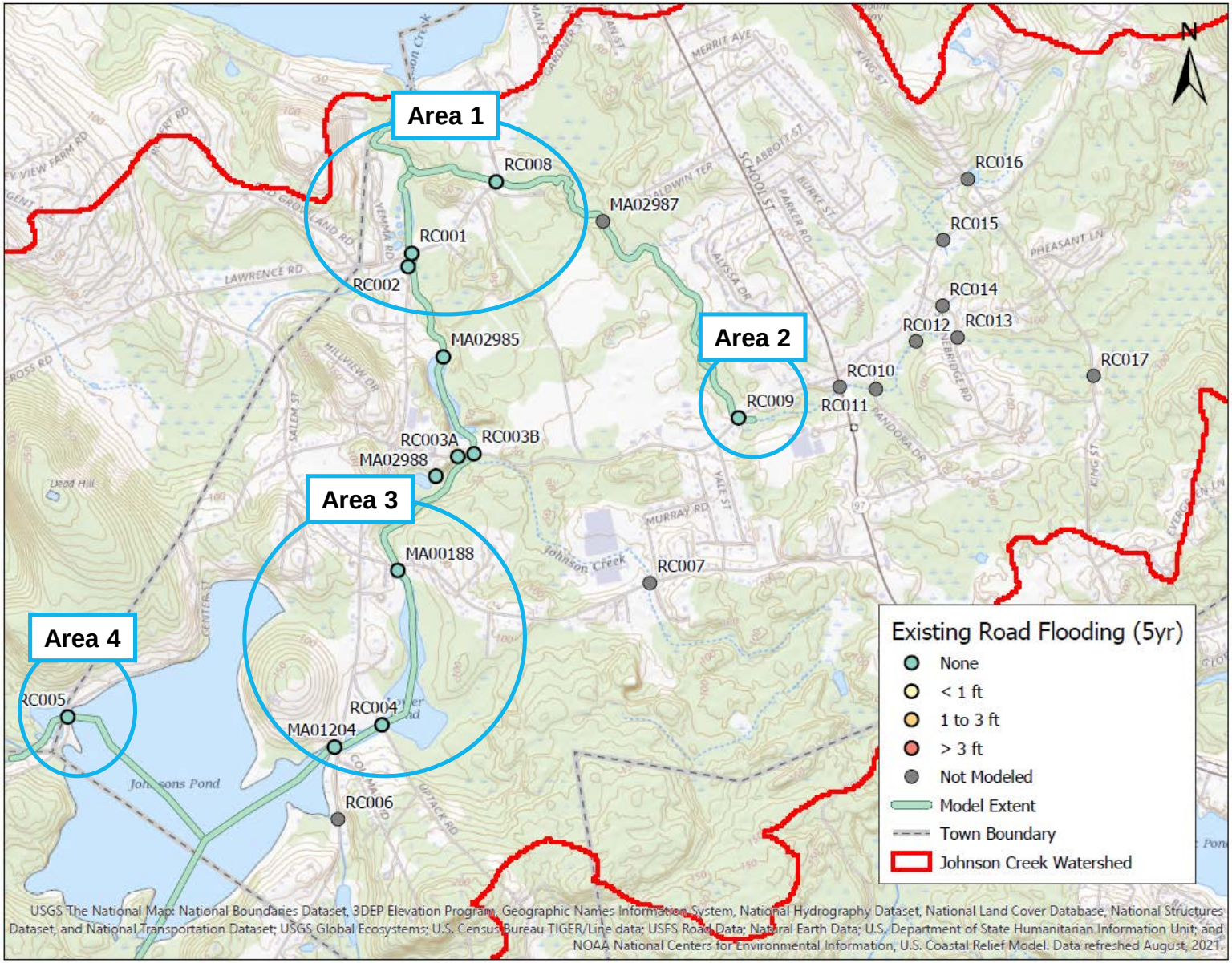

Figure 6-1. Simulated Potential Flooding with Improvements (Stage 5, 5-Year Storm, Existing Conditions)

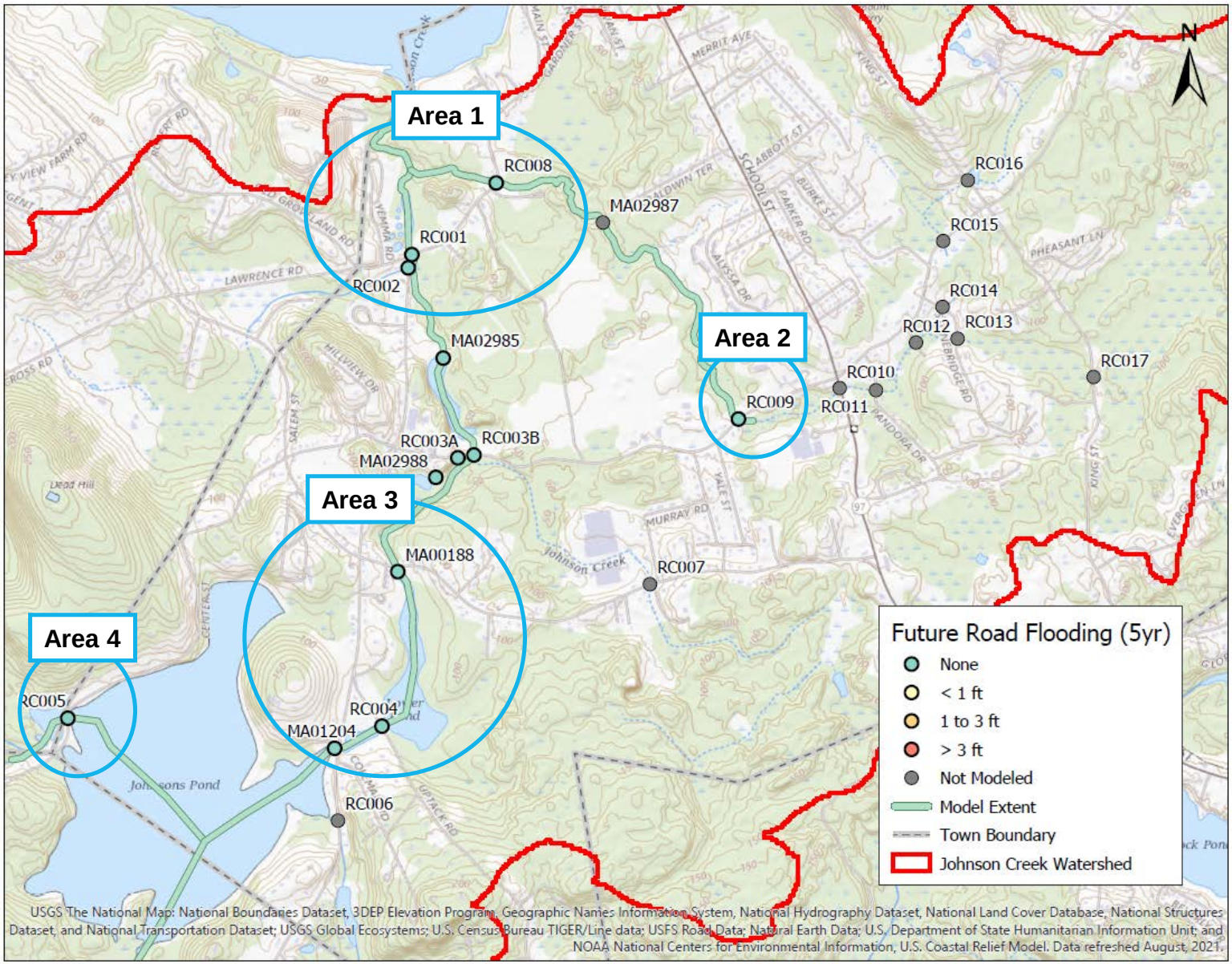

Figure 6-2. Simulated Potential Flooding with Improvements (Stage 5, 5-Year Storm, Potential Future Conditions)

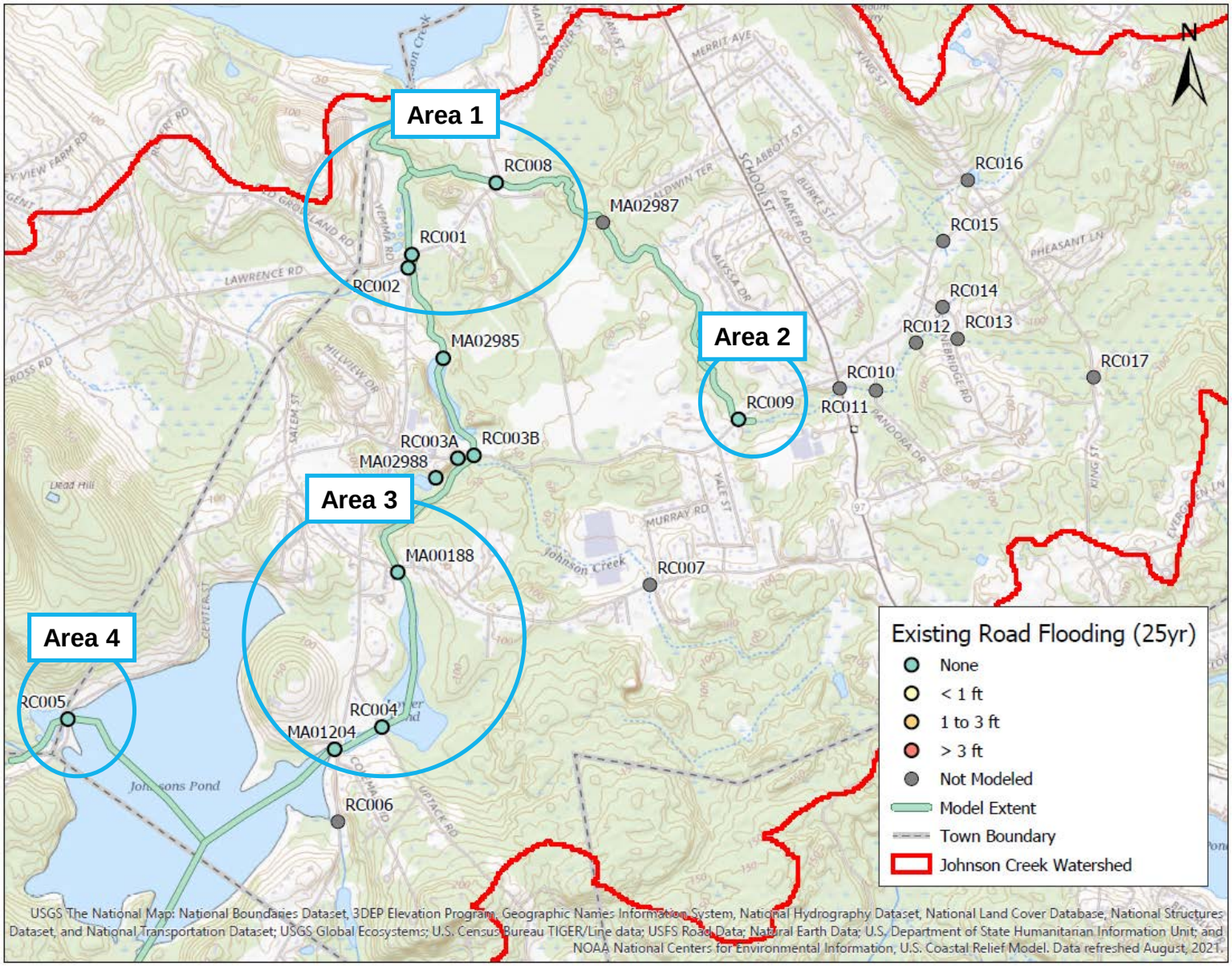

Figure 6-3. Simulated Potential Flooding with Improvements (Stage 5, 25-Year Storm, Existing Conditions)

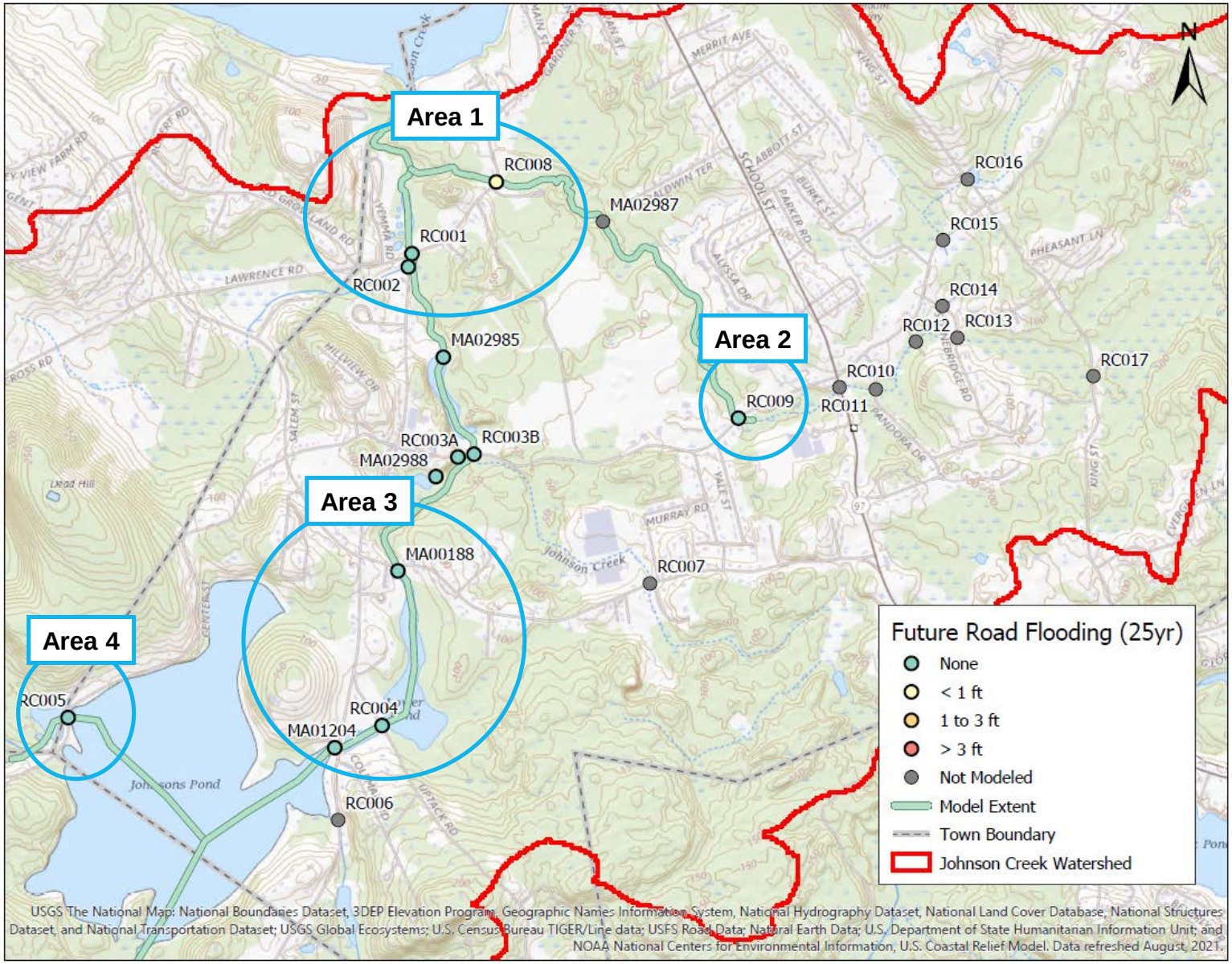

Figure 6-4. Simulated Potential Flooding with Improvements (Stage 5, 25-Year Storm, Potential Future Conditions)

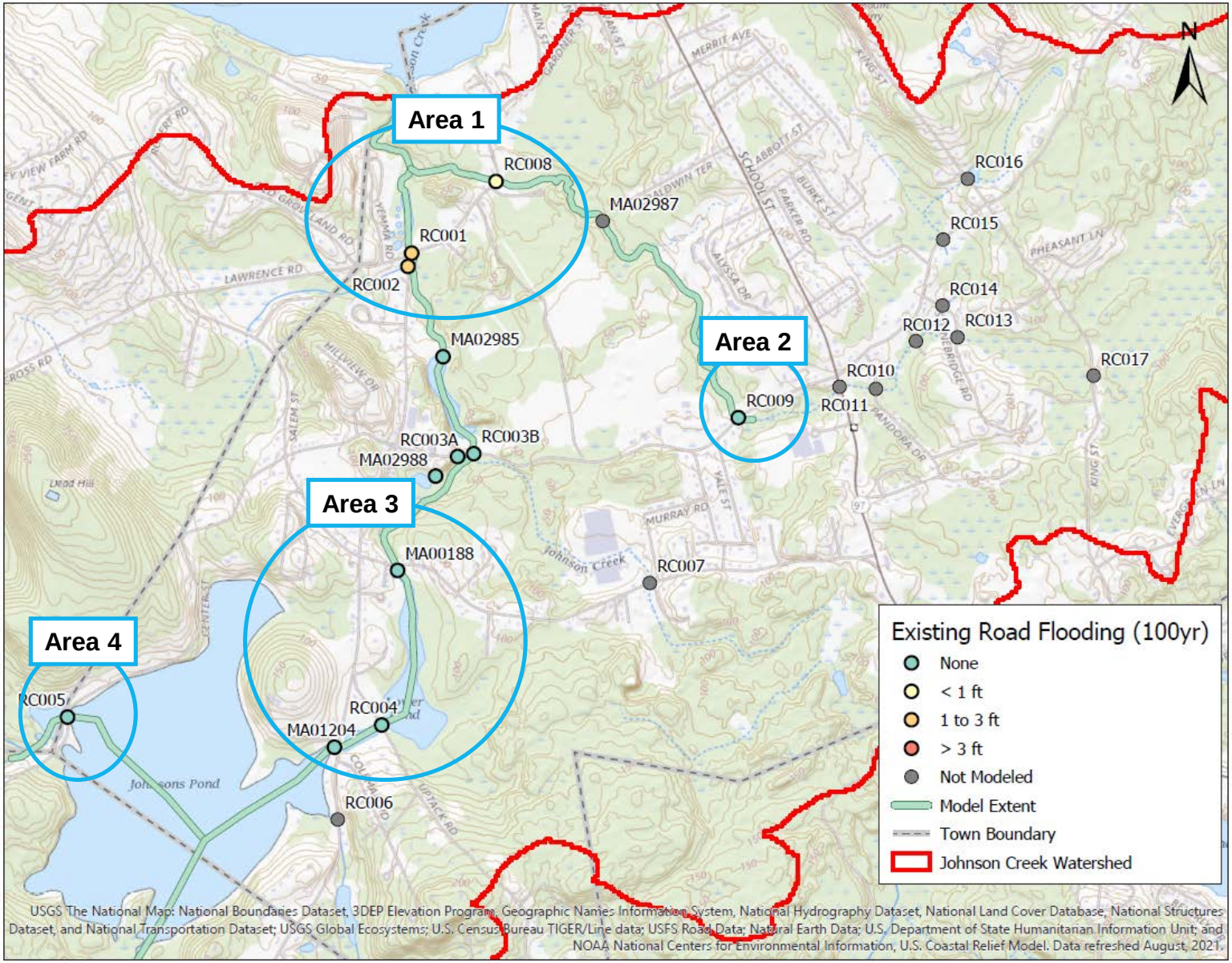

Figure 6-5. Simulated Potential Flooding with Improvements (Stage 5, 100-Year Storm, Existing Conditions)

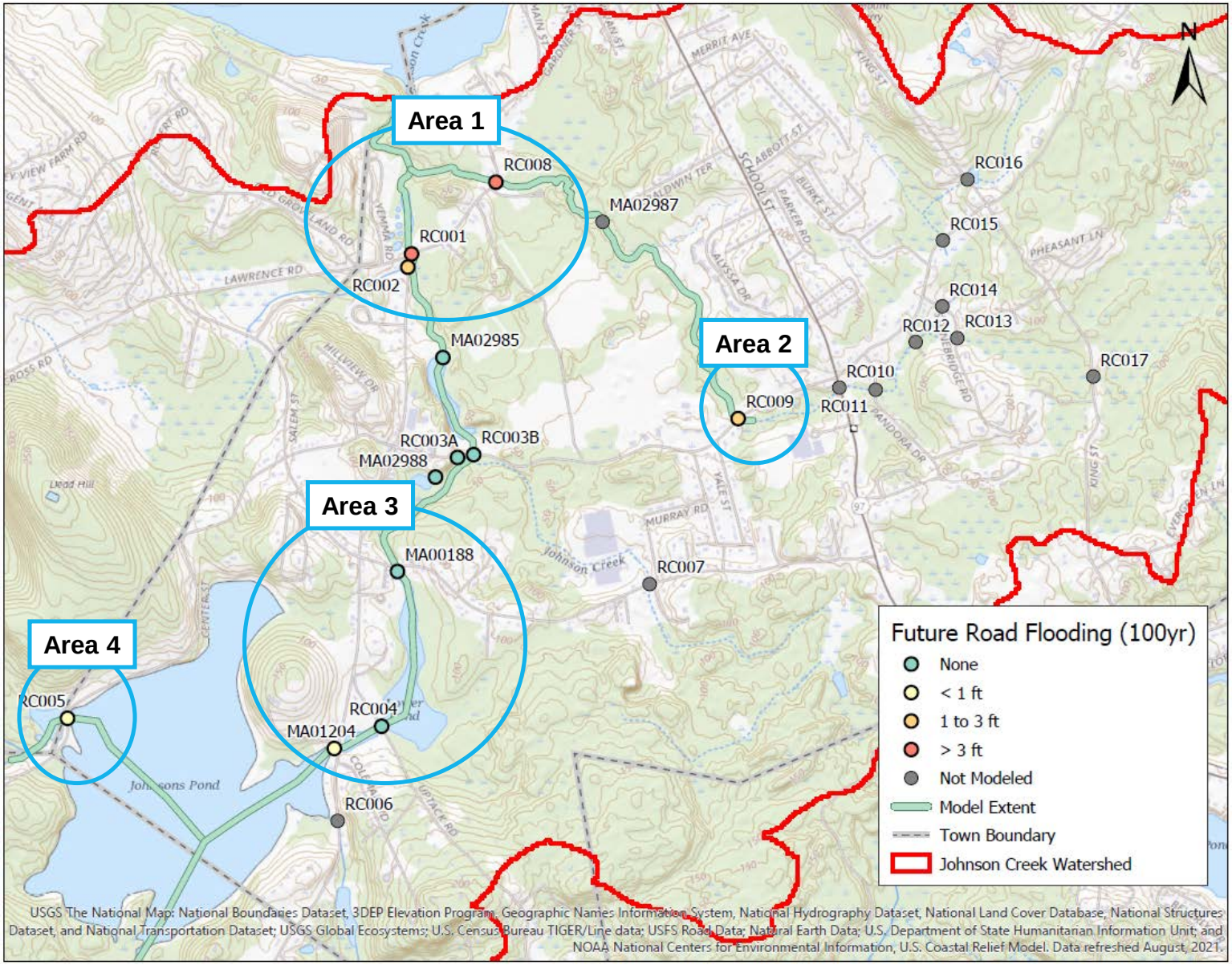

Figure 6-5. Simulated Potential Flooding with Improvements (Stage 5, 100-Year Storm, Potential Future Conditions)

7 Potential Improvement Evaluation (Detailed)

As previously indicated, a list of 15 recommendations was selected for more detailed evaluation. See **Section 5** for a larger list of preliminary recommendations. The purpose of this section is to describe how these 15 detailed recommendations were developed and ranked.

7.1 Recommendation Summary

Detailed conceptual recommendations for 15 potential improvements were developed based on results from previous sections of this report (see **Appendix C**). Information provided for each potential improvement includes the following:

- A site description, including location coordinates and existing issues;
- A summary of proposed improvements, including annotated photos;
- A discussion of potential flooding improvements;
- A discussion of anticipated **nature based components**; and
- Estimated planning level cost and recommended implementation priority.

A site map and accompanying summary table of proposed improvements is provided by **Figure 7-1** and **Table 7-1**, respectively. The summary table also includes information on anticipated permitting, design standards, and potential implementation complexity. Recommendations can generally be split into the following categories:

- Perform stream continuity improvements and restoration.
- Repair/retrofit dam outlets and modify operations to mimic natural floodplain function.
- Install green infrastructure.
- Purchase parcel to protect from development and maintain floodplain function.

It is recommended that Town work to implement the "**High Priority**" recommendations first. To that end, the Town submitted an application to the FY23 MVP Action Grant Program in May 2022 to fund implementation of three (3) "High Priority" Projects:

- SC-RC002: Install bioretention basin at Groveland Park.
- RC005: Perform stream continuity improvements at Lowe Center Street (inlet to Johnsons Pond)
- MA01204A: Perform retrofits to Johnsons Pond outlet structure to enable operations to mimic natural floodplain function (i.e., pre-storm releases).

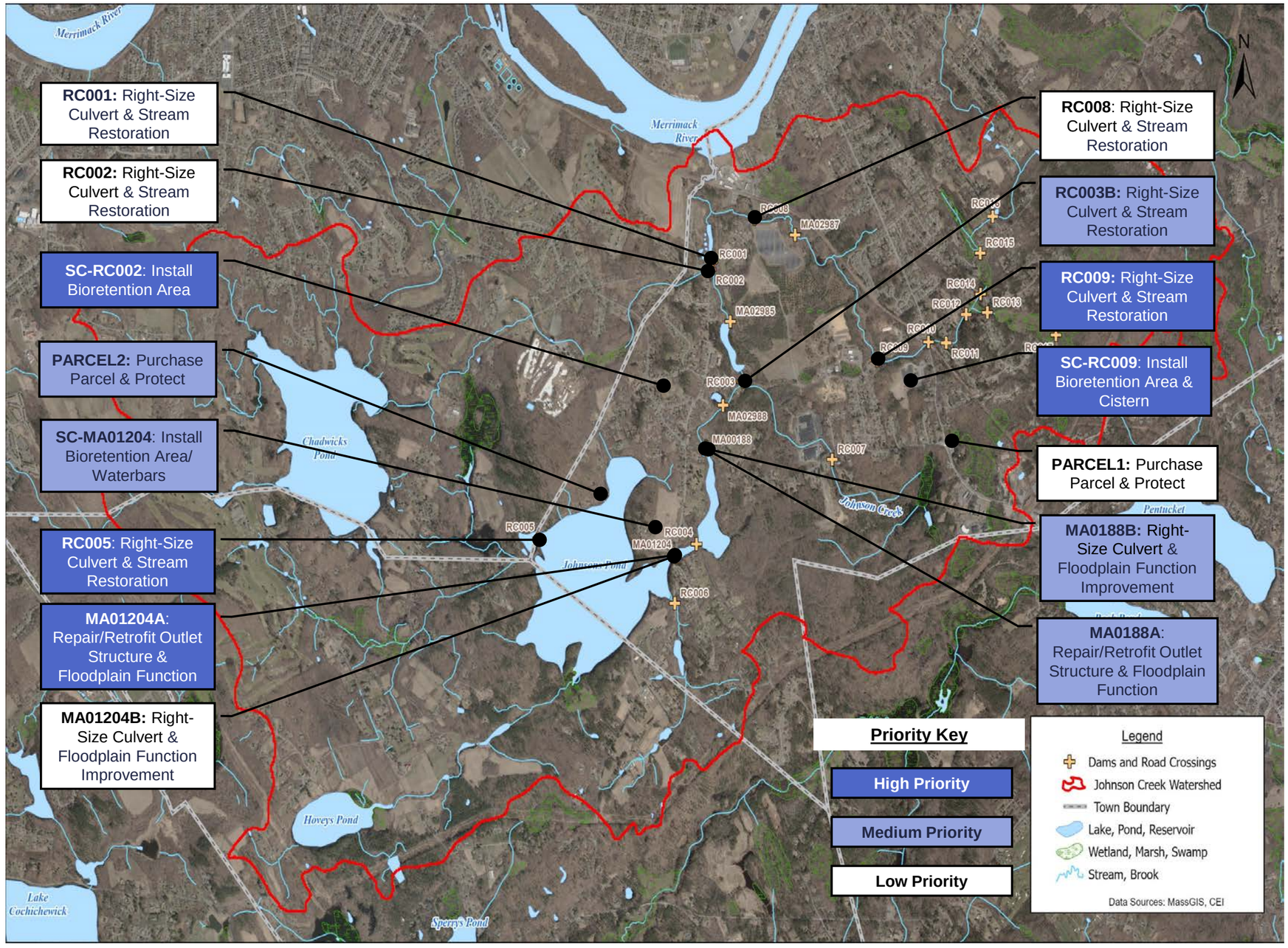

Figure 7-1. Site Map of Prioritized Recommendations

Table 7-1. Summary of Prioritized Recommendations

Eval. ID	Location Ref.	Site Type	Brief Description of Improvements	Nature-Based Solution				Environmental Co-Benefits								Anticipated and Potential Permitting[1]							Imp. Complex.[2]	Ordered of Magnitude Capital Cost Estimate[3]	Priority Rank[4]
				Floodplain Function	Stream Restoration	Green Infrastructure	Land Preservation	Flood Mitigation	Water Quality	Regulation of Water Cycle	Groundwater Recharge	Soil Quality & Erosion Prev.	Biodiversity	Pollination	Carbon Storage	WPA NOI	NHESP	401 WQC	MA GP	Chapter 85	Chapter 253	Phase I ESA			
RC005	Lower Center St.	Stream Crossing	Right-size and replace culvert; raise road elevation; improve stream continuity for fish and wildlife crossing; perform upstream and downstream streambank stabilization/restoration	✓	✓			✓	✓	✓	✓	✓	✓		✓	●		◐	◐	●			M	$ 380,000.0 - $ 480,000.0	H
MA01204A	Washington St.	Dam	Repair or retrofit outlet structure to provide outlet control flexibility; enhance wildlife crossing at weir opening	✓				✓		✓	✓	✓	✓		✓	●	◐	◐	◐		●		L	$ 60,000.0 - $ 80,000.0	H
MA01204B	Washington St.	Culvert	Repair and replace culvert; enhance wildlife crossing	✓				✓		✓	✓	✓	✓		✓	●	◐	◐	◐	◐	●		H	$ 310,000.0 - $ 390,000.0	L
MA00188A	Salem St.	Dam	Repair or retrofit outlet structure to provide outlet control flexibility; enhance wildlife crossing at weir opening	✓				✓		✓	✓	✓	✓		✓	●	◐	◐	◐		●		M	$ 120,000.0 - $ 150,000.0	M
MA00188B	Salem St.	Culvert	Repair and replace culvert; enhance wildlife crossing; perform downstream streambank stabilization/restoration	✓	✓			✓	✓	✓	✓	✓	✓		✓	●	◐	◐	◐	◐	●		H	$ 580,000.0 - $ 730,000.0	M
RC003B	Center St.	Stream Crossing	Right-size and replace culvert; improve stream continuity for fish and wildlife crossing; perform upstream and downstream streambank stabilization/restoration	✓	✓			✓	✓	✓	✓	✓	✓		✓	●	◐	◐	◐	●			H	$ 480,000.0 - $ 600,000.0	M
RC002	Washington St.	Stream Crossing	Right-size and replace culvert; repair undermining wingwall; raise road elevation; improve stream continuity for fish and wildlife crossing	✓	✓			✓	✓	✓	✓	✓	✓		✓	●	◐	◐	◐	●			H	$ 310,000.0 - $ 390,000.0	L
RC001	Main St.	Stream Crossing	Right-size and replace culvert; raise road elevation; improve stream continuity for fish and wildlife crossing; perform upstream streambank stabilization/restoration	✓	✓			✓	✓	✓	✓	✓	✓		✓	●	◐	◐	◐	●			H	$ 480,000.0 - $ 600,000.0	L
RC008	Main St.	Stream Crossing	Right-size and replace culvert; raise road elevation; address upstream debris blockage; improve stream continuity for fish and wildlife crossing	✓	✓			✓	✓	✓	✓	✓	✓		✓	●	◐	◐	◐	●			H	$ 380,000.0 - $ 480,000.0	L
RC009	Center St.	Stream Crossing	Right-size and replace culvert; raise road elevation; improve stream continuity for fish and wildlife crossing	✓	✓			✓	✓	✓	✓	✓	✓		✓	●	◐	◐	◐	●			M	$ 380,000.0 - $ 480,000.0	H
SC-MA01204	-	Subcatch.	Install bioretention area to collect parking lot runoff & waterbars to decrease road runoff velocity.	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	◐							L	$ 60,000.0 - $ 80,000.0	M
SC-RC002	Groveland Park	Subcatch.	Install bioretention area to collect parking lot runoff.	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓								L	$ 70,000.0 - $ 90,000.0	H
SC-RC009	Bagnall Elementary	Subcatch.	Install bioretention area to collect parking lot runoff and cistern to collect rooftop runoff.	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	◐							L	$ 70,000.0 - $ 80,000.0	H
PARCEL 1	Behind Groveland Gas	Parcel	Purchase parcel and protect from development to maintain floodplain function	✓			✓	✓		✓	✓	✓	✓		✓							◐	M	$1,760,000.0 - $2,200,000.0	L
PARCEL 2	Lower Center St.	Parcel	Purchase parcel and protect from development to maintain floodplain function	✓			✓	✓		✓	✓	✓	✓		✓							◐	M	$ 320,000.0 - $ 400,000.0	M

Notes:
1. See Report Section 7 for a description of Permits.
2. Overall implementation complexity is a qualitative indicator based on misc. criteria and professional judgement (e.g., property ownership, site access, permitting complexity, construction complexity, potential for traffic impacts, etc.)
3. Order of Magnitude Capital Planning Costs assume construction costs and engineering costs (i.e., design, permitting, survey).
4. Priority Rank is based on factors such as number of nature-based solutions, number of environmental co-benefits, overall implementation complexity, and cost estimate.

7.2 Recommendation Discussion

The purpose of this section is to provide more information on the detailed recommendations summarized in **Section 7.1**. Topics covered in this section include anticipated **nature based components** of proposed improvements, anticipated permitting and design, cost estimates, and development of site prioritization scoring criteria.

7.2.1 Nature-Based Components and Associated Environmental Co-Benefits

Stream Continuity and Streambank Restoration Recommendations[1]

- Replacement culverts will have (1) a span of at least 1.2x average bankfull width, (2) a minimum height of 6 feet, and (3) an openness ratio of at least 1.64 ft to meet optimum stream crossing standards per Division of Ecological Restoration (DER).
- Replacement culverts will be open-bottom. The embedment depth will be at least 2 feet or at least twice the D84 of the natural streambed material when the embedment material includes elements >15 inches in diameter. A pebble count will be completed to determine the embedment depth (DER).
- Natural bottom substrate will be used within the crossing and will match upstream and downstream streambed material to maximize stream continuity and reestablish fish and wildlife crossing (DER).
- Water depths and velocities will be reestablished such that they are comparable to natural flow conditions in the channel to maximize stream continuity and reestablish fish and wildlife crossing (DER).
- Streambanks will be stabilized with native vegetation where there is evidence of significant erosion and/or undercutting.

Floodplain Function Recommendations[2]

- Weirs will be repaired / retrofitted to provide appropriate hydraulic capacity and thus enhancing the natural floodplain functions of the impoundment.
- Natural floodplain function includes fish and wildlife protection, natural flood and erosion control, surface water quality maintenance, groundwater recharge, biological productivity, and higher recreational opportunities (FEMA).
- Enhancing natural floodplain function will provide excess water storage, reduce flood peaks, reduce flood velocities, reduce flow rate, reduce potential for erosion, slows down surface runoff, allows additional time for infiltration and groundwater recharge, and regulates flow during non-flood periods (FEMA).

Green Infrastructure Recommendations[3]

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[1] https://www.mass.gov/doc/massachusetts-stream-crossing-handbook/download

[2] https://www.fema.gov/floodplain-management/wildlife-conservation/benefits-natural

[3] https://www.mass.gov/guides/massachusetts-stormwater-handbook-and-stormwater-standards

- Bioretention areas will enhance exfiltration of stormwater runoff into groundwater. Bioretention areas will help decrease peak runoff, decrease downstream flooding, promote groundwater recharge, preserve natural water balance of the site, remove pollutants from stormwater runoff, enhance the habitats of amphibians or other small animals, and provide a pollinator habitat (MassDEP).
- Bioretention areas will (1) have some form of pretreatment, (2) be 5-7% of the drainage area, (3) be 2 feet above the groundwater table, (4) have a soil media depth between 2-4 feet, (5) have soil media composition and planting schedule meeting guidelines for bioretention systems designed to exfiltrate (MassDEP).

Land Preservation Recommendations

- By acquiring land, the Town may ensure that it is not developed.
- Preserving the natural landscape will prevent increase in stormwater runoff from the addition of impervious areas, eliminate the potential to worsen downstream flooding, protect existing water resources from pollution, potentially provide open spaces and parks/trails for the community, and protect existing forested areas and wildlife habitat from destruction.
- The potential land acquisition properties recommended in **Table 7-1** and summarized in more detail in **Appendix C** were selected based on discussions with the Town of known parcels that abut and provide buffer to critical ecological habitat (e.g., wetlands, Johnsons Pond). As recommended in **Section 7.2.5**, future efforts may seek to identify a more exhaustive list of potential acquisition targets throughout the entire watershed or Town.

7.2.2 Anticipated Permitting & Design Parameters for Recommendations

Anticipated permitting and design parameters for the proposed recommendations were determined based on a combination of available specifications and guidance, as summarized below.

Stream Continuity (Right-Sizing Culverts)

- Permitting: Anticipated and potential permitting requirements for culvert right-sizing were determined based on: (1) site location, (2) culvert dimensions, and (3) permitting completed for similar projects.
    - Anticipated permitting for all culverts:
        - Wetland Protection Act (WPA) Notice of Intent (NOI) Submittal for Temporary and Permanent Impacts to Buffer Zone & Resource Areas with MassDEP and Local Conservation Commission
    - Anticipated permitting for culvert spans greater than 10 feet:
        - MGL Chapter 85 Chapter 35 Review for a Proposed 'BRI' Bridge (10 ft < span < 20 ft) or 'NBI' Bridge (span > 20 ft) with MassDOT
    - Potential permitting:
        - MESA Review for work within NHESP Priority Habitat of Rare Species and NHESP Estimated Habitat of Rare Wildlife
        - 401 Water Quality Certification for >100 CY Fill and/or Excavation in Waters and Wetlands with MassDEP
        - Massachusetts General Permit for Any Work, including Construction and Dredging, Within the Nation's Navigable Waterways with US Army Corps of Engineers

- Design: Replacement culverts can be sized to (1) meet minimum hydraulic requirements (based on MassDOT roadway functional class or local specifications for the road) and/or (2) meet the DER Stream Crossing Performance Standards to the maximum extent practicable.
    - If the project is being funded by EEA/DER (i.e., MVP or CRMA Grant), the culvert **must** be designed based upon the MA Stream Crossing Performance Standards.
    - If the project is being funded by MassDOT (i.e., Small Bridge Program Grant) or the bridge span is greater than 10 feet, the culvert **must** be designed based upon MA Chapter 85 Design Requirements.
    - In most cases, preliminary culvert dimensions assume that the proposed culvert improvement would be designed to meet both MA Stream Crossing Performance Standards and MA Chapter 85 Design Requirements. These designs will need to be reevaluated based on detailed site survey, H&H study, geotechnical evaluation.

Repairing/Retrofitting Weirs and Right-Sizing Culverts (Weir Outlets)

- Permitting: Anticipated and potential permitting requirements for weir repair/retrofit and culvert right-sizing (weir outlet) were determined based on (1) site location, (2) culvert dimensions, and (3) permitting completed for similar projects.
    - Anticipated permitting for all weir/culvert retrofits/replacements:
        - Wetland Protection Act (WPA) Notice of Intent (NOI) Submittal for Temporary and Permanent Impacts to Buffer Zone & Resource Areas with MassDEP and Local Conservation Commission
        - Chapter 253 Permit Application for Dam Repair/Rehabilitation with MassDCR Office of Dam Safety (ODS)
    - Potential permitting for all weir/culvert retrofits/replacements:
        - MESA Review for work within NHESP Priority Habitat of Rare Species and NHESP Estimated Habitat of Rare Wildlife
        - 401 Water Quality Certification for >100 CY Fill and/or Excavation in Waters and Wetlands with MassDEP
        - Massachusetts General Permit for Any Work, including Construction and Dredging, Within the Nation's Navigable Waterways with US Army Corps of Engineers
        - MGL Chapter 85 Chapter 35 Review for a Proposed 'BRI' Bridge (10 ft < span < 20 ft) or 'NBI' Bridge (span > 20 ft) with MassDOT
- Design: Weir retrofits / repairs and replacement culverts downstream of the weirs (weir outlets) can be sized to meet minimum hydraulic requirements (based on MassDOT roadway functional class or local specifications for the road).
    - The goal of weir repairs and retrofit or replacement culverts downstream of the weirs (weir outlets) is not to return the system back to stream-like conditions, since this weir and culvert is part of an impoundment. Removing the dam will result in the loss of the impoundment and associated habitat. Therefore, a case can be made that the weir and culvert does not have to meet DER's stream crossing performance standards, and the weir will be designed based only upon the hydraulic needs of the dam. Efforts will be made to improve wildlife crossing to the maximum extent practicable.

Installing Green Infrastructure

- Permitting: Anticipated and potential permitting requirements for installing bioretention areas were determined based on (1) site location and (2) permitting completed for similar projects.
    - Potential permitting for bioretention area installation:
        - Wetland Protection Act (WPA) Notice of Intent (NOI) Submittal for Temporary and Permanent Impacts to Buffer Zone & Resource Areas with MassDEP and Local Conservation Commission
- Design: The bioretention area and appurtenant green infrastructure will be designed per MassDEP standards and the Massachusetts Stormwater Handbook design parameters for a bioretention area.

Purchase Parcel & Protect

- Permitting: Anticipated and potential permitting requirements for purchasing and protecting a parcel were determined based on (1) site location and (2) permitting completed for similar projects.
    - Potential permitting for purchase parcel and protect:
        - Phase I Environmental Site Assessment (ESA) to Identify Potential or Existing Environmental Contamination Liabilities in accordance with USEPA and ASTM Standards.
- Design: Not Applicable

7.2.3 Order-of-Magnitude Cost Estimates

Order-of-magnitude cost estimates are for planning purposes only. Construction and materials costs for replacement culverts, weir retrofits, and green infrastructure were estimated based on actual bid data from similar projects or best professional judgement. Costs may vary widely based on more detailed project design (i.e., roadway & utility work, traffic detours, temporary water handling, etc.).

Once construction costs were calculated, engineering costs (i.e., design & analysis, survey, permitting) were calculated based on actual costs from similar recent projects or from best professional judgement. Engineering costs ranged from approximately 25 to 50 percent of estimated construction costs.

The capital cost range for each project was then estimated by summing the construction and engineering costs, and applying a 25% contingency factor.

7.2.4 Site Prioritization

Table 7-2 describes how each of the 15 recommended improvements were prioritized based on a scoring system that assigns scores based on multiple factors that compare benefits vs. costs.

Table 7-2. Scoring Criteria for Prioritization of Recommended Improvements

Factor	Scoring Criteria			Assigned Score		
	Low	Medium	High	Low	Medium	High
Num. of Nature Based Solutions	0	1	2	10	15	25
Num. of Environmental Co-Benefits	1	2	3	10	15	25
Implementation Complexity [1]	High	Moderate	Low	10	15	25
Capital Cost [2]	> $500k	$150 - $500k	< $150k	10	15	25
Possible Point Range:				**40**	**60**	**100**

Notes:
1. Implementation complexity is a qualitative indicator based on misc. criteria and professional judgement (e.g., property ownership, site access, permitting complexity, construction complexity, potential for traffic impacts, etc.)
2. Capital costs assume construction costs and engineering costs (i.e., design, permitting, survey).

7.2.5 Miscellaneous Recommendations

The following miscellaneous improvements are also recommended:

- Perform an ecological study of the watershed mainstem (i.e. Johnson Creek and Argilla Brook) to understand species that may benefit from recommended improvements. Add findings from this study as an additional layer to the prioritization for an expanded understanding of potential co-benefits.
- Perform a study to identify additional potential land use acquisition targets throughout the watershed.
- Consider amending zoning bylaws and land use policies to be more protective of existing undeveloped parcels.
- Note: Potential impoundment removal at the Johnsons Pond outlet and Salem Street was considered at the early stages of this project; however, it was determined that both of these impoundments have diverse wildlife, fishing, kayaking, and other recreational interests that enhance public value.

8 Summary of Stakeholder Engagement Efforts

Stakeholder engagement was an important component of this project. A summary of primary activities and stakeholder feedback is summarized below.

8.1 Digital Engagement

- A Project Website was created describing the project and how to get involved.
- A Public Input Tool was developed to allow the general public to provide information on potential problem areas.
- A summary presentation of Project Findings was prepared and presented at the in-person meeting (see below). A recorded copy was also posted on the Town's YouTube channel at: http://youtube.com/user/GrovelandTV.

8.2 Print Engagement

- Project Posters were created and hung at publicly accessible venues and handed out at "Groveland Day" in the Fall of 2021.
- Flood signage was developed and installed at two locations (inlet of Johnsons Pond and the outlet of Johnsons Pond) (see **Figure 8-1** for a mockup)
- A digital survey was prepared to solicit input from the public. Responses were received from four (4) people and indicated that:
    - Previous flooding have been experienced at 113 Broad Street from torrential rainfall and clogged storm drains (this area is outside the Johnson Creek Watershed).
    - Previous flooding has been experienced near the package store on the corner of Washington Street and Main Street. This anecdotal evidence agrees with findings from **Section 4** and **Section 6**. Recommendations have been made to address this issues (**Section 7**).
    - A culvert at 86 School Street clogs and floods local resident yards (this area is outside the Johnson Creek Watershed).
    - The creek flooded a resident's basement on 11/9/2018 (location unknown).

8.3 In Person Engagement

- "Drop-in" hours and a "Project Hotline" were available at the Town Planning Department will be available to enable members of the general public to ask questions regarding the project and provide feedback.
- A meeting was held on 5/19/2022 as part of a Council for the Aging Event to discuss the project and obtain input from the public. During the meeting, members of the Project Team spoke with 13 people. Hard copies of the digital survey were handed out.

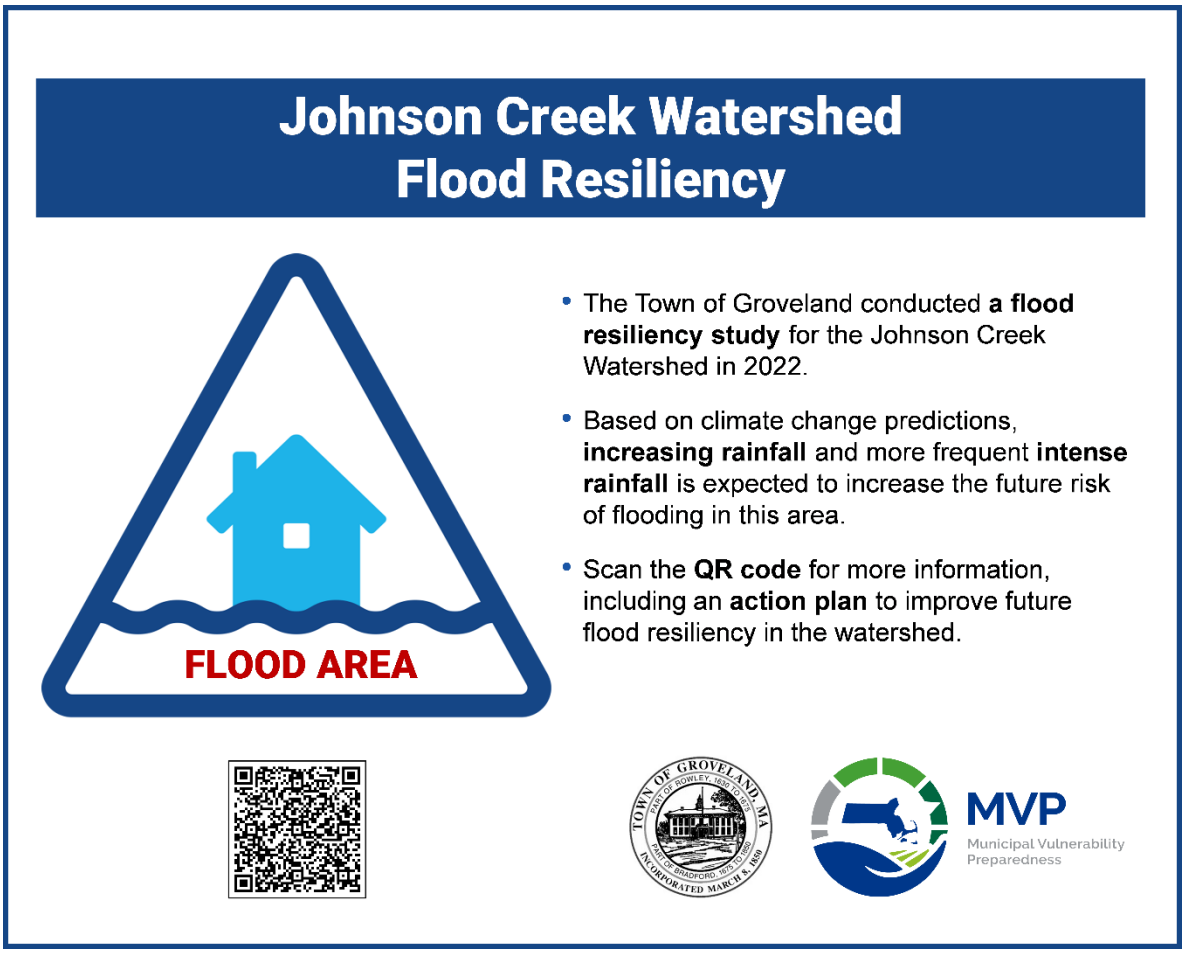


Figure 8-1. Flood Signage Mockup

Appendix A

Completed Field Inspection Forms

Culvert & Dam Observation Results

General Information	
Site ID: RC005	**Street:** Lower Center Street
Inspection Date: November 29, 2021	**Site Type:** Culvert

Location Map:

Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Circular	**Number of Barrels:** 2
Height (ft): 2.5	**Span (ft):** 2.5	**Length (ft):** 50

Geometry Notes (if any): Same (upstream is CMP, downstream is ADS)

Condition Observations: Debris / vegetation blockage, Culvert scour, Embankment erosion or instability, Beaver activity

Overall Condition: Poor

Comments: Culverts are undersized. They have overtopped onto Lower Center Street once or twice every wet season and periodically from upgradient beaver dams (i.e., private upstream landowner periodically removes beaver dams from unnamed pond near Marbles Lane).

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**

Control Mechanism Comments (if any):

Control Configuration Comments (if any):

Outlet / Spillway Observations:

Embankment Observations:

Overall Condition:

Comments:	
Upstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 7	**Sedimentation Level:** < 10%
Condition Observations channel erosion, overgrown vegetation, beaver activity *Comments:*	
Downstream Channel Information	
Geometry: Standing Water (i.e., Pond)	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 10	**Sedimentation Level:** No observed sedimentation
Condition Observations bank erosion/undermining, beaver activity *Comments:*	
General Recommendations (based on initial findings)	
The two (2), 30-inch reinforced concrete pipes are undersized for the amount of water that they receive. This results in upstream and downstream scour and overtopping over the road. Need to be right sized. Also address upgradient beaver activity.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

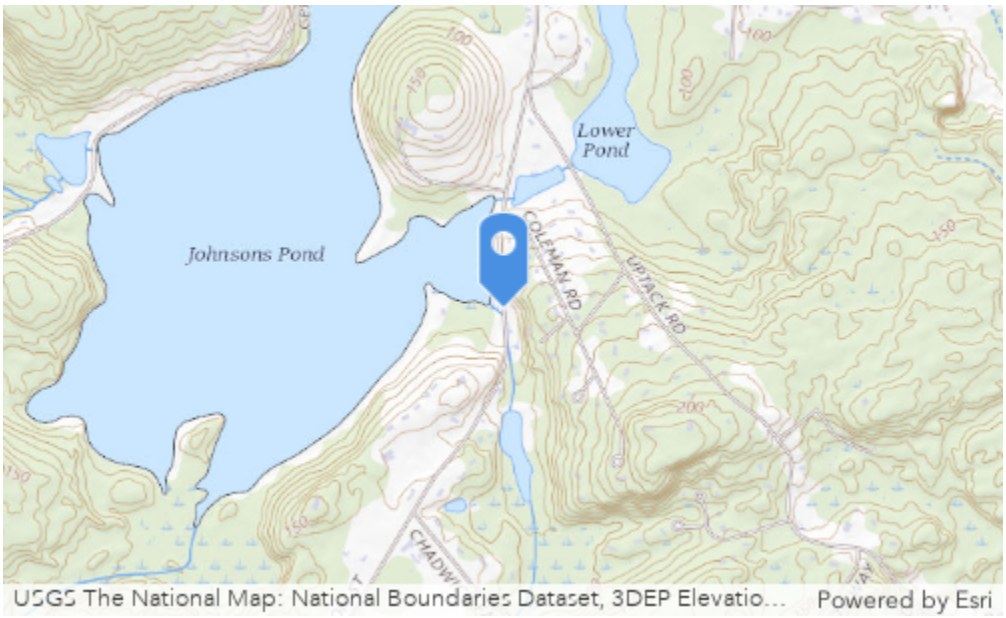
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC006	**Street:** Washington St
Inspection Date: December 3, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: High-Density Polyethylene (HDPE)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 3	**Span (ft):** 3	**Length (ft):** 35

Geometry Notes (if any):

Condition Observations: Debris / vegetation blockage, Culvert deformed or collapsing, Culvert undermining, Embankment erosion or instability

Overall Condition: Poor

Comments: Bottom of CMP is corroding away and culvert is collapsing. Emergency repair performed in 2020 to stub in a piece of HDPE pipe.

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**

Control Mechanism Comments (if any):

Control Configuration Comments (if any):

Outlet / Spillway Observations:

Embankment Observations:

Overall Condition:

Comments:

Upstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 10	**Sedimentation Level:** No observed sedimentation
Condition Observations channel erosion, overgrown vegetation, debris / blockage *Comments:* Channel needs to be cleaned out heavy vegetation and broken limbs	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 5	**Sedimentation Level:** < 10%
Condition Observations sedimentation, channel erosion, overgrown vegetation, evidence of previous overtopping onto floodplain *Comments:*	
General Recommendations (based on initial findings)	
Pipe has been repaired recently, but needs to be completely rebuilt. Clean debris (i.e., heavy limbs) from upstream channel. Stabilize downstream channel from further erosion.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: MA01204A	**Street:** Washington st
Inspection Date: November 29, 2021	**Site Type:** Dam

Location Map:

Culvert Information (If Applicable)		
Material:	**Geometry:**	**Number of Barrels:**
Height (ft):	**Span (ft):**	**Length (ft):**
Geometry Notes (if any):		
Condition Observations:		
Overall Condition: *Comments:*		

Dam Information (If Applicable)	
Dam Type: Concrete Dam	**Control Mechanism:** *Stoplogs / Flashboards*
Control Mechanism Comments (if any): *There are two overflow weirs with slots for stop logs. Each overflow weir currently has two (2) concrete stop logs installed. Each overflow weir can accept four (4) for an overall total of eight (8). stop logs can be installed in height. 8 stop logs in width. Each concrete stop log is approximately 10 inches tall by 6 feet wide.*	
Control Configuration Comments (if any):	
Outlet / Spillway Observations: *cracking / spalling / corroding concrete, collapsing concrete*	
Embankment Observations: *woody vegetation (trees/brush)*	
Overall Condition: Fair *Comments:* Controls on the inflow side are outdated and limited. Concrete weir is spalling. See inspection form for Culvert (MA01204B) for downstream issues.	

Upstream Channel Information	
Geometry: Standing Water (i.e., Pond)	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** 25-50%
Condition Observations sedimentation, channel erosion, bank erosion/undermining, overgrown vegetation, debris / blockage, evidence of previous overtopping onto floodplain, beaver activity *Comments:* Pond outlet headwall has come close to overtopping from beaver activity (i.e., buildup of debris and mud against structure which raises water level). Beaver deceiver or other beaver control solution may be needed.	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 12	**Sedimentation Level:** < 10%
Condition Observations sedimentation, channel erosion, bank erosion/undermining, overgrown vegetation, beaver activity *Comments:*	
General Recommendations (based on initial findings)	
Update upstream controls in culvert. Address constant beaver activity which poses flooding risk. See MA01204B culvert inspection form for recommendations for downgradient culvert.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: MA01204B	**Street:** Washington St
Inspection Date: December 29, 2021	**Site Type:** Culvert

Location Map:

Culvert Information (If Applicable)		
Material: Corrugated Metal (CMP)	**Geometry:** Arched (open bottom)	**Number of Barrels:** 1
Height (ft): 4	**Span (ft):** 6	**Length (ft):** 40
Geometry Notes (if any):		
Condition Observations: Headwall deformed or collapsing		
Overall Condition: Poor *Comments:* Upstream is metal pipe (newer), downstream is brick (50-60 yrs old). Downstream headwall and culvert outlet is starting to fall apart.		

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**
Control Mechanism Comments (if any):	
Control Configuration Comments (if any):	
Outlet / Spillway Observations:	
Embankment Observations:	
Overall Condition: *Comments:*	

Upstream Channel Information	
Geometry: Standing Water (i.e., Pond)	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues *Comments:*	
Downstream Channel Information	
Geometry: Standing Water (i.e., Pond)	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues *Comments:*	
General Recommendations (based on initial findings)	
Brick and mortar downstream outlet is starting to fall apart. Evaluate in more detail relative to the upstream portion of the culvert and replace or repair.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

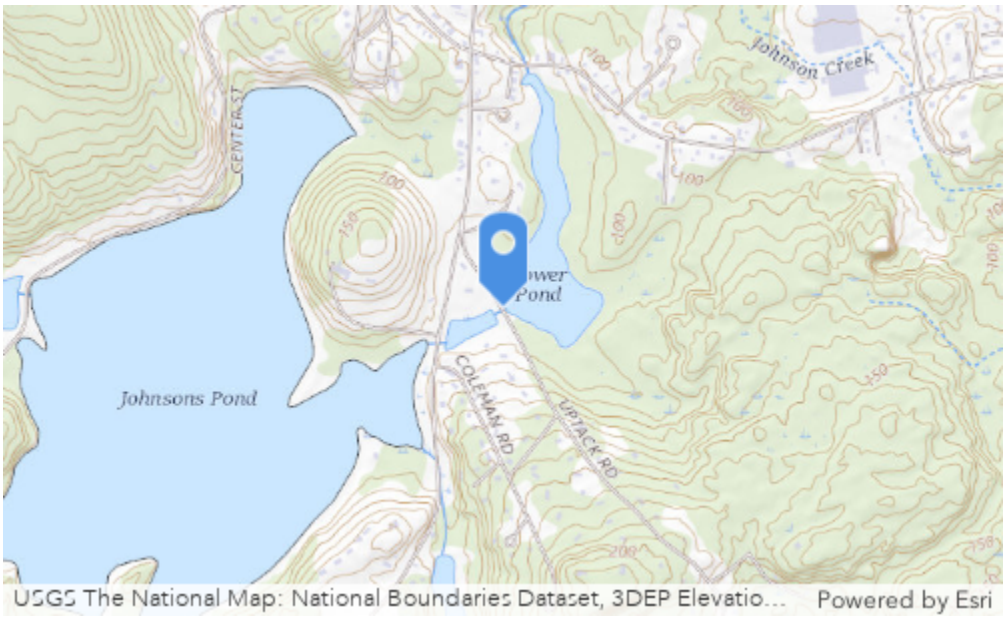
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC004	**Street:** Uptack Road
Inspection Date: November 29, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Masonry Block	**Geometry:** Box	**Number of Barrels:** 1, Box culvert stone built
Height (ft): 8	**Span (ft):** 6	**Length (ft):** 24

Geometry Notes (if any):

Condition Observations: Culvert lining cracking, spalling, corroding, Culvert deformed or collapsing, Culvert undermining, Culvert scour, Exposed footings, Embankment erosion or instability, Beaver activity

Overall Condition: Poor

Comments: Culvert has multiple issues (see above). Ongoing sinkhole directly above culvert footing in the northbound lane.

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**

Control Mechanism Comments (if any):

Control Configuration Comments (if any):

Outlet / Spillway Observations:

Embankment Observations:

Overall Condition:

Comments:

Upstream Channel Information	
Geometry: Standing Water (i.e., Pond)	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** < 10%
Condition Observations bank erosion/undermining, overgrown vegetation, evidence of previous overtopping onto floodplain, beaver activity *Comments:* This area consistently has Beaver activity. Beavers block the culvert inlet and increase floodplain issues - i.e., they can raise the water level by 2-3 feet.	
Downstream Channel Information	
Geometry: Standing Water (i.e., Pond)	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** < 10%
Condition Observations channel erosion, bank erosion/undermining, overgrown vegetation, debris / blockage, beaver activity *Comments:*	
General Recommendations (based on initial findings)	
Town has repaired this failing culvert multiple times. Town has obtained to re-construct and repair culvert. Construction is anticipated to start in the summer of 2021. Address beaver issues at newly constructed culvert.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

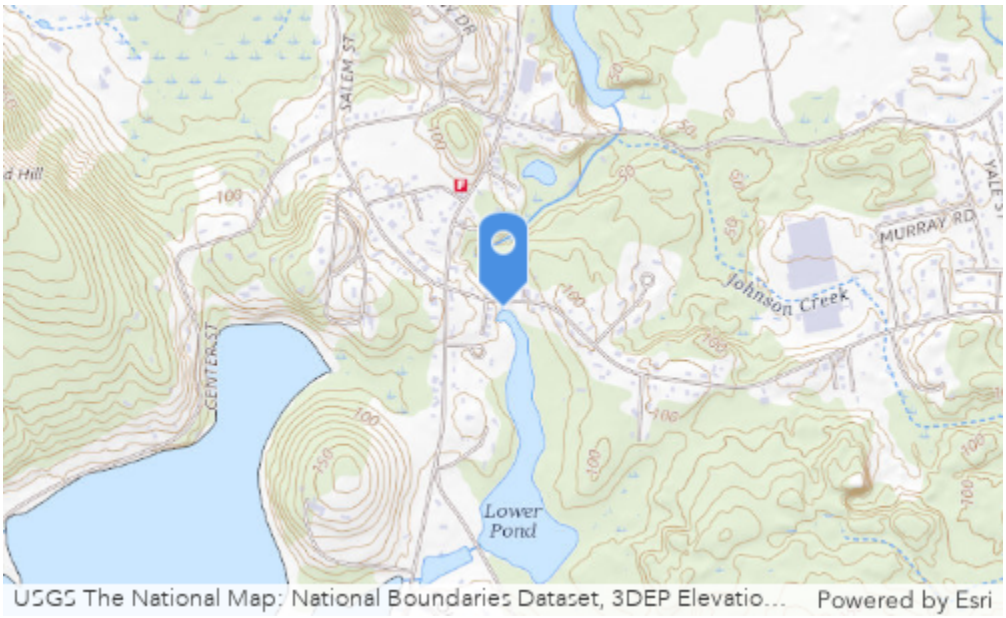
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: MA00188A	**Street:** Salem St
Inspection Date: December 3, 2021	**Site Type:** Dam

Location Map:



Culvert Information (If Applicable)		
Material:	**Geometry:**	**Number of Barrels:**
Height (ft):	**Span (ft):**	**Length (ft):**
Geometry Notes (if any):		
Condition Observations:		
Overall Condition: *Comments:*		

Dam Information (If Applicable)	
Dam Type: Masonry Dam	**Control Mechanism:** *Stoplogs / Flashboards*
Control Mechanism Comments (if any):	
Control Configuration Comments (if any):	
Outlet / Spillway Observations: *debris / blockage*	
Embankment Observations: *no observed issues*	
Overall Condition: Fair *Comments:* Embankment appears to be in good condition. Concrete outflow weir with flashboards appears to be in good condition. Grate above weir is deformed.	
Upstream Channel Information	

Geometry: Standing Water (i.e., Pond)	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations overgrown vegetation, debris / blockage, evidence of previous overtopping onto floodplain, beaver activity *Comments:* Dam overflow weir grates are susceptible to clogging. Periodic maintenance is required to inspect and remove debris to avoid flood risk from clogging.	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 25	**Sedimentation Level:** No observed sedimentation
Condition Observations channel erosion, bank erosion/undermining, overgrown vegetation, debris / blockage, evidence of previous overtopping onto floodplain *Comments:* Undermined trees and bank undercutting observed in downstream channel. Potential candidate for bank stabilization.	
General Recommendations (based on initial findings)	
Stabilize downstream channel and remove fallen debris (trees). Address failing CMP culvert at outflow (i.e., no bottom) (see inspection form MA00188B).	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

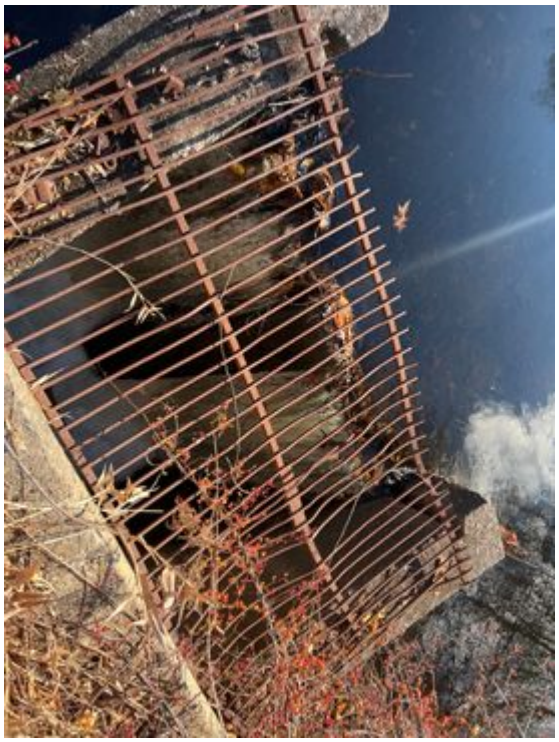


Photo 2: Upstream Channel

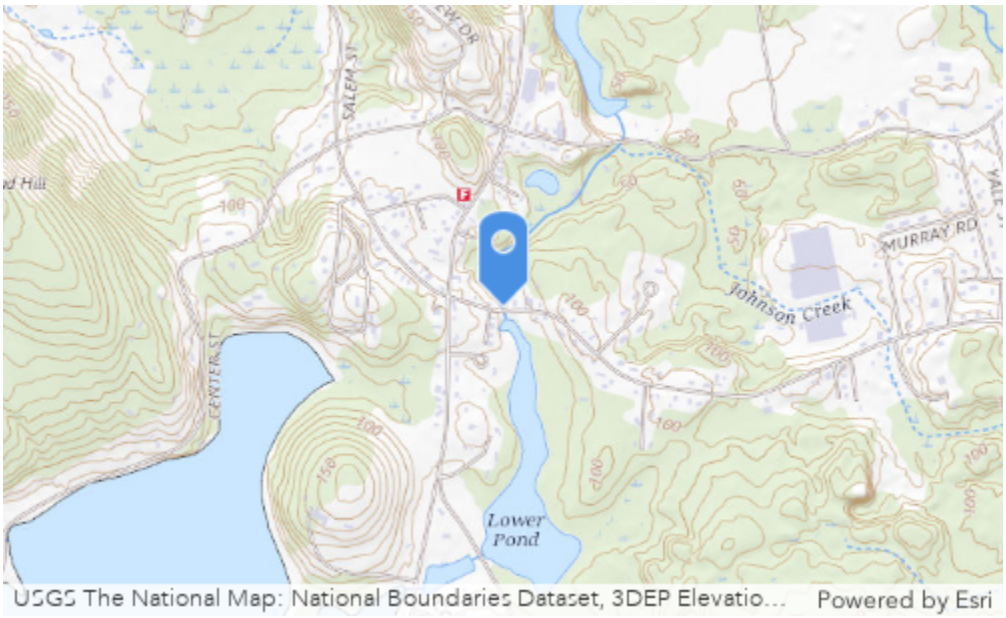
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: MA00188B	**Street:** Salem St
Inspection Date: December 29, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Corrugated Metal (CMP)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 4.5	**Span (ft):** 4.5	**Length (ft):** 75

Geometry Notes (if any):

Condition Observations: Culvert lining cracking, spalling, corroding, Culvert undermining, Culvert scour, Exposed footings

Overall Condition: Poor

Comments: Bottom of downstream pipe completely corroded. Foundation is being undermined at outflow headwall.

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**

Control Mechanism Comments (if any):

Control Configuration Comments (if any):

Outlet / Spillway Observations:

Embankment Observations:

Overall Condition:

Comments:

Upstream Channel Information	
Geometry: Standing Water (i.e., Pond)	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations debris / blockage *Comments:* Debris starting to pile up in front of culvert inlet.	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations bank erosion/undermining *Comments:* See inspection form for MA00188A.	
General Recommendations (based on initial findings)	
Address failing CMP culvert at outflow (i.e., no bottom). Fix undermining foundation footing out outflow headwall. Could lead to overall instability of the dam over time. See MA00188A for recommendations for downstream channel.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

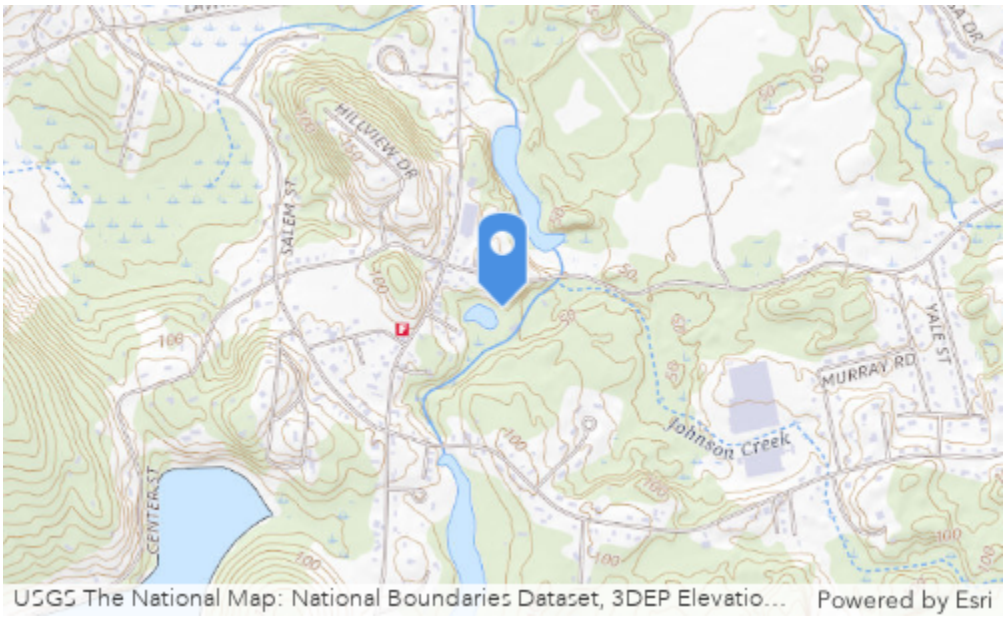
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: MA02988	**Street:** Mill Street Extension
Inspection Date: December 7, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 6	**Span (ft):** 6	**Length (ft):** 120

Geometry Notes (if any): Note: The mainstem channel is located directly to the southeast of the this culvert. It used to be a dam (i.e., MA02988), but has been long removed. The only evidence of a previous dam are crumbling stone headwalls on either side of the channel.

Condition Observations: Debris / vegetation blockage, Culvert deformed or collapsing, Culvert undermining, Embankment erosion or instability, Beaver activity

Overall Condition: Fair

Comments: Previous 60” steep pipe was repaired years ago with upgradient and downgradient RCP – a section of steel pipe still remains in the center. One of the repair joints appears to be failing and is causing a depression in the road.

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**

Control Mechanism Comments (if any):

Control Configuration Comments (if any):

Outlet / Spillway Observations:

Embankment Observations:

Overall Condition: *Comments:*	
Upstream Channel Information	
Geometry: Standing Water (i.e., Pond)	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** 10-25%
Condition Observations overgrown vegetation, debris / blockage, beaver activity *Comments:* Large upstream beaver dam is completely blocking the outflow. Has been in place for many years.	
Downstream Channel Information	
Geometry: Irregular	**Material:** Riprap
Appx. Bankfull Width (ft): 20	**Sedimentation Level:** < 10%
Condition Observations sedimentation, channel erosion, bank erosion/undermining, overgrown vegetation, debris / blockage, evidence of previous overtopping onto floodplain, beaver activity *Comments:*	
General Recommendations (based on initial findings)	
Replace failing pipe. Address beaver issues at the inflow.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

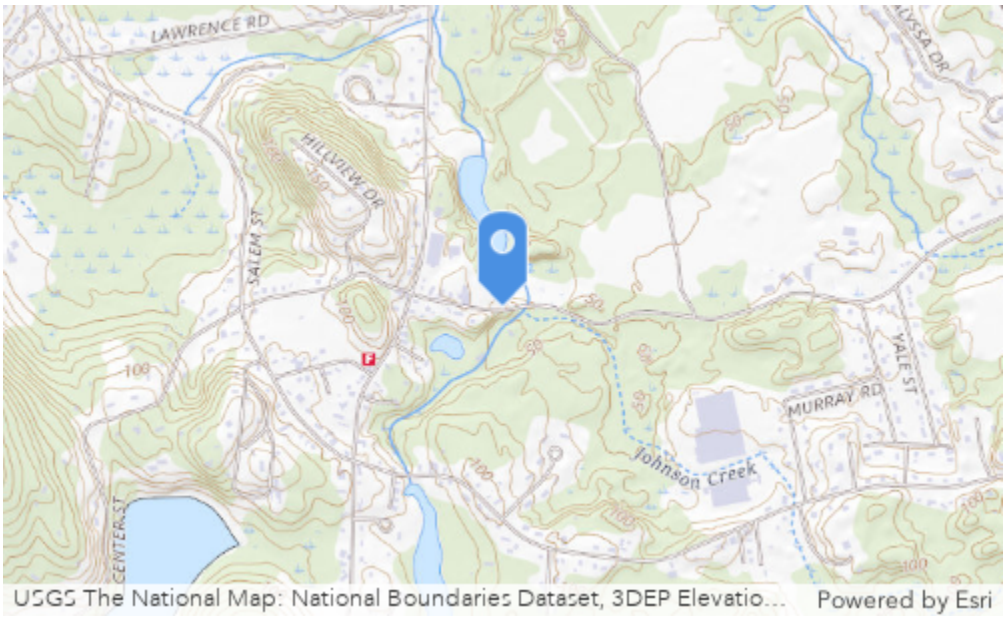
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC003A	**Street:** Center St
Inspection Date: December 29, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Box	**Number of Barrels:** 1
Height (ft): 3	**Span (ft):** 6	**Length (ft):** 60
Geometry Notes (if any):		
Condition Observations: no observed issues		
Overall Condition: Good *Comments:* Culvert in good condition, looks relatively new		

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**
Control Mechanism Comments (if any):	
Control Configuration Comments (if any):	
Outlet / Spillway Observations:	
Embankment Observations:	
Overall Condition: *Comments:*	
Upstream Channel Information	

Geometry: Trapazoidal	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 15	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues *Comments:*	
Downstream Channel Information	
Geometry: Trapazoidal	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 20	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues *Comments:*	
General Recommendations (based on initial findings)	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

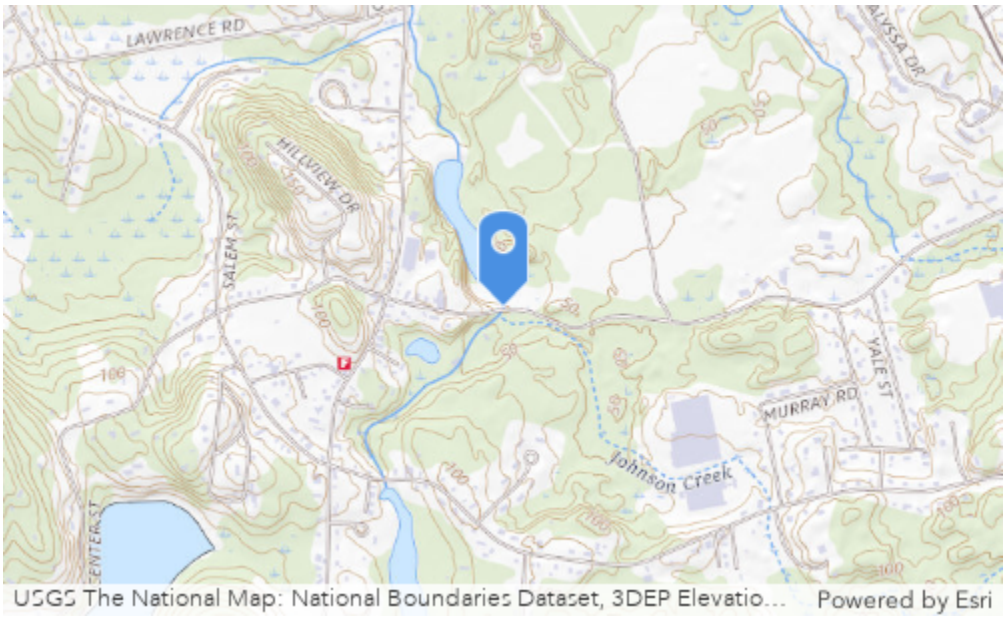
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC003B	**Street:** Center St
Inspection Date: December 10, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Box	**Number of Barrels:** 1
Height (ft): 4	**Span (ft):** 8	**Length (ft):** 30

Geometry Notes (if any):

Condition Observations: Culvert scour, Exposed footings, Headwall undermining, Embankment erosion or instability

Overall Condition: Poor

Comments: See above observations. Center Street is a high traffic area for large trucks. Concern that culvert is not rated for constant heavy trucking loads.

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**

Control Mechanism Comments (if any):

Control Configuration Comments (if any):

Outlet / Spillway Observations:

Embankment Observations:

Overall Condition:

Comments:

Upstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 7	**Sedimentation Level:** 10-25%
Condition Observations sedimentation, channel erosion, bank erosion/undermining *Comments:*	
Downstream Channel Information	
Geometry: Irregular	**Material:** Riprap
Appx. Bankfull Width (ft): 8	**Sedimentation Level:** 10-25%
Condition Observations sedimentation, channel erosion, bank erosion/undermining, overgrown vegetation, debris / blockage *Comments:*	
General Recommendations (based on initial findings)	
This aging culvert has been patched and reworked. Many observed issues (i.e., undermining, scour, exposed footings). Needs to be considered for replacement.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC007	**Street:** Salem st @Uptack ave
Inspection Date: December 3, 2021	**Site Type:** Culvert

Location Map:

Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 3	**Span (ft):** 3	**Length (ft):** 40

Geometry Notes (if any):

Condition Observations: Culvert lining cracking, spalling, corroding, Culvert scour, Evidence of previous surcharging, Headwall cracking, spalling, corroding, Headwall deformed or collapsing, Beaver activity

Overall Condition: Fair

Comments: Upstream and downstream headwall is cracking. Culvert appears to be corroding.

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**

Control Mechanism Comments (if any):

Control Configuration Comments (if any):

Outlet / Spillway Observations:

Embankment Observations:

Overall Condition:

Comments:

Upstream Channel Information	
Geometry: Rectangular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 5	**Sedimentation Level:** 10-25%
Condition Observations sedimentation, channel erosion, overgrown vegetation, evidence of previous overtopping onto floodplain, beaver activity *Comments:* Beaver activity makes it very difficult to address issues	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 5	**Sedimentation Level:** 10-25%
Condition Observations sedimentation, channel erosion, evidence of previous overtopping onto floodplain, beaver activity *Comments:*	
General Recommendations (based on initial findings)	
Replace collapsing headwalls. Repair or replace culvert.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

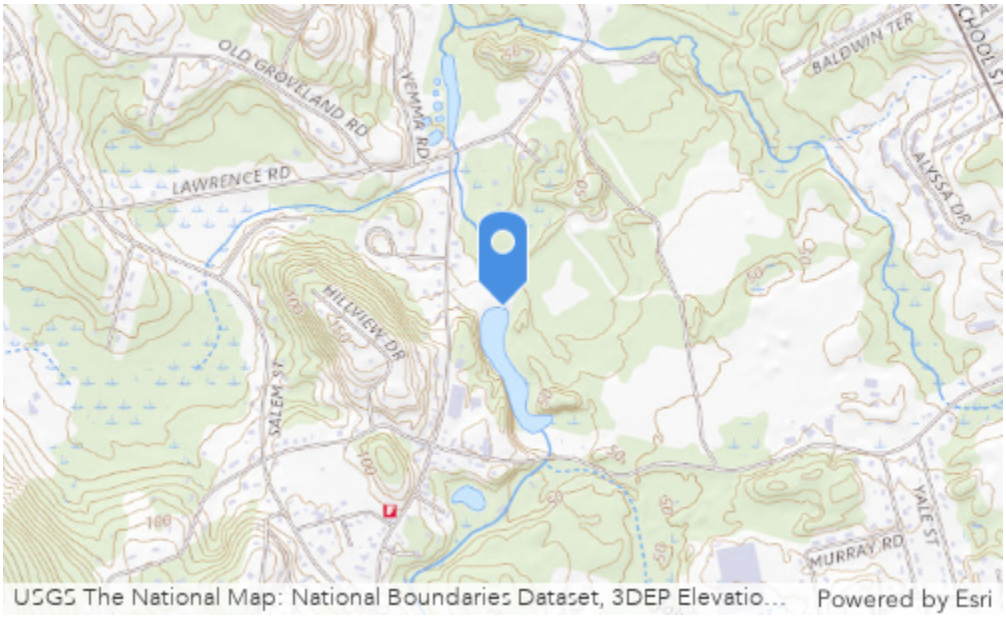
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: MA02985	**Street:** Washington Street behind old water /sewer building.
Inspection Date: December 7, 2021	**Site Type:** Dam

Location Map:



Culvert Information (If Applicable)		
Material:	**Geometry:**	**Number of Barrels:**
Height (ft):	**Span (ft):**	**Length (ft):**
Geometry Notes (if any):		
Condition Observations:		
Overall Condition: *Comments:*		

Dam Information (If Applicable)	
Dam Type: Earthen Dam	**Control Mechanism:** *Stoplogs / Flashboards*
Control Mechanism Comments (if any): *Was previously used for swimming up until the 1980's. There is a superfund directly downgradient of the site. Stoplog controls have been removed. The stop log control structure is appx. 12' high and 6' wide. The control structure discharges to a 5' circular RCP perched outlet pipe.*	
Control Configuration Comments (if any):	
Outlet / Spillway Observations: *cracking / spalling / corroding concrete*	
Embankment Observations: *sinkholes, animal burrows*	
Overall Condition: Fair *Comments:* Concrete at outlet control structure is spalling. Undermining observed at outlet structure.	

Sinkhole observed in dam embankment that is several feet deep.	
Upstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** < 10%
Condition Observations no observed issues *Comments:*	
Downstream Channel Information	
Geometry: Irregular	**Material:** Riprap
Appx. Bankfull Width (ft): 40	**Sedimentation Level:** 10-25%
Condition Observations channel erosion, bank erosion/undermining *Comments:*	
General Recommendations (based on initial findings)	
Inspect and repair sinkhole observed on dam embankment.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

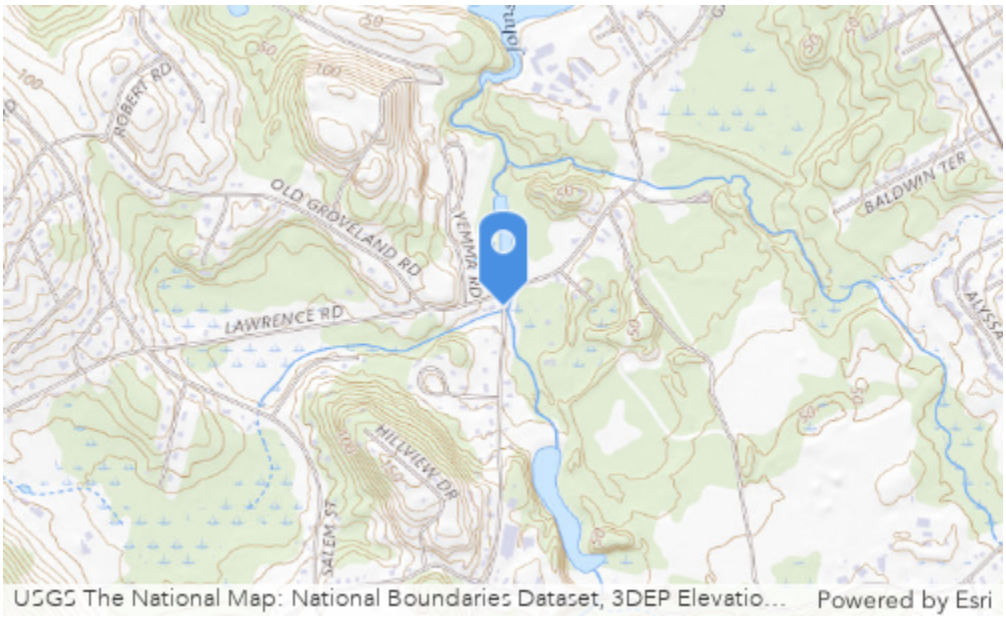
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC002	**Street:** Washington st @ Main St
Inspection Date: December 3, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 4	**Span (ft):** 4	**Length (ft):** 45
Geometry Notes (if any):		
Condition Observations: Headwall undermining		
Overall Condition: Fair *Comments:* Culvert is relatively new. Headwall is starting to undermine on upstream end. Culvert surcharges rapidly during large storm events. Likely undersized.		

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**
Control Mechanism Comments (if any):	
Control Configuration Comments (if any):	
Outlet / Spillway Observations:	
Embankment Observations:	
Overall Condition: *Comments:*	
Upstream Channel Information	

Geometry: Rectangular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 6	**Sedimentation Level:** 10-25%
Condition Observations no observed issues *Comments:*	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 3	**Sedimentation Level:** 10-25%
Condition Observations no observed issues *Comments:*	
General Recommendations (based on initial findings)	
Fixed upgradient undermining headwall. Explore upgradient opportunities to limit discharge to undersized culvert and decrease chances of surcharging.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

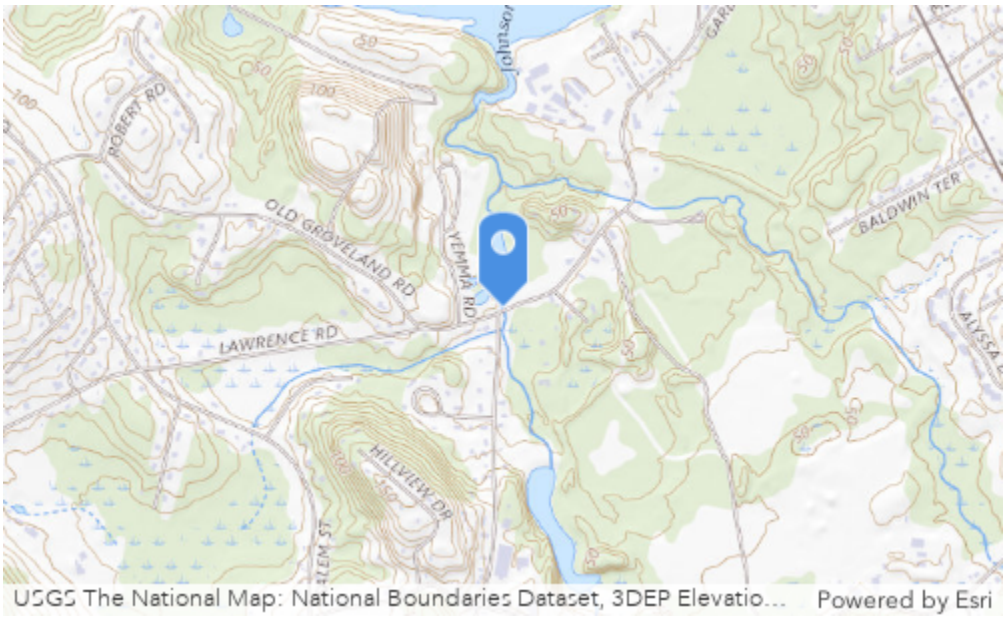
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC001	**Street:** Main st @ Washington st
Inspection Date: December 3, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Box	**Number of Barrels:** Newer style Box culvert
Height (ft): 3	**Span (ft):** 8	**Length (ft):** 35
Geometry Notes (if any): NA		
Condition Observations: no observed issues, Culvert scour		
Overall Condition: Good *Comments:* This is a newer box culvert		

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**
Control Mechanism Comments (if any):	
Control Configuration Comments (if any):	
Outlet / Spillway Observations:	
Embankment Observations:	
Overall Condition: *Comments:*	
Upstream Channel Information	

Geometry: Rectangular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 12	**Sedimentation Level:** 10-25%
Condition Observations sedimentation, channel erosion, bank erosion/undermining, overgrown vegetation, evidence of previous overtopping onto floodplain *Comments:* Severe bank erosion of upstream channel. Debris frequently piles up at this confluence point.	
Downstream Channel Information	
Geometry: Rectangular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 12	**Sedimentation Level:** 10-25%
Condition Observations no observed issues *Comments:* No apparent issues.	
General Recommendations (based on initial findings)	
Streambank stabilization recommended.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

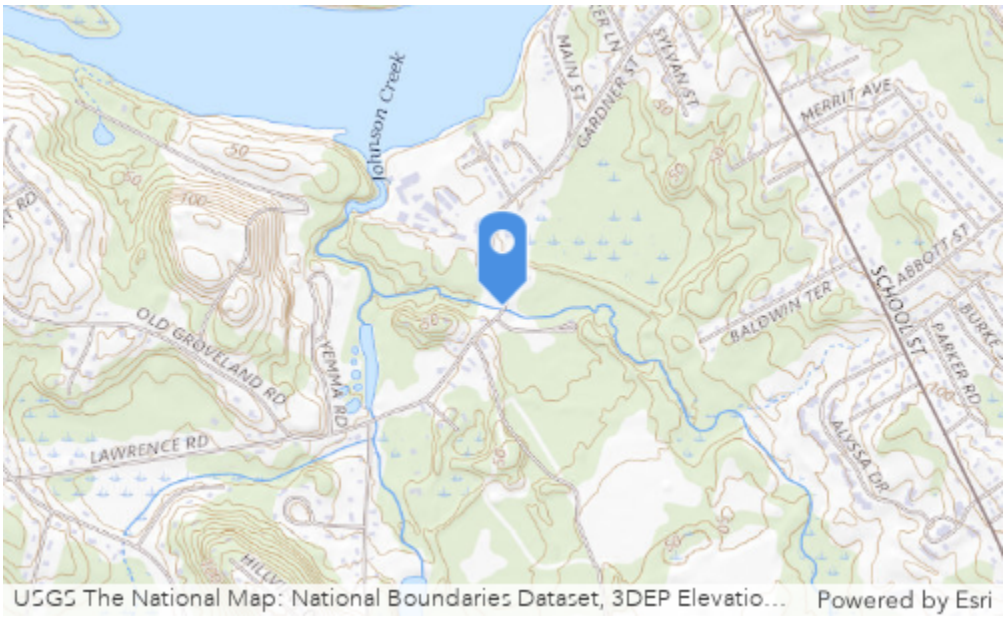
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC008	**Street:** Main St
Inspection Date: December 6, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Masonry Block	**Geometry:** Box	**Number of Barrels:** 1
Height (ft): 6	**Span (ft):** 8	**Length (ft):** 40
Geometry Notes (if any):		
Condition Observations: no observed issues		
Overall Condition: Good *Comments:* Access to culvert is challenging. Culvert is aging, but does not have any apparent issues.		

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**
Control Mechanism Comments (if any):	
Control Configuration Comments (if any):	
Outlet / Spillway Observations:	
Embankment Observations:	
Overall Condition: *Comments:*	

Upstream Channel Information

Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations debris / blockage *Comments:* Upstream channel frequently receives debris from storms.	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues *Comments:*	
General Recommendations (based on initial findings)	
Monitor for upgradient debris blockages.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

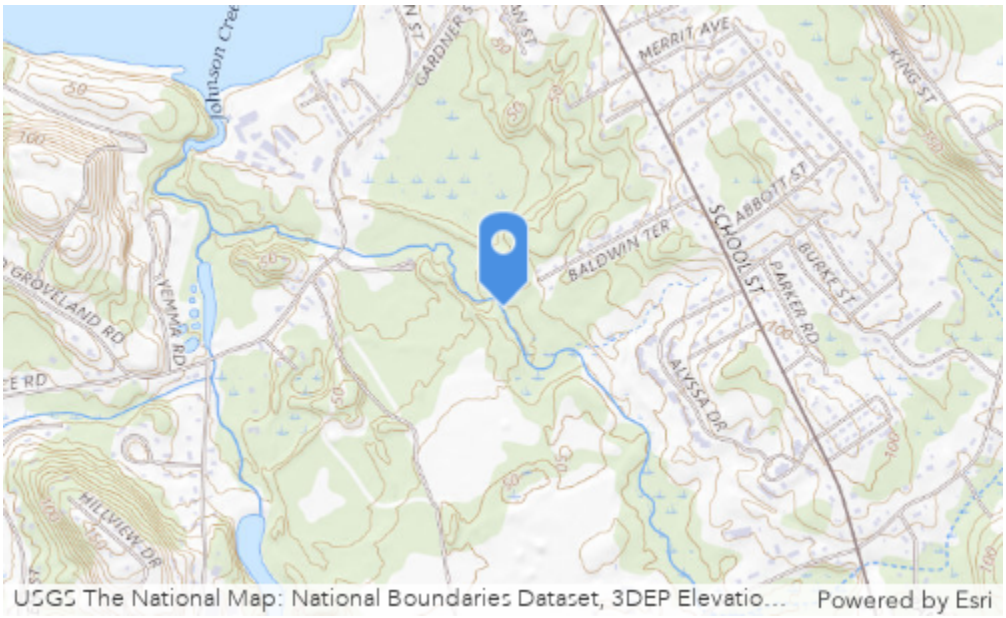
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: MA02987	**Street:** Baldwin Terrace
Inspection Date: December 10, 2021	**Site Type:** Dam

Location Map:



Culvert Information (If Applicable)		
Material:	**Geometry:**	**Number of Barrels:**
Height (ft):	**Span (ft):**	**Length (ft):**
Geometry Notes (if any):		
Condition Observations:		
Overall Condition: *Comments:*		

Dam Information (If Applicable)	
Dam Type: Masonry Dam	**Control Mechanism:** *No Control Mechanism*
Control Mechanism Comments (if any):	
Control Configuration Comments (if any): *Box style built by stones*	
Outlet / Spillway Observations: *debris / blockage, collapsing concrete*	
Embankment Observations: *evidence of previous overtopping, sinkholes, animal burrows, erosion, poor abutment contact*	
Overall Condition: Good *Comments:* Condition is "N/A". This damn collapsed and fell apart almost 20 years ago.	

Upstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural

Appx. Bankfull Width (ft):	**Sedimentation Level:** < 10%
Condition Observations channel erosion, overgrown vegetation, debris / blockage *Comments:* Beavers have in a day to this area and created their own ponds upstream	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** < 10%
Condition Observations bank erosion/undermining, overgrown vegetation, evidence of previous overtopping onto floodplain *Comments:*	
General Recommendations (based on initial findings)	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

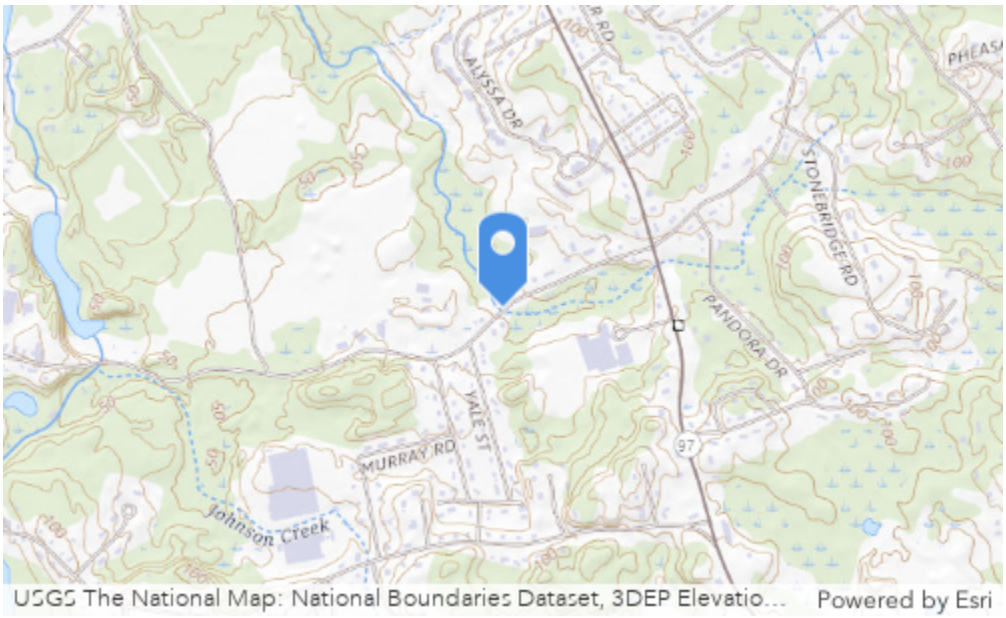
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC009	**Street:** Center St
Inspection Date: December 6, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Corrugated Metal (CMP)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 3	**Span (ft):** 3	**Length (ft):** 35

Geometry Notes (if any):

Condition Observations: Debris / vegetation blockage, Culvert deformed or collapsing, Evidence of previous surcharging, Embankment erosion or instability

Overall Condition: Poor

Comments: Culvert was almost full with standing water at time of inspection and may be partially blocked. Appears to be collapsing or deforming.

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**

Control Mechanism Comments (if any):

Control Configuration Comments (if any):

Outlet / Spillway Observations:

Embankment Observations:

Overall Condition:

Comments:

Upstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 10	**Sedimentation Level:** No observed sedimentation
Condition Observations bank erosion/undermining, overgrown vegetation *Comments:*	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 13	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues *Comments:*	
General Recommendations (based on initial findings)	
Replace failing culvert. Reconfigure installation elevations to enable passage of water.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

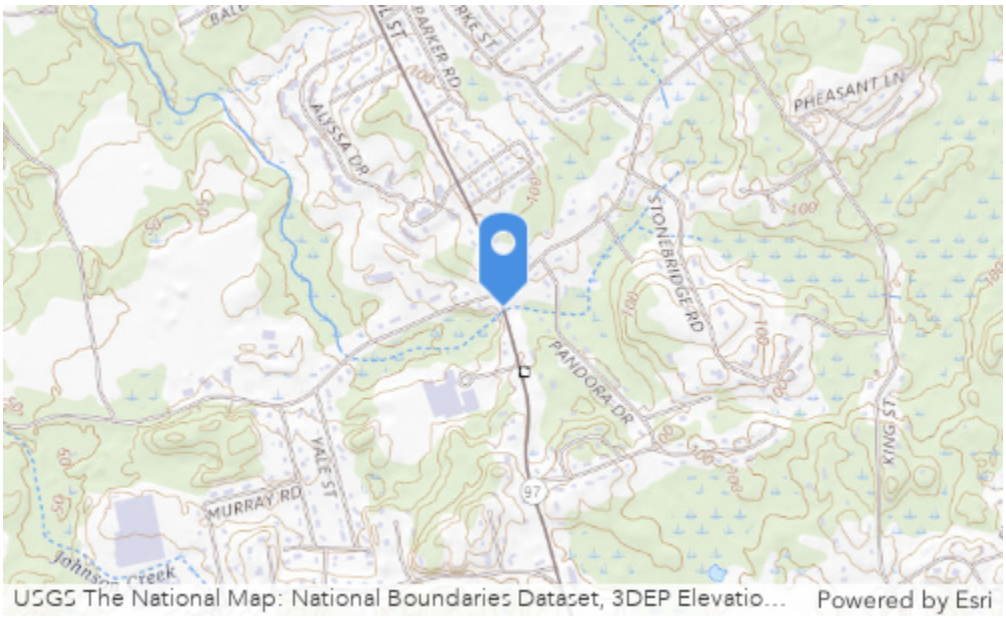
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC010	**Street:** School St
Inspection Date: December 6, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 4	**Span (ft):** 4	**Length (ft):** 65
Geometry Notes (if any):		
Condition Observations: no observed issues, Perched culvert		
Overall Condition: Good *Comments:*		

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**
Control Mechanism Comments (if any):	
Control Configuration Comments (if any):	
Outlet / Spillway Observations:	
Embankment Observations:	
Overall Condition: *Comments:*	
Upstream Channel Information	

Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 5	**Sedimentation Level:** 10-25%
Condition Observations sedimentation, channel erosion, overgrown vegetation, debris / blockage, evidence of previous overtopping onto floodplain *Comments:*	
Downstream Channel Information	
Geometry: Irregular	**Material:** Riprap
Appx. Bankfull Width (ft): 8	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues *Comments:*	
General Recommendations (based on initial findings)	
Upstream channel showed signs of bank erosion and instability (i.e., toppled tree) and sedimentation at the culvert inlet. Potential recommendation to stabilize/restore upstream channel. Explore opportunities at the upgradient Bagnall School to limit the amount of runoff to the channel.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

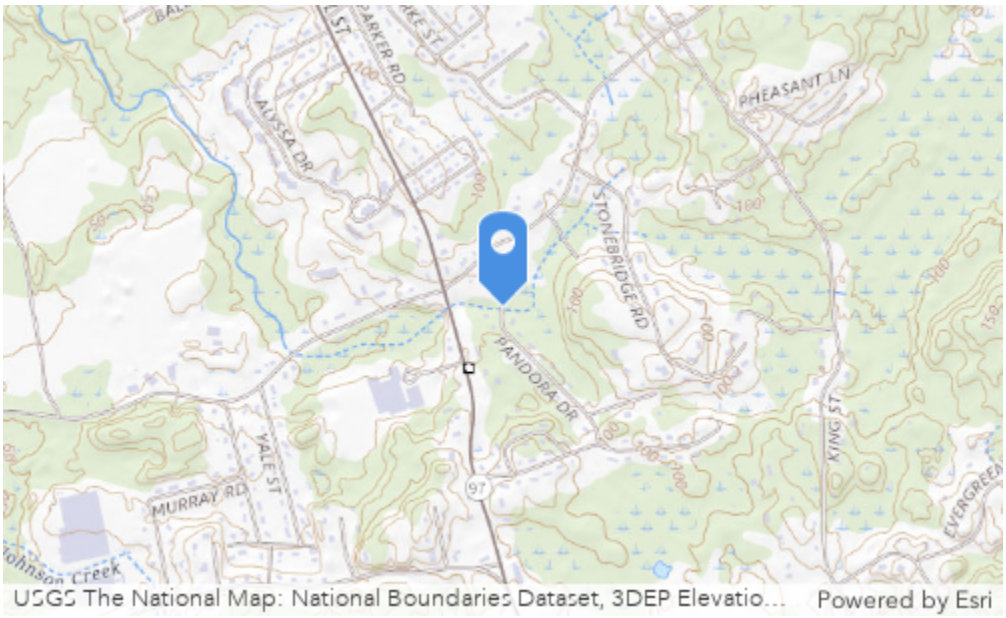
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC011	**Street:** Pandora Dr
Inspection Date: December 6, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 4	**Span (ft):** 4	**Length (ft):** 50

Geometry Notes (if any):

Condition Observations: Debris / vegetation blockage

Overall Condition: Good

Comments: Culvert condition appears to be good, but upstream channel is frequently impacted by debris.

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**

Control Mechanism Comments (if any):

Control Configuration Comments (if any):

Outlet / Spillway Observations:

Embankment Observations:

Overall Condition:

Comments:

Upstream Channel Information

Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 5	**Sedimentation Level:** No observed sedimentation
Condition Observations overgrown vegetation, debris / blockage *Comments:* Channel frequently impacted by debris.	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations channel erosion *Comments:*	
General Recommendations (based on initial findings)	
Maintain debris in upgradient channel.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

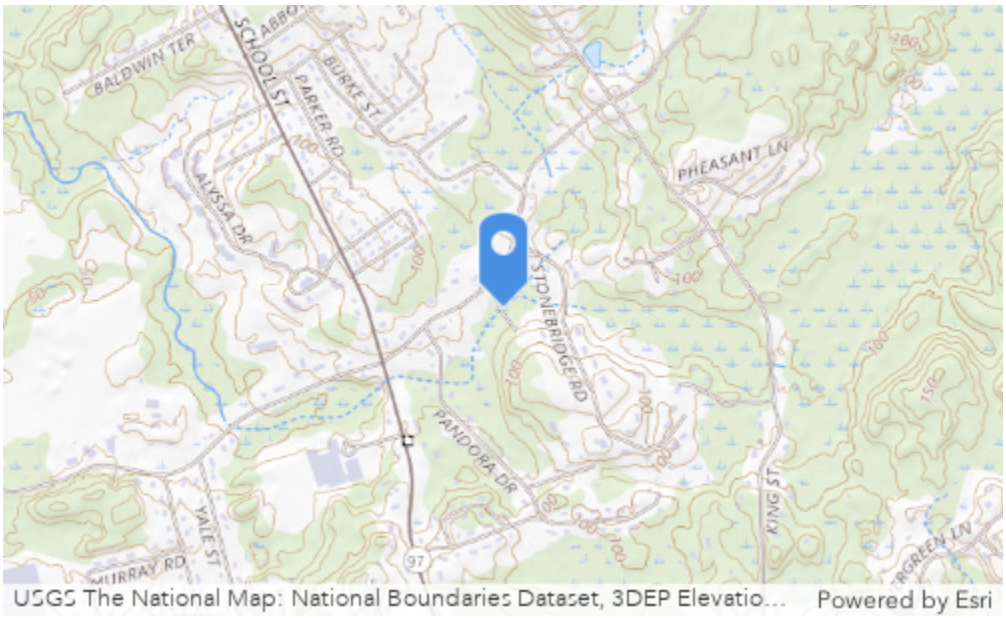
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC012	**Street:** Center st
Inspection Date: December 10, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 1	**Span (ft):** 1	**Length (ft):** 40
Geometry Notes (if any):		
Condition Observations: no observed issues		
Overall Condition: Good *Comments:* New culvert from new development.		

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**
Control Mechanism Comments (if any):	
Control Configuration Comments (if any):	
Outlet / Spillway Observations:	
Embankment Observations:	
Overall Condition: *Comments:*	
Upstream Channel Information	

Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues *Comments:*	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues *Comments:*	
General Recommendations (based on initial findings)	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

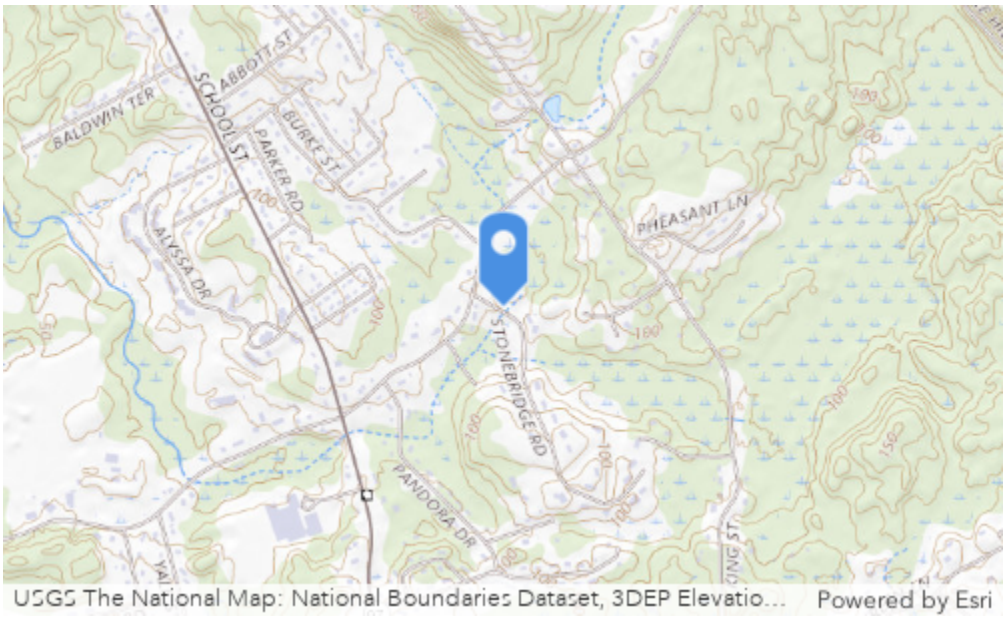
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC014	**Street:** Stonebridge Rd
Inspection Date: December 7, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 3	**Span (ft):** 10	**Length (ft):** 40
Geometry Notes (if any):		
Condition Observations: Debris / vegetation blockage, Sediment blockage		
Overall Condition: Good *Comments:*		

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**
Control Mechanism Comments (if any):	
Control Configuration Comments (if any):	
Outlet / Spillway Observations:	
Embankment Observations:	
Overall Condition: *Comments:*	
Upstream Channel Information	

Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 14	**Sedimentation Level:** < 10%
Condition Observations sedimentation, overgrown vegetation, debris / blockage, evidence of previous overtopping onto floodplain *Comments:*	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft): 14	**Sedimentation Level:** 10-25%
Condition Observations sedimentation, channel erosion, bank erosion/undermining, overgrown vegetation, debris / blockage *Comments:*	
General Recommendations (based on initial findings)	
Upstream and downstream channel show signs of instability (i.e., bank erosion) and blockages from sediment and vegetation. Potential recommendation to stabilize channel, remove debris, and remove accumulated sediment.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

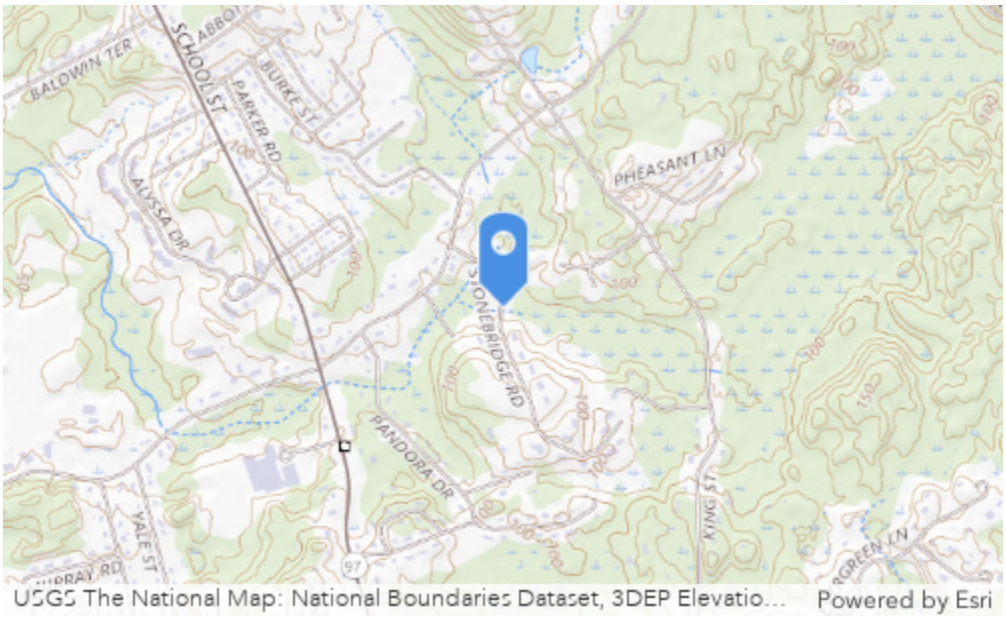
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC013	**Street:** Stonebridge Rd
Inspection Date: December 7, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Box	**Number of Barrels:** 1
Height (ft): 3	**Span (ft):** 10	**Length (ft):** 40
Geometry Notes (if any):		
Condition Observations: no observed issues		
Overall Condition: Good *Comments:*		

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**
Control Mechanism Comments (if any):	
Control Configuration Comments (if any):	
Outlet / Spillway Observations:	
Embankment Observations:	
Overall Condition: *Comments:*	
Upstream Channel Information	

Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues *Comments:*	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues, bank erosion/undermining, debris / blockage *Comments:*	
General Recommendations (based on initial findings)	
Remove debris blockage (ie, tree) from downstream channel. Stabilize channel to prevent future blockage.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

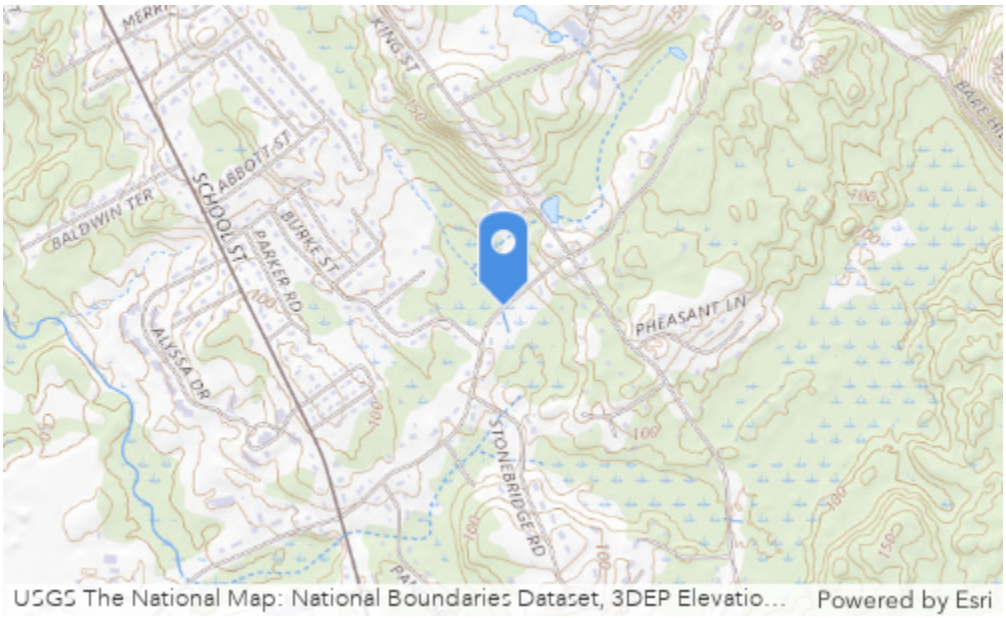
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC015	**Street:** Center St
Inspection Date: December 7, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Reinforced Concrete (RCP)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 2	**Span (ft):** 2	**Length (ft):** 35

Geometry Notes (if any):

Condition Observations: Exposed footings, Headwall cracking, spalling, corroding, Headwall deformed or collapsing, Headwall undermining

Overall Condition: Fair

Comments: Headwall is beginning to fail. Culvert appears to be undersized which may be causing headwall issues.

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**

Control Mechanism Comments (if any):

Control Configuration Comments (if any):

Outlet / Spillway Observations:

Embankment Observations:

Overall Condition:

Comments:

Upstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** < 10%
Condition Observations sedimentation, channel erosion *Comments:*	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** < 10%
Condition Observations sedimentation, overgrown vegetation, evidence of previous overtopping onto floodplain *Comments:*	
General Recommendations (based on initial findings)	
Culvert headwall is starting to collapse. Potential recommendation to repair the headwall, replace (upsize) culvert, and fix observed channel issues (i.e., downstream blockage, upstream bank erosion). It is possible channel issues are caused by undersized culvert.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

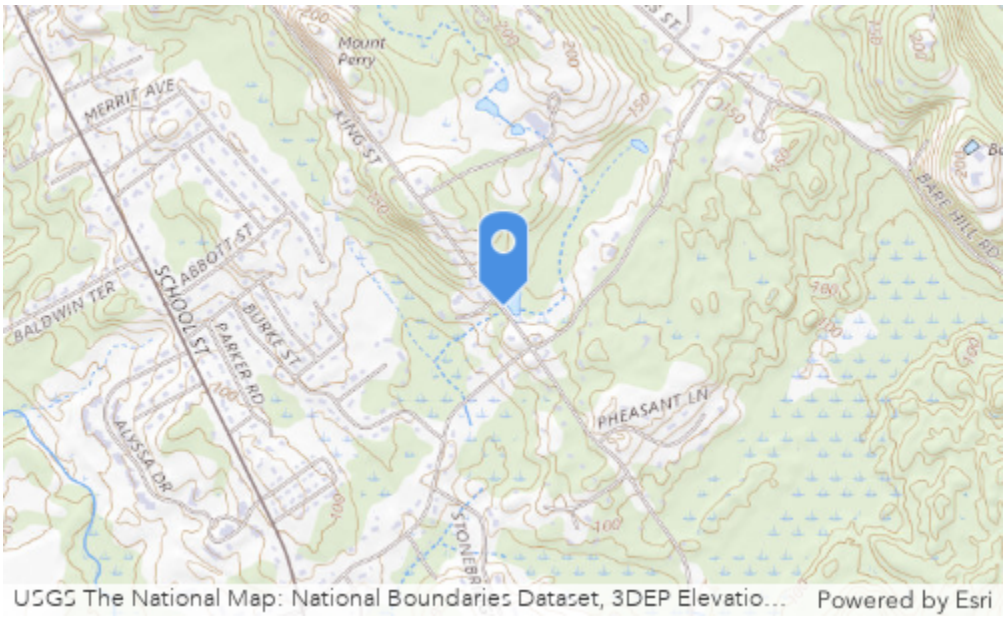
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC016	**Street:** King St @ Briarwood
Inspection Date: December 7, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Corrugated Metal (CMP)	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 2	**Span (ft):** 2	**Length (ft):** 40

Geometry Notes (if any):

Condition Observations: Culvert lining cracking, spalling, corroding, Culvert deformed or collapsing, Culvert undermining, Exposed footings, Perched culvert, Embankment erosion or instability

Overall Condition: Poor

Comments: Headwall of culvert cracked and split in half; downstream embankment appears to be eroding.

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**

Control Mechanism Comments (if any):

Control Configuration Comments (if any):

Outlet / Spillway Observations:

Embankment Observations:

Overall Condition:

Comments:

Upstream Channel Information	
Geometry: Standing Water (i.e., Pond)	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations no observed issues *Comments:*	
Downstream Channel Information	
Geometry: Rectangular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** 10-25%
Condition Observations no observed issues *Comments:*	
General Recommendations (based on initial findings)	
Replace failing culvert and stabilize eroding downstream embankment.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

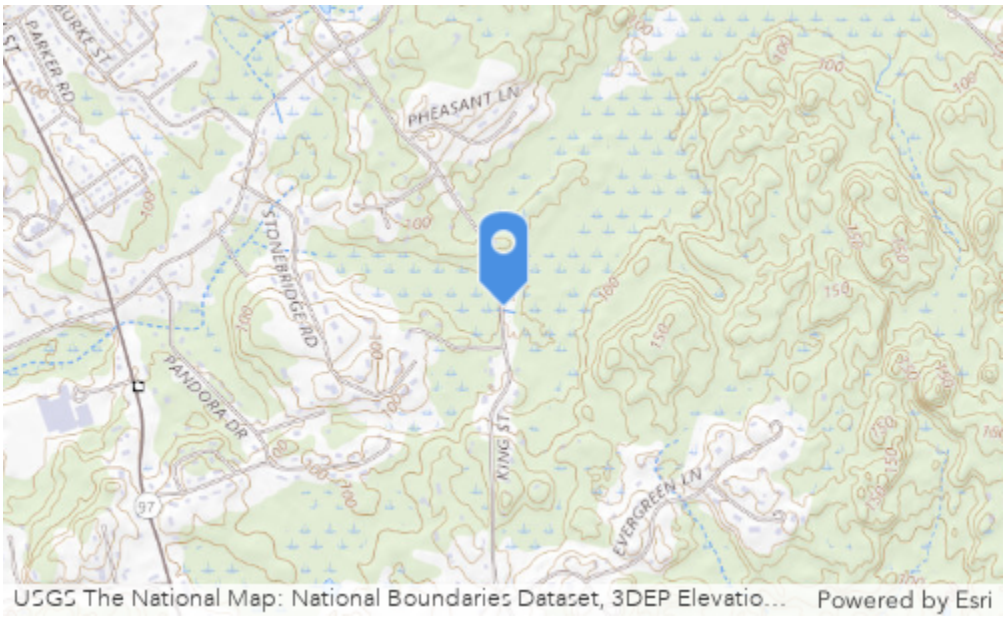
Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Culvert & Dam Observation Results

General Information	
Site ID: RC017	**Street:** King St
Inspection Date: December 7, 2021	**Site Type:** Culvert

Location Map:



Culvert Information (If Applicable)		
Material: Clay pipe	**Geometry:** Circular	**Number of Barrels:** 1
Height (ft): 1	**Span (ft):** 1	**Length (ft):** 30
Geometry Notes (if any):		
Condition Observations: Undersized and also set too high to adequately drain the wetlands		
Overall Condition: Fair *Comments:* Needs updating.		

Dam Information (If Applicable)	
Dam Type:	**Control Mechanism:**
Control Mechanism Comments (if any):	
Control Configuration Comments (if any):	
Outlet / Spillway Observations:	
Embankment Observations:	
Overall Condition: *Comments:*	
Upstream Channel Information	

Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations overgrown vegetation, debris / blockage, evidence of previous overtopping onto floodplain *Comments:*	
Downstream Channel Information	
Geometry: Irregular	**Material:** Vegetated / Natural
Appx. Bankfull Width (ft):	**Sedimentation Level:** No observed sedimentation
Condition Observations overgrown vegetation, debris / blockage, evidence of previous overtopping onto floodplain *Comments:*	
General Recommendations (based on initial findings)	
Replace culvert at proper elevation and size.	

Photo Log

Photo 1: Upstream Photo of Culvert / Dam

Photo 2: Upstream Channel

Photo 3: Downstream Photo of Culvert / Dam

Photo 4: Downstream Channel

Appendix B

Model Simulation Files (*available electronically only*)

Appendix C

Detailed Conceptual Recommendations

Johnson Creek Watershed Resiliency Project
Groveland, MA

POTENTIAL WATERSHED IMPROVEMENTS

May 2022

General Notes:

1. See accompanying Report and Attachments for more information on each potential improvement site, including flood modeling simulation results, and summary tables.

2. Replacement culverts can be sized to (1) meet minimum hydraulic requirements (based on MassDOT roadway functional class or local specifications for the road) and/or (2) meet the DER Stream Crossing Performance Standards to the maximum extent practicable.
   a) If the project is being funded by EEA/DER (i.e., MVP or CRMA Grant), the culvert **must** be designed based upon the MA Stream Crossing Performance Standards.
   b) If the project is being funded by MassDOT (i.e., Small Bridge Program Grant) or the bridge span is greater than 10 feet, the culvert **must** be designed based upon MA Chapter 85 Design Requirements.
   c) Unless otherwise indicated, preliminary culvert dimensions indicated herein assume that the proposed culvert improvement would be designed to meet both **MA Stream Crossing Performance Standards and MA Chapter 85 Design Requirements**. These designs will need to be reevaluated based on detailed site survey, H&H study, geotechnical evaluation.

3. Order-of-magnitude cost estimates are for planning purposes only. Culvert costs are based on actual bid data from similar projects. Costs may vary widely based on more detailed project design (i.e., roadway & utility work, traffic detours, temporary water handling, etc.). Unless otherwise indicated, culvert replacement cost estimates herein assume that the proposed culvert improvement would be designed to meet both **MA Stream Crossing Performance Standards and MA Chapter 85 Design Requirements**.

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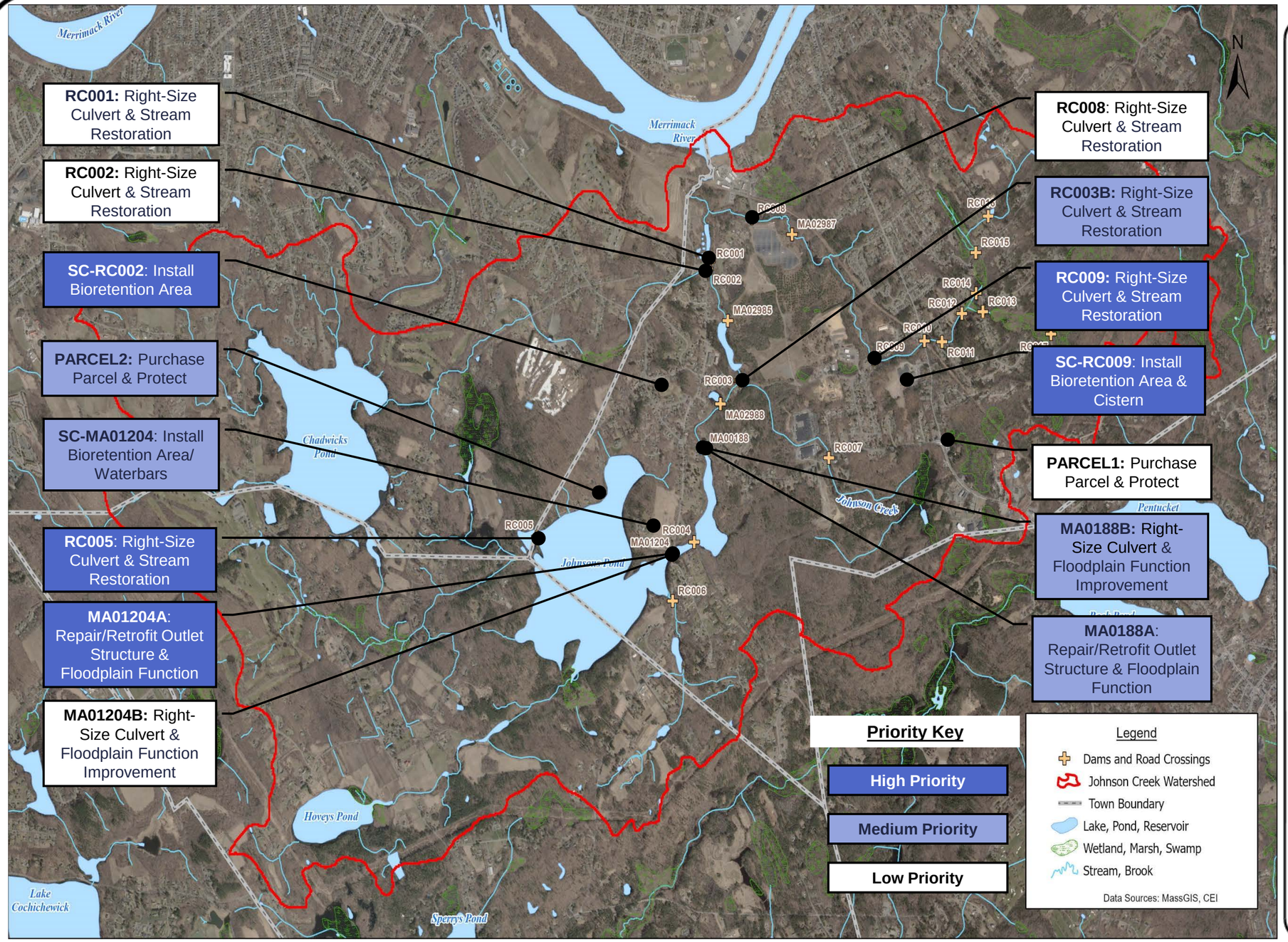


GENERAL NOTES

No.	Revisions/Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

Potential Improvement Site Locations

Project No.:	Sheet
Date:	1
Drawn By:	
Checked By:	
Scale:	

RC005: Culvert Crossing on Lower Center Street

ESTIMATED COST: $ 380,000 – $ 480,000

PRIORITY RANK: HIGH

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- Coordinates: 42.7336, -71.0581
- Location Reference: Lower Center Street
- The existing crossing is a 2-barrel circular culvert. The culverts have a diameter of 2.5 feet and are constructed with reinforced concrete pipe (RCP) and corrugated metal pipe (CMP).
- The culverts are in **POOR** condition.

Proposed Site Improvements

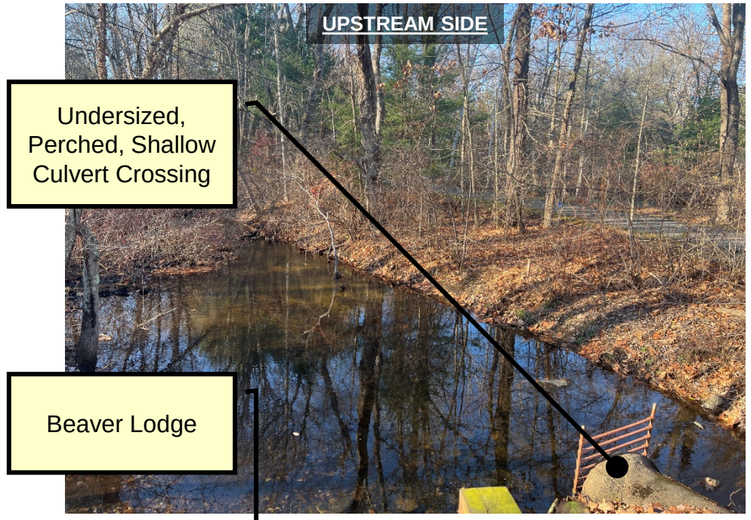
- Replace the existing culvert with an open-bottom culvert designed to pass the 10-year flood with less than 2 feet of freeboard. The proposed culvert will have a span of approximately 18 feet, height of 6 feet, and length of 40 feet.
- Raise the roadway over the culvert crossing to provide flood resiliency against the 100-year flood. Based on modeling results, the road should be raised by approximately 3 feet.
- Remove and monitor overgrown vegetation and debris buildup upstream and downstream of the culvert crossing.
- Address and monitor beaver activity upstream and downstream of the culvert crossing.

Potential Flooding Improvements

- During existing conditions, the road is simulated to flood during the 5-yr, 25-yr, and 100-yr future storms.
- Based on model simulations, during proposed conditions, potential flooding during the 5-yr and 25-yr future storms is eliminated.

PRIMARY NATURE-BASED COMPONENTS

- **Stream Continuity**
  - The proposed culvert will have (1) a span of at least 1.2x average bankfull width, (2) a minimum height of 6 feet, and (3) an openness ratio of at least 1.64 ft to meet optimum stream crossing standards per Division of Ecological Restoration (DER).
  - The proposed culvert is open-bottom. The embedment depth will be at least 2 feet or at least twice the D84 of the natural streambed material when the embedment material includes elements >15 inches in diameter. A pebble count will be completed to determine the embedment depth (DER).
  - Natural bottom substrate will be used within the crossing and will match upstream and downstream streambed material to maximize stream continuity and reestablish fish and wildlife crossing (DER).
  - Water depths and velocities will be reestablished such that they are comparable to natural flow conditions in the channel to maximize stream continuity and reestablish fish and wildlife crossing (DER).
- **Streambank Stabilization**
  - The stream embankment upstream and downstream of the culvert crossing will be stabilized with native vegetation where there is evidence of significant erosion and/or undercutting.



GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

RC005 Proposed Improvements

Project No.:	Sheet
Date:	2
Drawn By:	
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MA01204A: Dam on Washington Street (Johnsons Pond Dam)

ESTIMATED COST: **$ 60,000 – $ 80,000**

PRIORITY RANK: **HIGH**

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- Coordinates: 42.7325, -71.0457
- Location Reference: Washington Street
- The existing impoundment is a earthen embankment with a 6-foot span concrete weir that discharges to a downstream culvert structure. The weir controls are stoplogs. There is a road on the earthen embankment.
- The dam outlet is in **FAIR** condition.

Proposed Site Improvements

- Repair or retrofit the existing concrete weir to improve the functionality and usability of the outlet controls (flashboards).
- As an interim solution, fabricate a concrete stop log to insert into the right side of the outlet structure; core a hole into the stop log and install a manually operated knife gate valve with an upstream trash rack.
- Develop a protocol to release water from the Pond prior to significant forecast storm events.

Potential Flooding Improvements

- During existing conditions, the road is simulated to flood during the 25-yr and 100-yr future storms.
- Based on model simulations, during proposed conditions, potential flooding during the 25-yr future storm is eliminated.

PRIMARY NATURE-BASED COMPONENTS

- **Floodplain Function**
  - The weir will be retrofitted to provide appropriate hydraulic capacity and thus enhancing the natural floodplain functions of Johnsons Pond.
  - Natural floodplain function includes fish and wildlife protection, natural flood and erosion control, surface water quality maintenance, groundwater recharge, biological productivity, and higher recreational opportunities (FEMA).
  - Enhancing natural floodplain function will provide excess water storage, reduce flood peaks, reduce flood velocities, reduce flow rate, reduce potential for erosion, slows down surface runoff, allows additional time for infiltration and groundwater recharge, and regulates flow during non-flood periods (FEMA).
- ***Note**: The goal of this weir repair / retrofit is not to return the system back to stream-like conditions, since this weir is part of an impoundment. Removing the dam will result in the loss of Johnsons Pond and associated habitat. Therefore, a case can be made that the weir does not have to meet DER's stream crossing performance standards, and the weir will be designed based only upon the hydraulic needs of the dam. Efforts will be made to improve wildlife crossing to the maximum extent practicable.*

Deteriorating Outlet Structure

GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

MA01204A Proposed Improvements

Project No.:	Sheet
Date:	3
Drawn By:	
Checked By:	
Scale:	

MA01204B: Culvert Crossing on Washington Street

ESTIMATED COST: $ 310,000 – $ 390,000

PRIORITY RANK: LOW

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- Coordinates: 42.7325, -71.0457
- Location Reference: Washington Street
- The existing crossing is an arched culvert. The culvert has a span of 6 feet, height of 4 feet. The upstream end is corrugated metal pipe (CMP). The downstream end of brick.
- The culvert outlet is in **POOR** condition.

Proposed Site Improvements

- Replace the existing culvert with an open-bottom culvert designed to pass the 25-year flood with 2 feet of freeboard. The proposed culvert will have a span of approximately 9 feet, height of 6 feet, and length of 40 feet.
- Address and monitor beaver activity upstream and downstream of the culvert crossing.

Potential Flooding Improvements

- During existing conditions, the road is simulated to flood during the 25-yr and 100-yr future storms.
- Based on model simulations, during proposed conditions, potential flooding during the 25-yr future storm is eliminated.

PRIMARY NATURE-BASED COMPONENTS

- **Floodplain Function**
  - The weir will be retrofitted to provide appropriate hydraulic capacity and thus enhancing the natural floodplain functions of Johnsons Pond.
  - Natural floodplain function includes fish and wildlife protection, natural flood and erosion control, surface water quality maintenance, groundwater recharge, biological productivity, and higher recreational opportunities (FEMA).
  - Enhancing natural floodplain function will provide excess water storage, reduce flood peaks, reduce flood velocities, reduce flow rate, reduce potential for erosion, slows down surface runoff, allows additional time for infiltration and groundwater recharge, and regulates flow during non-flood periods (FEMA).
- ***Note**: The goal of this culvert replacement is not to return the system back to stream-like conditions, since this culvert is part of an impoundment. Removing the dam will result in the loss of Johnsons Pond and associated habitat. Therefore, a case can be made that the culvert does not have to meet DER's stream crossing performance standards, and the culvert will be designed based only upon the hydraulic needs of the dam. Efforts will be made to improve wildlife crossing to the maximum extent practicable.*

Deteriorating Headwall and Culvert; Undersized Culvert Crossing

GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

MA01204B Proposed Improvements

Project No.:	Sheet
Date:	4
Drawn By:	
Checked By:	
Scale:	

MA01204B: Culvert Crossing on Washington Street (continued)

UPSTREAM SIDE (CHANNEL)

DOWNSTREAM SIDE (CHANNEL)

GENERAL NOTES

No.	Revision / Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

MA01204B Proposed Improvements

Project No.:	Sheet
Date:	5
Drawn By:	
Checked By:	
Scale:	

MA00188A: Dam on Salem Street (Lower Pond Dam)

ESTIMATED COST: **$ 120,000 – $ 150,000**

PRIORITY RANK: **MEDIUM**

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- Coordinates: 42.7386, -71.0428
- Location Reference: Salem Street
- The existing impoundment is a earthen embankment with a 4.5-foot span masonry weir that discharges to a downstream culvert structure. The weir controls are stoplogs. There is a road on the earthen embankment.
- The dam outlet is in **FAIR** condition.

Proposed Site Improvements

- Repair or retrofit the existing concrete weir to improve the functionality and usability of the outlet controls (flashboards).
- Install a sluice gate at the bottom of the outlet structure.
- Develop a protocol to release water from the Pond prior to significant forecast storm events.

Potential Flooding Improvements

- During existing conditions, the road is simulated to flood during the 25-yr and 100-yr future storms.
- Based on model simulations, during proposed conditions, potential flooding during the 25-yr future storm is eliminated.

PRIMARY NATURE-BASED COMPONENTS

- **Floodplain Function**
  - The weir will be retrofitted to provide appropriate hydraulic capacity and thus enhancing the natural floodplain functions of Lower Pond.
  - Natural floodplain function includes fish and wildlife protection, natural flood and erosion control, surface water quality maintenance, groundwater recharge, biological productivity, and higher recreational opportunities (FEMA).
  - Enhancing natural floodplain function will provide excess water storage, reduce flood peaks, reduce flood velocities, reduce flow rate, reduce potential for erosion, slows down surface runoff, allows additional time for infiltration and groundwater recharge, and regulates flow during non-flood periods (FEMA).
- ***Note**: The goal of this weir repair / retrofit is not to return the system back to stream-like conditions, since this weir is part of an impoundment. Removing the dam will result in the loss of Lower Pond and associated habitat. Therefore, a case can be made that the weir does not have to meet DER's stream crossing performance standards, and the weir will be designed based only upon the hydraulic needs of the dam. Efforts will be made to improve wildlife crossing to the maximum extent practicable.*

GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

MA00188A Proposed Improvements

Project No.:	Sheet
Date:	
Drawn By:	6
Checked By:	
Scale:	

MA00188B: Culvert Crossing on Salem Street

ESTIMATED COST: $ 580,000 – $ 730,000

PRIORITY RANK: MEDIUM

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- Coordinates: 42.7386, -71.0428
- Location Reference: Salem Street
- The existing crossing is a 1-barrel circular culvert. The culvert has a diameter of 4.5 feet and is constructed with corrugated metal pipe (CMP).
- The culvert outlet in **POOR** condition.

Proposed Site Improvements

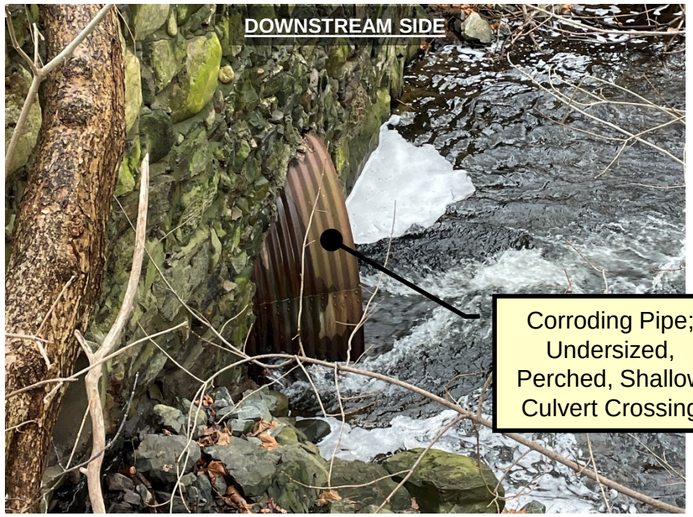
- Replace the existing culvert with a culvert designed to pass the 25-year flood with 2 feet of freeboard. (MassDOT)
- Replace the existing culvert with a culvert which has a span of approximately 9 feet, height of 6 feet, and length of 75 feet.
- Remove and monitor overgrown vegetation and debris buildup upstream and downstream of the culvert crossing.
- Address and monitor beaver activity upstream of the culvert crossing.

Potential Flooding Improvements

- During existing conditions, the road is simulated to flood during the 25-yr and 100-yr future storms.
- Based on model simulations, during proposed conditions, potential flooding during the 25-yr future storm is eliminated.

PRIMARY NATURE-BASED COMPONENTS

- **Floodplain Function**
  - The weir will be retrofitted to provide appropriate hydraulic capacity and thus enhancing the natural floodplain functions of Lower Pond.
  - Natural floodplain function includes fish and wildlife protection, natural flood and erosion control, surface water quality maintenance, groundwater recharge, biological productivity, and higher recreational opportunities (FEMA).
  - Enhancing natural floodplain function will provide excess water storage, reduce flood peaks, reduce flood velocities, reduce flow rate, reduce potential for erosion, slows down surface runoff, allows additional time for infiltration and groundwater recharge, and regulates flow during non-flood periods (FEMA).
- **Streambank Stabilization**
  - The stream embankment downstream of the impoundment will be stabilized with native vegetation where there is evidence of erosion and/or undercutting.
- ***Note**: The goal of this culvert replacement is not to return the system back to stream-like conditions, since this culvert is part of an impoundment. Removing the dam will result in the loss of Lower Pond and associated habitat. Therefore, a case can be made that the culvert does not have to meet DER's stream crossing performance standards, and the culvert will be designed based only upon the hydraulic needs of the dam. Efforts will be made to improve wildlife crossing to the maximum extent practicable.*



GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

MA00188B Proposed Improvements

Project No.:	Sheet
Date:	7
Drawn By:	
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Scale:	

MA00188B: Culvert Crossing on Salem Street (continued)

GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

MA00188B Proposed Improvements

Project No.:	Sheet
Date:	8
Drawn By:	
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Scale:	

RC003B: Culvert Crossing on Center Street

ESTIMATED COST: **$ 480,000 – $ 600,000**

PRIORITY RANK: **MEDIUM**

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- Coordinates: 42.7426, -71.0392
- Location Reference: Center Street
- The existing crossing is a rectangular box culvert. The culvert has a span of 8 feet, height of 4 feet, and is constructed with reinforced concrete pipe (RCP).
- The culvert is in **POOR** condition.

Proposed Site Improvements

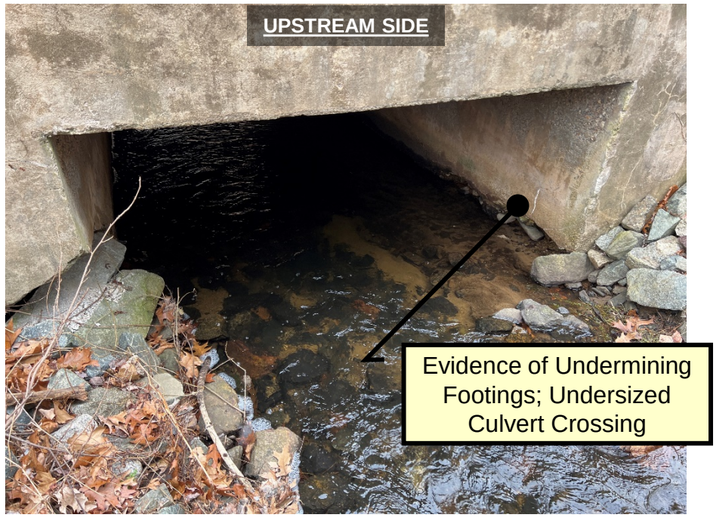
- Replace the existing culvert with an open-bottom culvert designed to pass the 10-year flood with less than 2 feet of freeboard. The proposed culvert will have a span of approximately 24 feet, height of 6 feet, and length of 40 feet.
- Remove and monitor overgrown vegetation and debris buildup downstream of the culvert crossing.

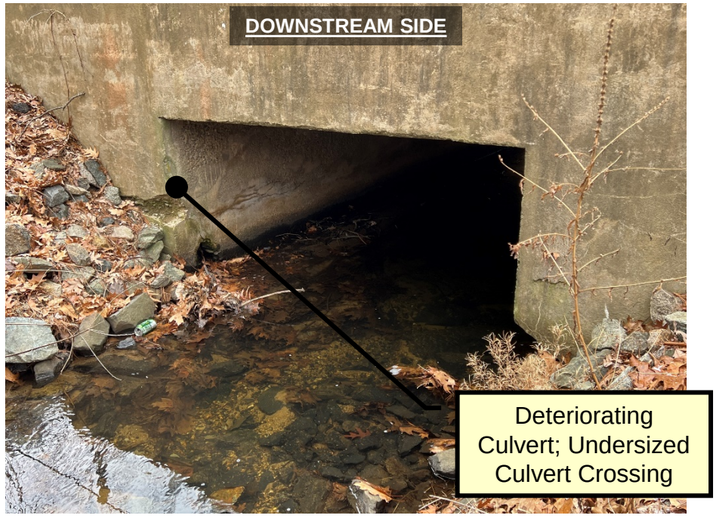
Potential Flooding Improvements

- During existing conditions, the road is simulated to flood during the 100-yr future storm.
- Based on model simulations, during proposed conditions, potential flooding during the 100-yr future storm is eliminated.

PRIMARY NATURE-BASED COMPONENTS

- **Stream Continuity**
  - The proposed culvert will have (1) a span of at least 1.2x average bankfull width, (2) a minimum height of 6 feet, and (3) an openness ratio of at least 1.64 ft to meet optimum stream crossing standards per Division of Ecological Restoration (DER).
  - The proposed culvert is open-bottom. The embedment depth will be at least 2 feet or at least twice the D84 of the natural streambed material when the embedment material includes elements >15 inches in diameter. A pebble count will be completed to determine the embedment depth (DER).
  - Natural bottom substrate will be used within the crossing and will match upstream and downstream streambed material to maximize stream continuity and reestablish fish and wildlife crossing (DER).
  - Water depths and velocities will be reestablished such that they are comparable to natural flow conditions in the channel to maximize stream continuity and reestablish fish and wildlife crossing (DER).
- **Streambank Stabilization**
  - The stream embankment upstream and downstream of the culvert crossing will be stabilized with native vegetation where there is evidence of significant erosion and/or undercutting.





GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

RC003B Proposed Improvements

Project No.:	Sheet
Date:	9
Drawn By:	
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RC003B: Culvert Crossing on Center Street (continued)

GENERAL NOTES

No.	Revision / Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

RC003B Proposed Improvements

Project No.:	Sheet
Date:	10
Drawn By:	
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RC002: Culvert Crossing on Washington Street

ESTIMATED COST: $ 310,000 – $ 390,000

PRIORITY RANK: LOW

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- Coordinates: 42.7490, -71.0422
- Location Reference: Washington Street
- The existing crossing is a 1-barrel circular culvert. The culvert has a diameter of 4 feet and is constructed with reinforced concrete pipe (RCP).
- The culvert is in **FAIR** condition.

Proposed Site Improvements

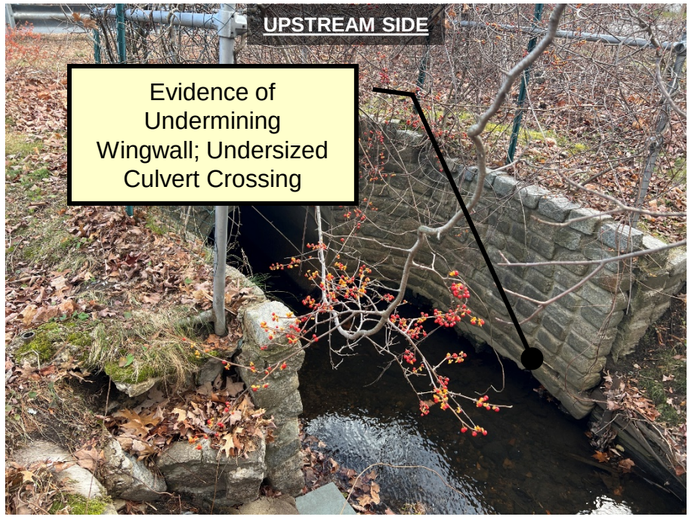
- Replace the existing culvert with an open-bottom culvert designed to pass the 25-year flood with 2 feet of freeboard. The proposed culvert will have a span of approximately 12 feet, height of 6 feet, and length of 40 feet.
- Raise the roadway over the culvert crossing to provide flood resiliency against the 100-year flood. Based on modeling results, the road should be raised approximately 3 feet.

Potential Flooding Improvements

- During existing conditions, the road is simulated to flood during the 5-yr, 25-yr, and 100-yr future storms.
- Based on model simulations, during proposed conditions, potential flooding during the 5-yr and 25-yr future storms is eliminated.

PRIMARY NATURE-BASED COMPONENTS

- **Stream Continuity**
  - The proposed culvert will have (1) a span of at least 1.2x average bankfull width, (2) a minimum height of 6 feet, and (3) an openness ratio of at least 1.64 ft to meet optimum stream crossing standards per Division of Ecological Restoration (DER).
  - The proposed culvert is open-bottom. The embedment depth will be at least 2 feet or at least twice the D84 of the natural streambed material when the embedment material includes elements >15 inches in diameter. A pebble count will be completed to determine the embedment depth (DER).
  - Natural bottom substrate will be used within the crossing and will match upstream and downstream streambed material to maximize stream continuity and reestablish fish and wildlife crossing (DER).
  - Water depths and velocities will be reestablished such that they are comparable to natural flow conditions in the channel to maximize stream continuity and reestablish fish and wildlife crossing (DER).



GENERAL NOTES

No.	Revision / Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

RC002 Proposed Improvements

Project No.:	Sheet
Date:	11
Drawn By:	
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Scale:	

RC001: Culvert Crossing on Main Street

ESTIMATED COST: $ 480,000 – $ 600,000

PRIORITY RANK: LOW

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- Coordinates: 42.7495, -71.0420
- Location Reference: Main Street
- The existing crossing is a rectangular box culvert. The culvert has a span of 8 feet, height of 3 feet, and is constructed with reinforced concrete pipe (RCP).
- The culvert is in **GOOD** condition.

Proposed Site Improvements

- Replace the existing culvert with an open-bottom culvert designed to pass the 25-year flood with 2 feet of freeboard. The proposed culvert will have a span of approximately 24 feet, height of 6 feet, and length of 40 feet.
- Raise the roadway over the culvert crossing to provide flood resiliency against the 100-year flood. Based on modeling results, the road should be raised approximately 3 feet.
- Remove and monitor overgrown vegetation and debris buildup upstream of the culvert crossing.

Potential Flooding Improvements

- During existing conditions, the road is simulated to flood during the 5-yr, 25-yr, and 100-yr future storms.
- Based on model simulations, during proposed conditions, potential flooding during the 5-yr and 25-yr future storms is eliminated.

PRIMARY NATURE-BASED COMPONENTS

- **Stream Continuity**
  - The proposed culvert will have (1) a span of at least 1.2x average bankfull width, (2) a minimum height of 6 feet, and (3) an openness ratio of at least 1.64 ft to meet optimum stream crossing standards per Division of Ecological Restoration (DER).
  - The proposed culvert is open-bottom. The embedment depth will be at least 2 feet or at least twice the D84 of the natural streambed material when the embedment material includes elements >15 inches in diameter. A pebble count will be completed to determine the embedment depth (DER).
  - Natural bottom substrate will be used within the crossing and will match upstream and downstream streambed material to maximize stream continuity and reestablish fish and wildlife crossing (DER).
  - Water depths and velocities will be reestablished such that they are comparable to natural flow conditions in the channel to maximize stream continuity and reestablish fish and wildlife crossing (DER).
- **Streambank Stabilization**
  - The stream embankment upstream of the culvert crossing will be stabilized with native vegetation where there is evidence of significant erosion and/or undercutting.

GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

RC001 Proposed Improvements

Project No.:	Sheet
Date:	12
Drawn By:	
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Scale:	

RC001: Culvert Crossing on Main Street (continued)

GENERAL NOTES

No.	Revision / Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

RC001 Proposed Improvements

Project No.:	Sheet
Date:	13
Drawn By:	
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RC008: Culvert Crossing on Main Street

ESTIMATED COST: $ 380,000 – $ 480,000

PRIORITY RANK: LOW

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- Coordinates: 42.7519, -71.0381
- Location Reference: Main Street
- The existing crossing is a rectangular box culvert. The culvert has a span of 8 feet, height of 6 feet, and is constructed with masonry blocks.
- The culvert is in **GOOD** condition.

Proposed Site Improvements

- Replace the existing culvert with an open-bottom culvert designed to pass the 25-year flood with 2 feet of freeboard. The proposed culvert will have a span of approximately 18 feet, height of 6 feet, and length of 40 feet.
- Raise the roadway over the culvert crossing to provide flood resiliency against the 100-year flood. Based on modeling results, the road should be raised approximately 3 feet.
- Remove and monitor overgrown vegetation and debris buildup upstream of the culvert crossing.

Potential Flooding Improvements

- During existing conditions, the road is simulated to flood during the 5-yr, 25-yr, and 100-yr future storms.
- Based on model simulations, during proposed conditions, potential flooding during the 5-yr future storms is eliminated.

PRIMARY NATURE-BASED COMPONENTS

- **Stream Continuity**
  - The proposed culvert will have (1) a span of at least 1.2x average bankfull width, (2) a minimum height of 6 feet, and (3) an openness ratio of at least 1.64 ft to meet optimum stream crossing standards per Division of Ecological Restoration (DER).
  - The proposed culvert is open-bottom. The embedment depth will be at least 2 feet or at least twice the D84 of the natural streambed material when the embedment material includes elements >15 inches in diameter. A pebble count will be completed to determine the embedment depth (DER).
  - Natural bottom substrate will be used within the crossing and will match upstream and downstream streambed material to maximize stream continuity and reestablish fish and wildlife crossing (DER).
  - Water depths and velocities will be reestablished such that they are comparable to natural flow conditions in the channel to maximize stream continuity and reestablish fish and wildlife crossing (DER).

GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

RC008 Proposed Improvements

Project No.:	Sheet
Date:	14
Drawn By:	
Checked By:	
Scale:	

RC008: Culvert Crossing on Main Street (continued)

GENERAL NOTES

No.	Revision / Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

RC008 Proposed Improvements

Project No.:	Sheet
Date:	15
Drawn By:	
Checked By:	
Scale:	

RC009: Culvert Crossing on Center Street

ESTIMATED COST: $ 380,000 – $ 480,000

PRIORITY RANK: HIGH

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- Coordinates: 42.7438, -71.0269
- Location Reference: Center Street
- The existing crossing is a 1-barrel circular culvert. The culvert has a diameter of 3 feet and is constructed with corrugated metal pipe (CMP).
- The culvert is in **POOR** condition.

Proposed Site Improvements

- Replace the existing culvert with an open-bottom culvert designed to pass the 25-year flood with 2 feet of freeboard. The proposed culvert will have a span of approximately 18 feet, height of 6 feet, and length of 40 feet.
- Raise the roadway over the culvert crossing to provide flood resiliency against the 100-year flood. Based on modeling results, the road should be raised approximately 3 feet.

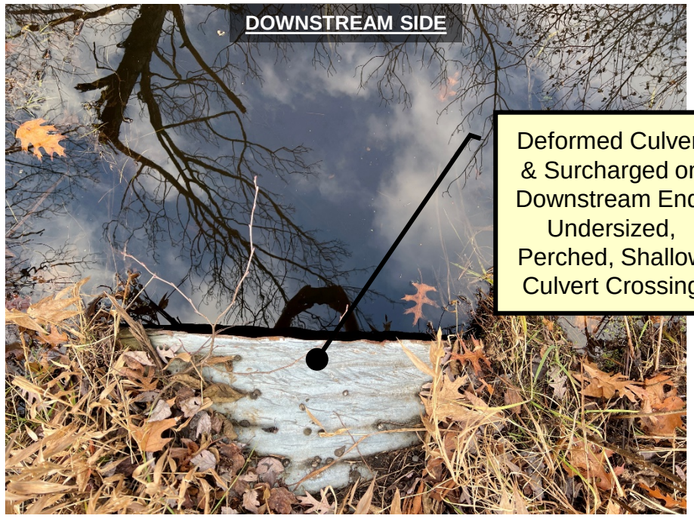
Potential Flooding Improvements

- During existing conditions, the road is simulated to flood during the 5-yr, 25-yr, and 100-yr future storms.
- Based on model simulations, during proposed conditions, potential flooding during the 5-yr and 25-yr future storms is eliminated.

PRIMARY NATURE-BASED COMPONENTS

- **Stream Continuity**
  - The proposed culvert will have (1) a span of at least 1.2x average bankfull width, (2) a minimum height of 6 feet, and (3) an openness ratio of at least 1.64 ft to meet optimum stream crossing standards per Division of Ecological Restoration (DER).
  - The proposed culvert is open-bottom. The embedment depth will be at least 2 feet or at least twice the D84 of the natural streambed material when the embedment material includes elements >15 inches in diameter. A pebble count will be completed to determine the embedment depth (DER).
  - Natural bottom substrate will be used within the crossing and will match upstream and downstream streambed material to maximize stream continuity and reestablish fish and wildlife crossing (DER).
  - Water depths and velocities will be reestablished such that they are comparable to natural flow conditions in the channel to maximize stream continuity and reestablish fish and wildlife crossing (DER).

Deformed Culvert & Surcharged on Upstream End; Undersized, Perched, Shallow Culvert Crossing



Deformed Culvert & Surcharged on Downstream End; Undersized, Perched, Shallow Culvert Crossing

GENERAL NOTES

No.	Revisions/Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

RC009 Proposed Improvements

Project No.:	Sheet
Date:	16
Drawn By:	
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Scale:	

RC009: Culvert Crossing on Center Street (continued)

GENERAL NOTES

No.	Revision / Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

RC009 Proposed Improvements

Project No.:	Sheet
Date:	17
Drawn By:	
Checked By:	
Scale:	

SC-MA01204: Veasey Memorial Park
(201 Washington St.)

Site Description

- An existing paved parking area and steep access road at Veasey Memorial Park does not have any subsurface drainage
- Concentrated runoff likely enters an adjacent wooded area (to the south) and eventually discharges into Johnsons Pond.

Proposed Site Improvements

- Install a bioretention area at the southeast corner of the parking lot with a deep sump catch basin inlet, an underdrain, and a riprap overflow.
- Install appx. four (4) runoff diversion water bars at approximate 100-ft intervals along length of access road. Install depressed riprap aprons with level spreader at each discharge point to capture and infiltrate runoff and reduce erosion potential.
- The goal will be to decrease watershed runoff and subsequent downstream flooding.
- The BMP will also improve water quality by removing pollutants from the parking lot runoff (i.e., metals, nutrients, etc.).

***See next sheet for site plan of proposed improvements.**

Potential Conflicts

- Site survey will be required to verify portion of road that slopes to the proposed BMP. Re-grading or re-direction of runoff may be needed to fully capture runoff from the parking lot.
- Soil Types are Merrimac C (Fine sandy loam). Soil testing will be needed to verify infiltration ability of soil and depth to groundwater.
- Coordinate snow removal to avoid plowing into the BMP.

ESTIMATED COST: **$ 60,000 – $ 80,000**

PRIORITY RANK: **MEDIUM**

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

PRIMARY NATURE-BASED COMPONENTS

- **Green Infrastructure / Low Impact Development**
  - A bioretention area will be installed to enhance exfiltration of stormwater runoff into groundwater. This bioretention area will help decrease peak runoff, decrease downstream flooding, promote groundwater recharge, preserve natural water balance of the site, remove pollutants from stormwater runoff, enhance the habitats of amphibians or other small animals, and provide a pollinator habitat (MassDEP).
  - The bioretention area will (1) have some form of pretreatment, (2) be 5-7% of the drainage area, (3) be 2 feet above the groundwater table, (4) have a soil media depth between 2-4 feet, (5) have soil media composition and planting schedule meeting guidelines for bioretention systems designed to exfiltrate (MassDEP).

GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

SC-MA01204: Prop. Conditions Overview

Project No.:	Sheet
Date:	18
Drawn By:	
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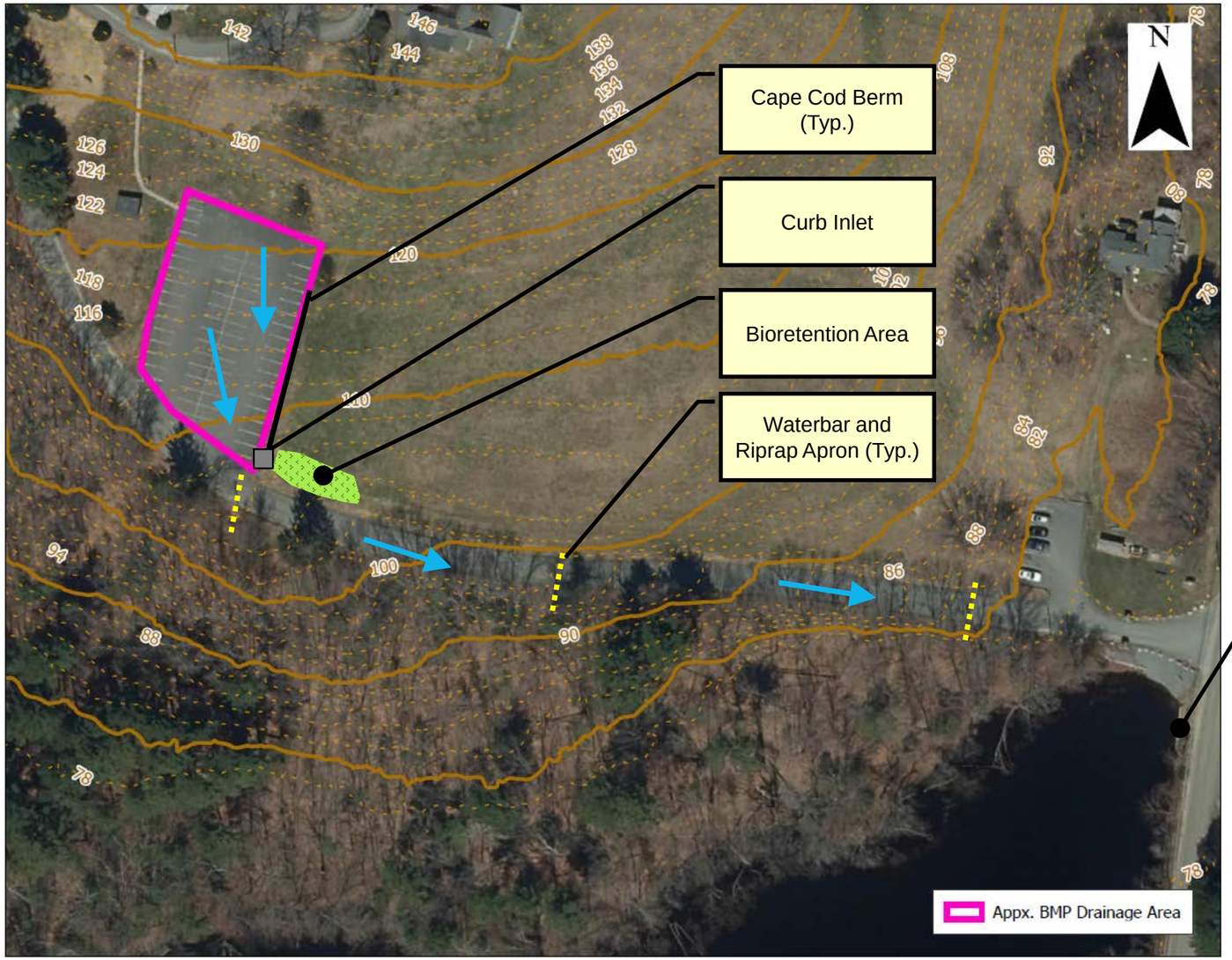

Infiltration Area Notes:

- Install appx. 40’ by 15’ x 3’ deep infiltration area with deep sump curb inlet and riprap overflow.
- Install protective fencing in front of infiltration area.

GENERAL NOTES

No.	Revisions/Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

SC-MA01204: Prop. Conditions Site Plan

Project No.:	Sheet
Date:	
Drawn By:	19
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SC-RC002: Groveland Baseball Fields and Playground (90 Center St.)

Site Description

- An existing paved parking lot at the Groveland Baseball Fields and Playground does not have any subsurface drainage.
- Runoff from the parking lot drains to a small grassed area at the northwest corner of the parking lot.
- It appears that the grassed area connects to the drainage system on Center Street.

Proposed Site Improvements

- Install bioretention area at the northwest corner of the parking lot with a deep sump catch basin inlet, an underdrain, and an overflow riser pipe to the existing drainage system on Center Street.
- The goal will be to decrease watershed runoff and subsequent downstream flooding.
- The BMP will also improve water quality by removing pollutants from the parking lot runoff (i.e., metals, nutrients, etc.).

***See next sheet for site plan of proposed improvements.**

Potential Conflicts

- Site survey will be required to verify portion of road that slopes to the proposed BMP. Re-grading or re-direction of runoff may be needed to fully capture runoff from the parking lot.
- Soil Types are Windsor A (Loamy Sand). Soil testing will be needed to verify infiltration ability of soil and depth to groundwater.
- Coordinate snow removal to avoid plowing into the BMP.

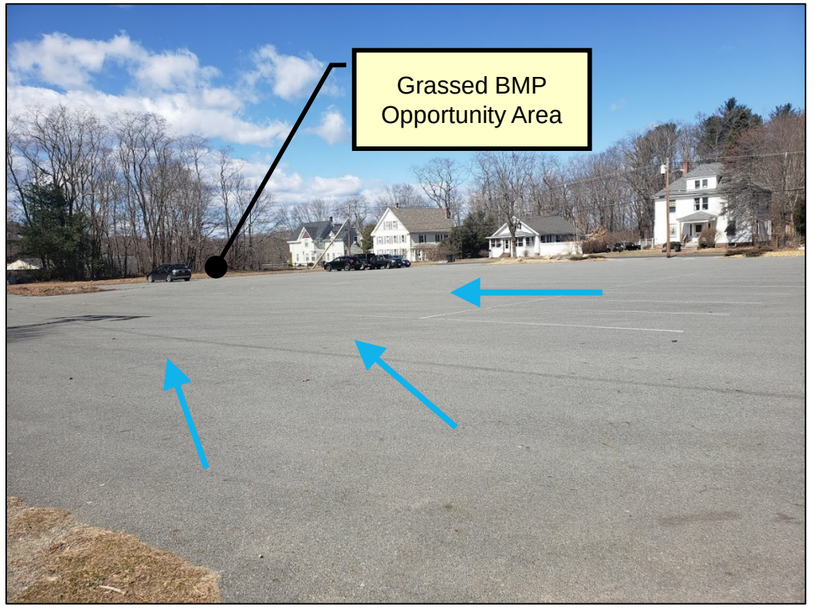
ESTIMATED COST: **$ 70,000 – $ 90,000**

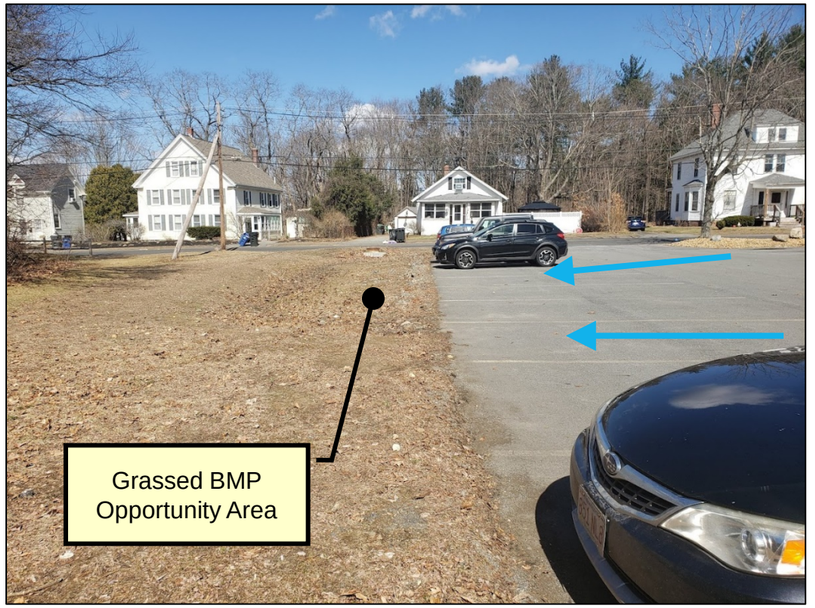
PRIORITY RANK: **HIGH**

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

PRIMARY NATURE-BASED COMPONENTS

- **Green Infrastructure / Low Impact Development**
  - A bioretention area will be installed to enhance exfiltration of stormwater runoff into groundwater. This bioretention area will help decrease peak runoff, decrease downstream flooding, promote groundwater recharge, preserve natural water balance of the site, remove pollutants from stormwater runoff, enhance the habitats of amphibians or other small animals, and provide a pollinator habitat (MassDEP).
  - The bioretention area will (1) have some form of pretreatment, (2) be 5-7% of the drainage area, (3) be 2 feet above the groundwater table, (4) have a soil media depth between 2-4 feet, (5) have soil media composition and planting schedule meeting guidelines for bioretention systems designed to exfiltrate (MassDEP).





GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

SC-RC002: Prop. Conditions Overview

Project No.:	Sheet
Date:	20
Drawn By:	
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SC-RC002: Cont…

Infiltration Area Notes:

- Install appx. 60’ by 15’ x 3’ deep infiltration area with deep sump curb inlet, underdrain, and riser style outlet structure.
- Install protective fencing in front of infiltration area.

GENERAL NOTES

No.	Revision / Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

SC-RC002: Prop. Conditions Site Plan

Project No.:	Sheet
Date:	
Drawn By:	21
Checked By:	
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SC-RC009: Bagnall Elementary School (253 School St.)

Site Description

- The access road to the Bagnall Elementary School slopes to an existing catch basin which then discharges to the adjacent wetland area to the north.
- There are also buildings where roof runoff could be captured.

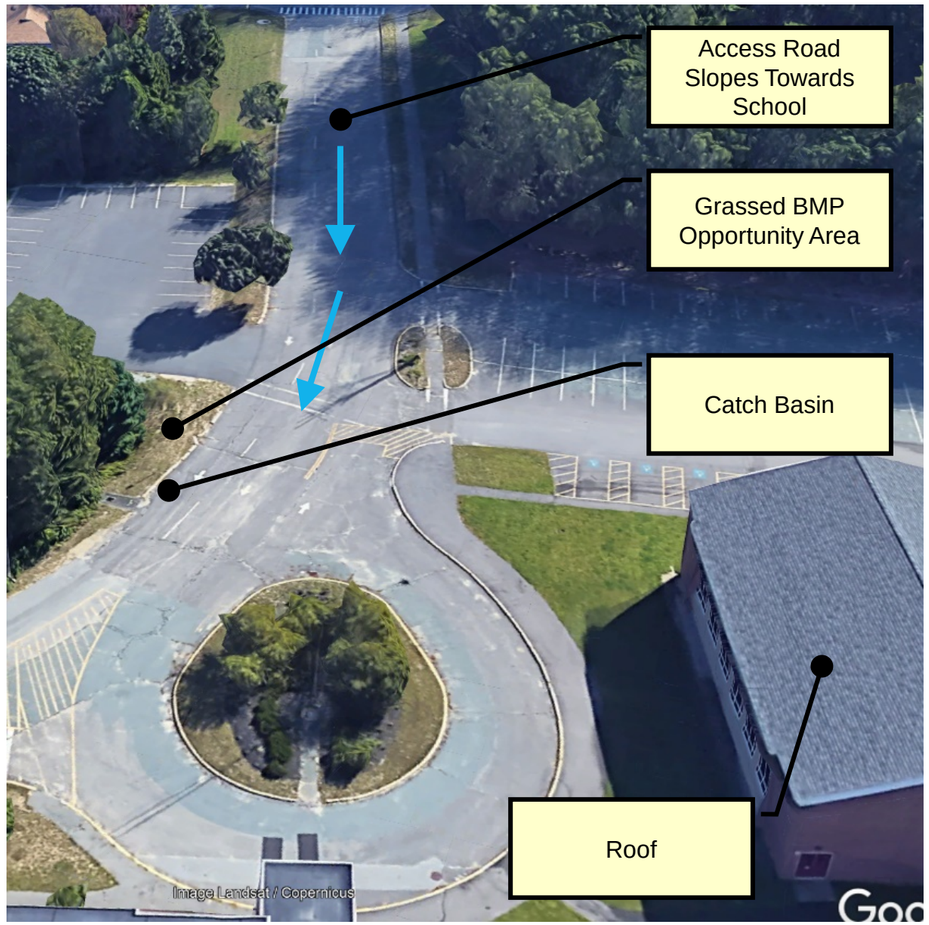
Proposed Site Improvements

- Install a bioretention area within an existing grassed area with a deep sump catch basin inlet, an underdrain, and an overflow riser pipe to the existing downgradient catch basin.
- Also install a rainwater cistern to capture runoff from half of the gymnasium roof. Install drip irrigation system at outlet of cistern that irrigates a native wildflower garden.
- The goal will be to decrease watershed runoff and subsequent downstream flooding.
- The BMPs will also improve water quality by removing pollutants from the parking lot and roof runoff (i.e., metals, nutrients, etc.).

***See next sheet for site plan of proposed improvements.**

Potential Conflicts

- Site survey will be required to verify portion of road that slopes to the proposed BMP. Re-grading or re-direction of runoff may be needed to fully capture runoff from the parking lot.
- Soil type is Udorthants (developed). Soil testing will be needed to verify infiltration ability of soil and depth to groundwater.
- Coordinate snow removal to avoid plowing into the bioretention area.



ESTIMATED COST: **$ 70,000 – $ 80,000**

PRIORITY RANK: **HIGH**

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

PRIMARY NATURE-BASED COMPONENTS

- **Green Infrastructure / Low Impact Development**
  - A bioretention area will be installed to enhance exfiltration of stormwater runoff into groundwater. This bioretention area will help decrease peak runoff, decrease downstream flooding, promote groundwater recharge, preserve natural water balance of the site, remove pollutants from stormwater runoff, enhance the habitats of amphibians or other small animals, and provide a pollinator habitat (MassDEP).
  - The bioretention area will (1) have some form of pretreatment, (2) be 5-7% of the drainage area, (3) be 2 feet above the groundwater table, (4) have a soil media depth between 2-4 feet, (5) have soil media composition and planting schedule meeting guidelines for bioretention systems designed to exfiltrate (MassDEP).

GENERAL NOTES

No. | Revisions/Issues | Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

SC-RC009: Prop. Conditions Overview

Project No.:
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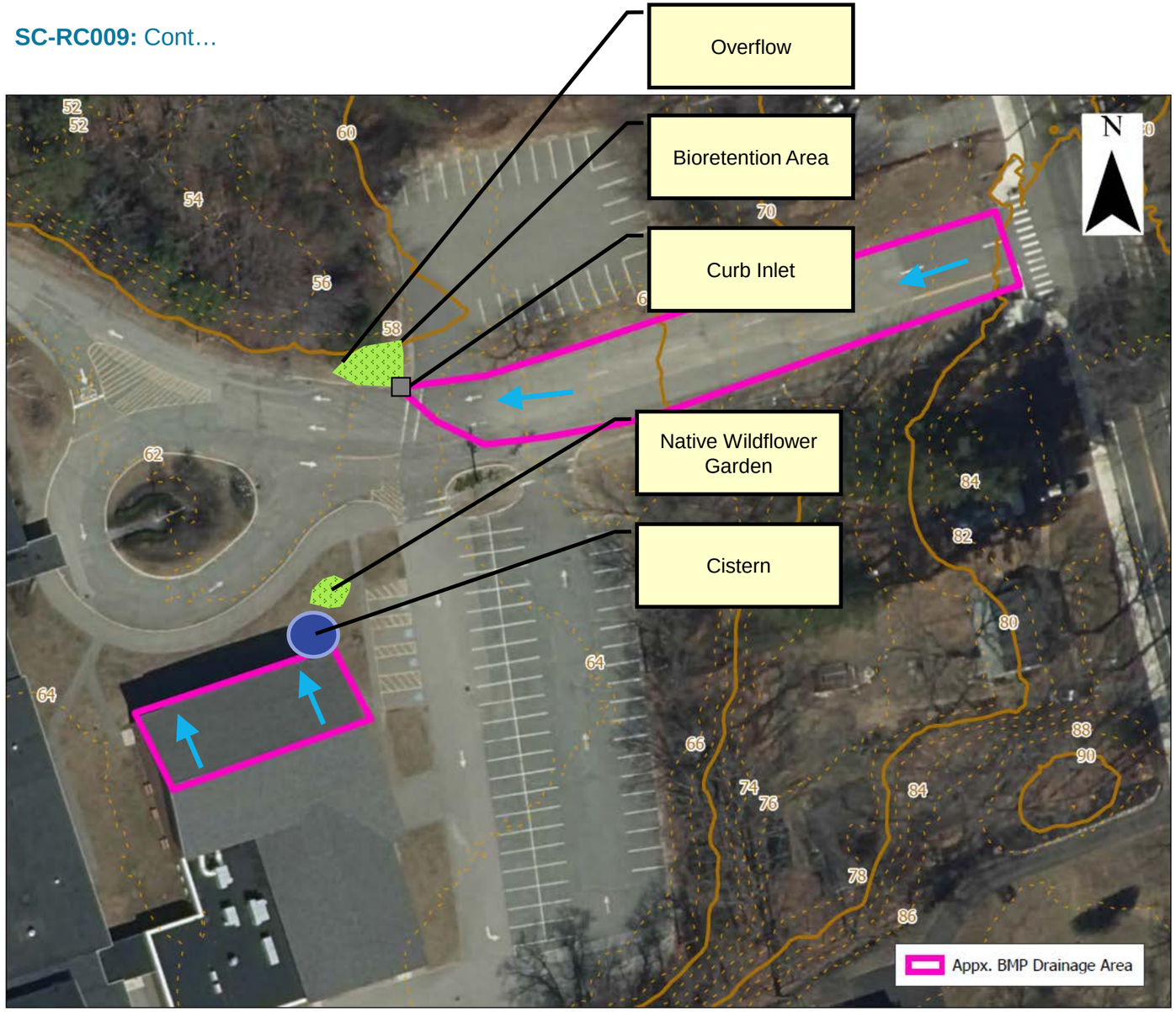
Sheet 22

SC-RC009: Cont…



Bioretention Area Notes:

- Install appx. 30’ by 15’ x 2’ deep bioretention area with deep sump curb inlet and outlet riser
- Install protective fencing in front of bioretention area.

Cistern Notes:

- Install gutters and direct roof runoff to an appx. 2,500 gallon cistern (i.e., 10 ft tall by 6 ft diameter).
- Install ball valve within locked valve box at outlet of cistern and buried drip irrigation system to water new wildflower garden.

GENERAL NOTES

No.	Revisions/Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

SC-RC009: Prop. Conditions Site Plan

Project No.:	Sheet
Date:	23
Drawn By:	
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Parcel 1: Undeveloped Parcel at 912 Salem Street

ESTIMATED COST: **$ 1.8M – $ 2.2M**

PRIORITY RANK: **LOW**

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- An existing 24.2 acre mostly undeveloped lot is located behind Groveland Gas.
- The lot adjoins the Salem Street Conservation Area.
- Runoff from the lot discharges to Grindle Brook which joins with Johnson Creek at Center Street.

Proposed Site Improvements

- Purchase the lot and transform it into conservation land.
- Preservation of the lot would ensure that future development will not occur which could lead to an increase in impervious surface, increased runoff, and downstream flooding.

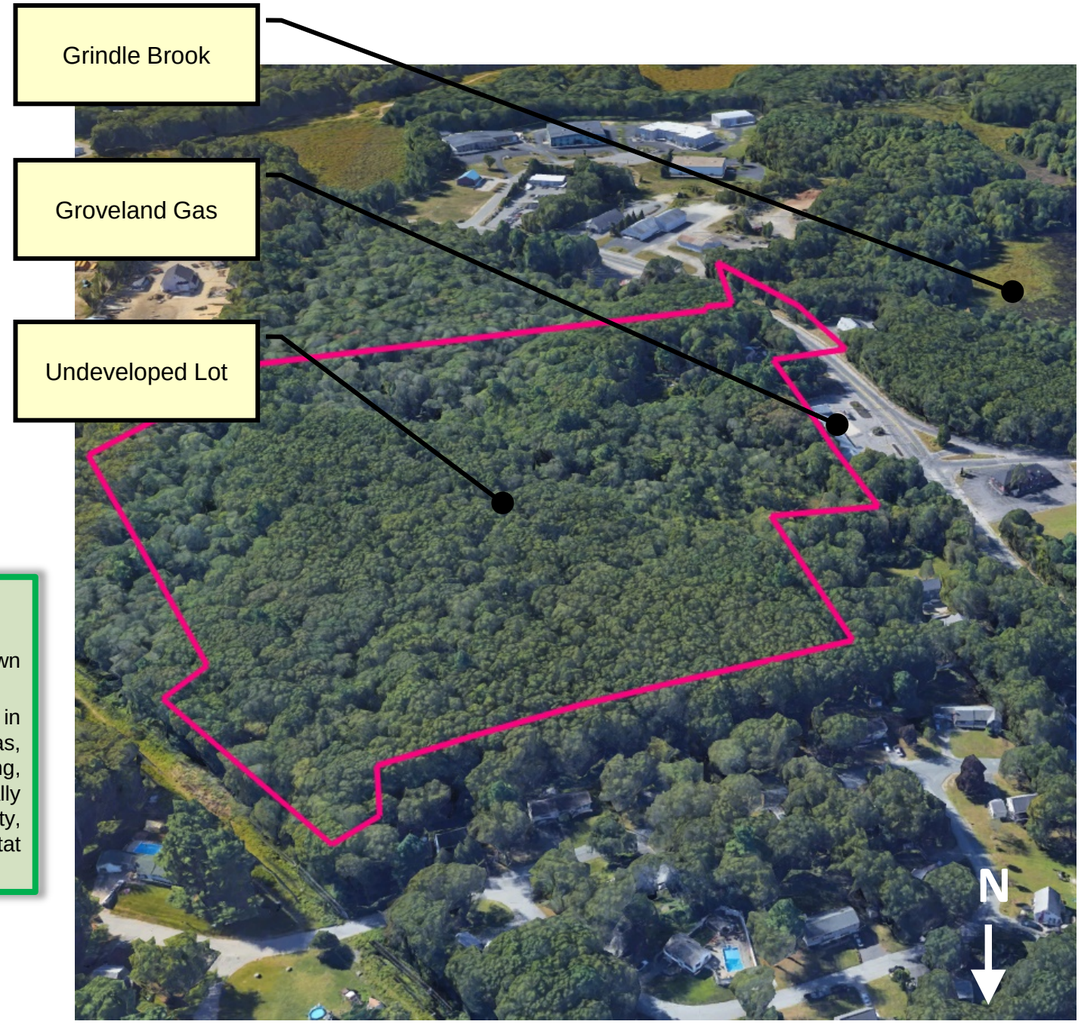
***See next sheet for site map.**

Permitting / Potential Conflicts

- Will potentially require a Phase I Environmental Site Assessment.
- Will require negotiations with current property owner.
- Once purchased, existing structures on site will likely need to be removed.

PRIMARY NATURE-BASED COMPONENTS

- **Land Preservation**
  - By acquiring the aforementioned lot of land, the Town may ensure that it is not developed.
  - Preserving the natural landscape will prevent increase in stormwater runoff from the addition of impervious areas, eliminate the potential to worsen downstream flooding, protect existing water resources from pollution, potentially provide open spaces and parks/trails for the community, and protect existing forested areas and wildlife habitat from destruction.



GENERAL NOTES

No.	Revisions/Issues	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

SC-RC002: Prop. Conditions Overview

Project No.:	Sheet
Date:	24
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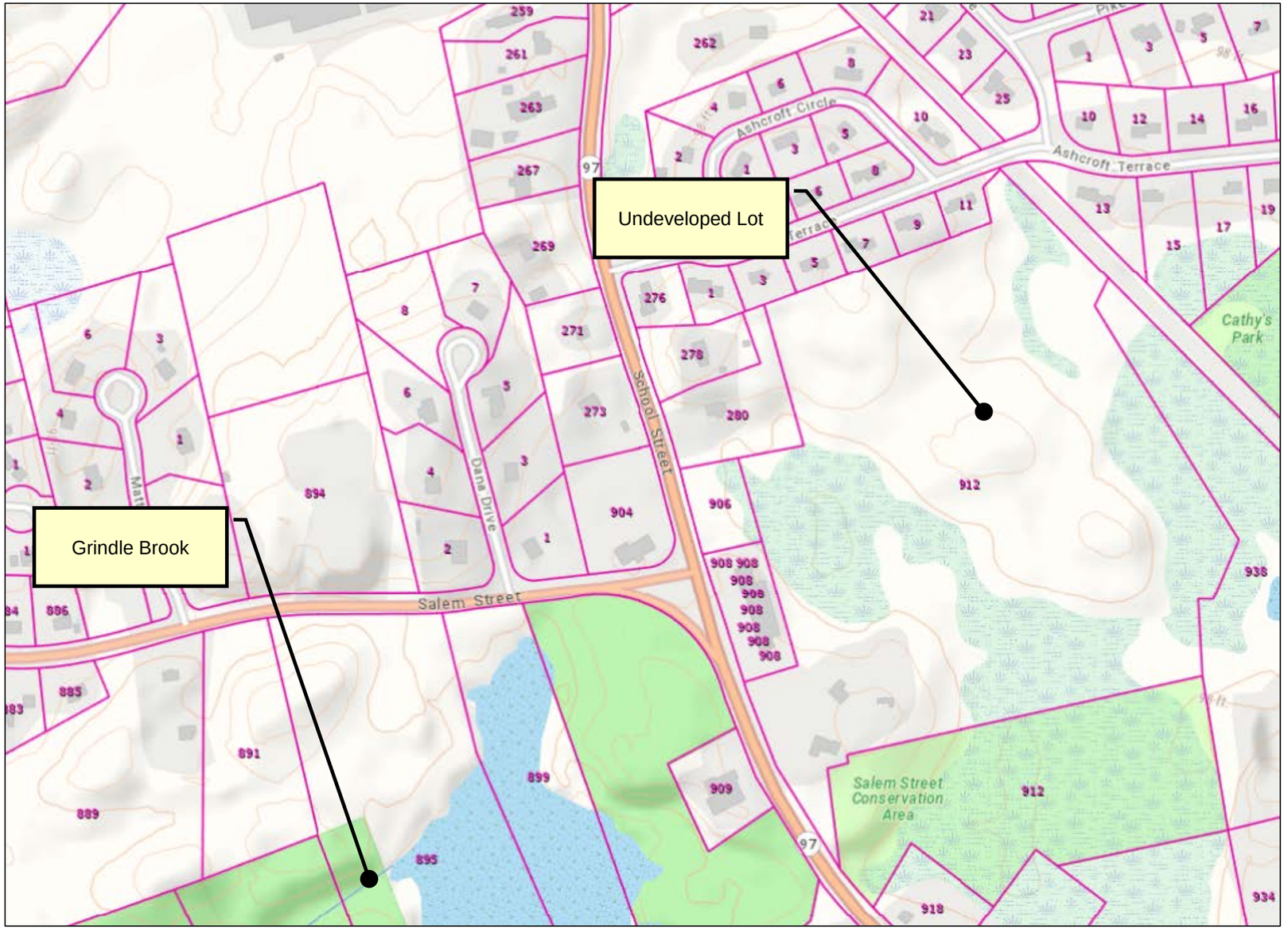
Parcel 1: Cont.…



GENERAL NOTES

No.	Revision / Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

SC-RC009: Prop. Conditions Site Plan

Project No.:	Sheet
Date:	25
Drawn By:	
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Parcel 2: Undeveloped Parcel at 29 Center Street

ESTIMATED COST: **$ 320,000 – $ 400,000**

PRIORITY RANK: **MEDIUM**

***Priority rank is based on potential benefits, nature-based solutions, project complexity, and costs. See Project Report for more information.**

Site Description

- An existing 2.5 acre undeveloped lot (Parcel 46-3) is located adjacent to Johnsons Pond.
- The lot is owned by the City of Haverhill
- The lot includes an abandoned pumping station from when the City used to use Johnsons Pond as a public water supply.

Proposed Site Improvements

- Purchase the lot and transform it into conservation land.
- Preservation of the lot would ensure that future development will not occur which could lead to an increase in impervious surface, increased runoff, and downstream flooding.
- Provide public access to the Pond.

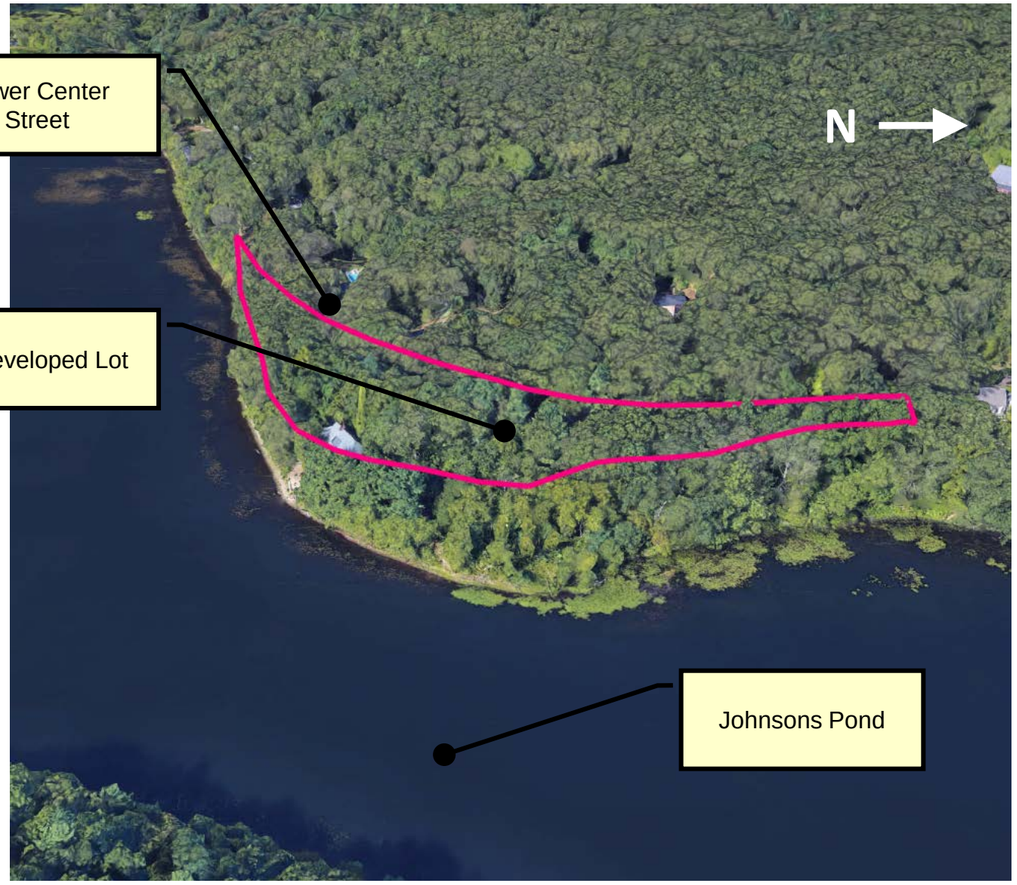
***See next sheet for a site map.**

Permitting / Potential Conflicts

- Will potentially require a Phase I Environmental Site Assessment.
- Will require negotiations with current property owner (i.e., City of Haverhill)
- Once purchased, existing structures on site will likely need to be removed.

PRIMARY NATURE-BASED COMPONENTS

- **Land Preservation**
  - By acquiring the aforementioned lot of land, the Town may ensure that it is not developed.
  - Preserving the natural landscape will prevent increase in stormwater runoff from the addition of impervious areas, eliminate the potential to worsen downstream flooding, protect existing water resources from pollution, potentially provide open spaces and parks/trails for the community, and protect existing forested areas and wildlife habitat from destruction.



GENERAL NOTES

No.	Revision / Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

SC-RC002: Prop. Conditions Overview

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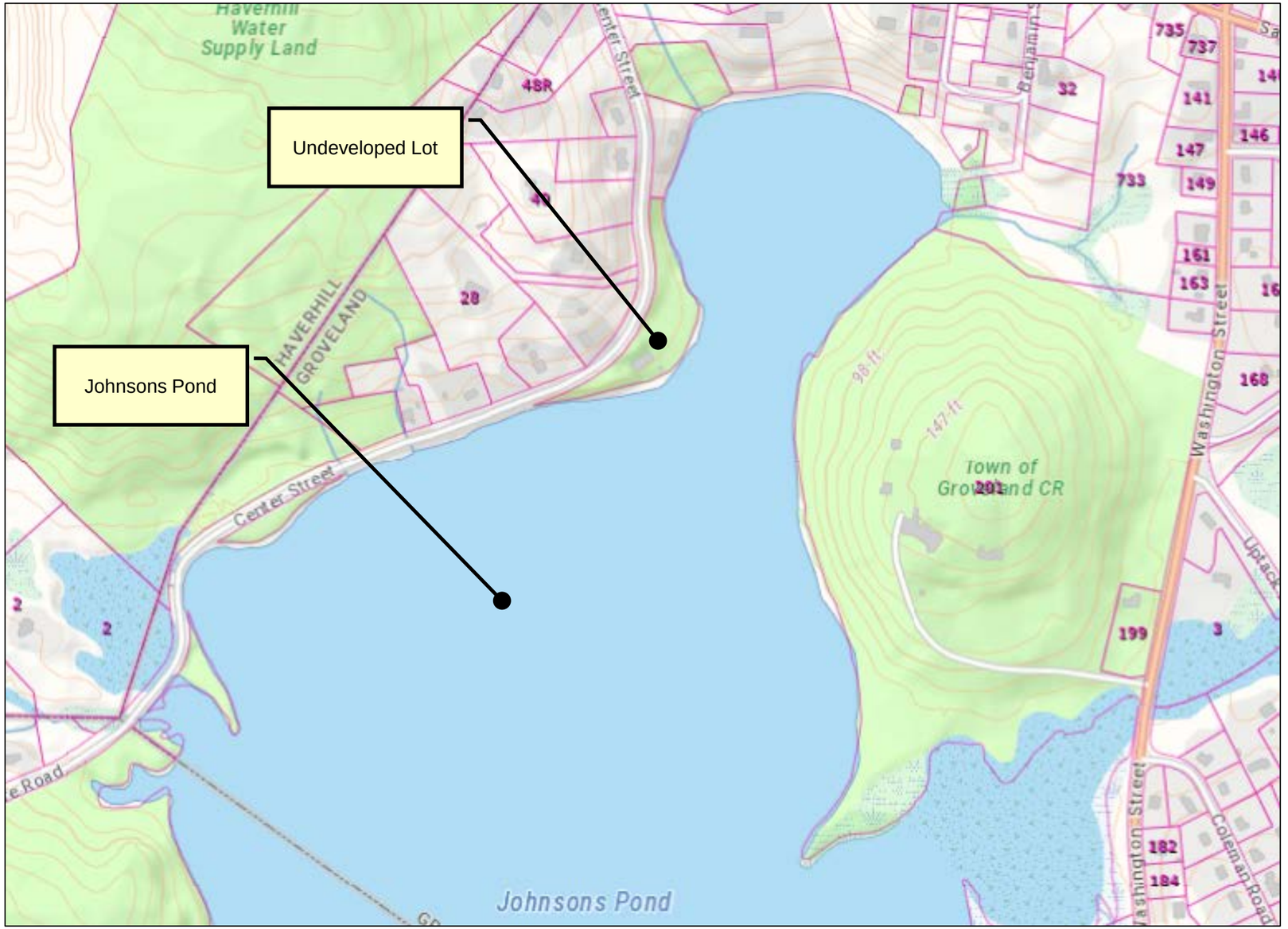
Parcel 2: Cont.…



GENERAL NOTES

No.	Revision / Issue	Date

COMPREHENSIVE ENVIRONMENTAL INCORPORATED

SC-RC009: Prop. Conditions Site Plan

Project No.:	Sheet
Date:	27
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