STORMWATER MANAGEMENT PLAN FOR SPRUCE POND BROOK SUBWATERSHED

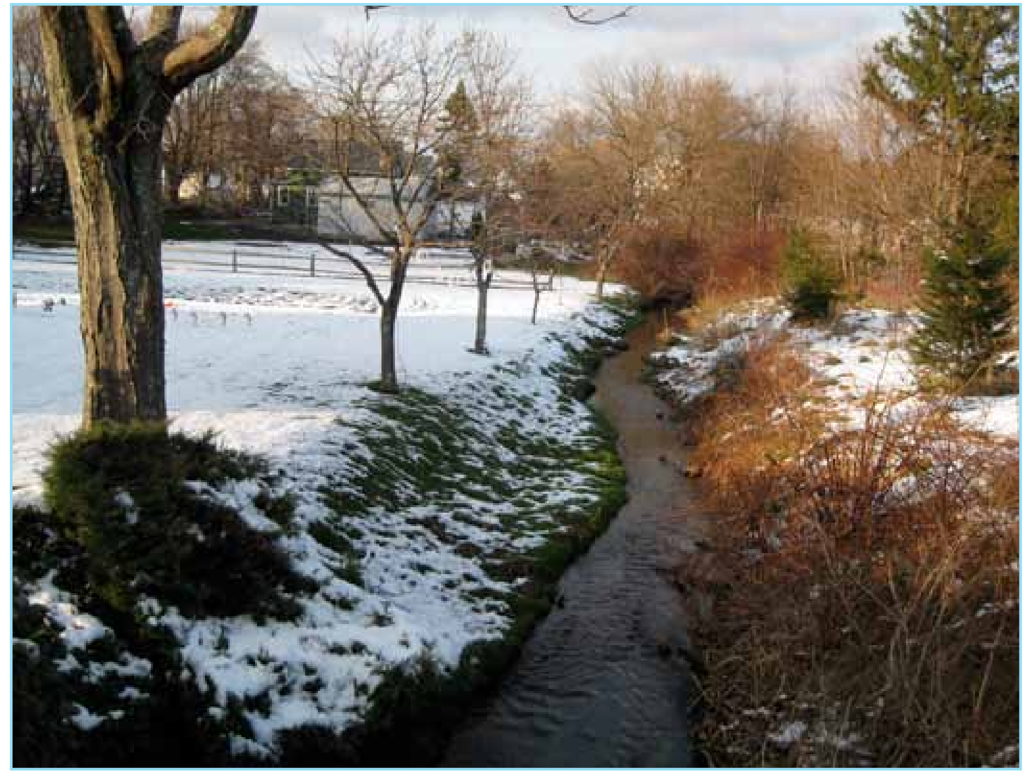
Produced by

CRWA

Charles River Watershed Association
for
The Town of Franklin, Massachusetts

Supported by

Jesse B. Cox Charitable Trust Fund
ESRI
Horsley Witten Group



ACKNOWLEDGEMENTS

This Plan would not have been possible without the significant support of many project partners. In particular, Charles River Watershed Association gratefully acknowledges Jeff Nutting, Robert Cantoreggi, Bill Yadisernia, Nicholas Alfieri, James Esterbrook and Beth Dahlstrom from the Town of Franklin; Rich Claytor and Michelle West from Horsely Witten Group; Mark Voorhees of EPA; Tham Saravanapavan and Guoshun Zhang of TetraTech; and CRWA interns Jordan Hanley, Hannah Carlson and Kate Benesik. CRWA would also like to acknowledge the Jesse B. Cox Trust and ESRI for financial support of this project.

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The Jessie B. Cox Trust

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INTRODUCTION

Like many municipalities in eastern Massachusetts, the Town of Franklin faces significant water resource challenges. Traditional development patterns and infrastructure designs have altered the environment, disrupting the natural hydrologic cycle and creating unanticipated problems town planners and engineers must now solve. Local aquifers, the source of all of Franklin's water supplies, are stressed in summer months, leading to outdoor watering bans and creating challenges for future growth. Baseflows in local rivers and streams, which depend on the same aquifers, often drop to levels that threaten fish and wildlife, as well as recreation. Rainfall, which was once absorbed as it fell by plants or soaked into the ground to fill aquifers, is now drained rapidly off developed land through underground pipes and culverts, creating water pollution, flooding and erosion.

Charles River Watershed Association (CRWA) has been working to understand urban hydrology for the past two decades. In 2005, CRWA launched the Blue Cities™ Initiative, a program to develop sustainable urban water resource management and to use redevelopment as the driver for urban watershed restoration. Our goal is to identify techniques and management approaches to reengineer the built environment to make it function more like the natural environment. Our work has demonstrated that sustainable solutions exist, and that by using techniques such as green infrastructure, low impact development, smart sewering and water reuse, watershed towns can balance their water budgets, protect their ground- and surface water resources, and continue to grow.

Franklin's water resource challenges are mirrored in cities and towns across the New England region and to some extent across the country. Changing the way water is managed in urban and suburban areas has become a national priority. The Charles River watershed is of particular interest because stormwater runoff has been identified as the main reason the river does not meet water quality standards, leading to a new set of federal regulations that will impact not only municipal governments, but also private property owners throughout the watershed. Specifically, the Environmental Protection Agency (EPA) will now require Franklin to reduce phosphorus loads in its stormwater runoff in order to prevent excessive nutrient pollution and the rapid eutrophication of the Charles River.

Franklin, long aware of these issues, is committed to the long term stewardship of its natural resources and is actively seeking sustainable approaches to managing its natural resources. CRWA has been working with Franklin for many years to improve the river and its tributaries, and to help Franklin protect its water supplies. In 2008, funded by a grant from the Jessie B. Cox Charitable Trust Fund, CRWA began work on **Building Blue: Planning for Subwatershed Restoration**, a project to work with Franklin town officials to develop a plan for a subwatershed area in Franklin that would restore water quality, reduce flooding and erosion, and comply with new and emerging stormwater regulations, particularly the Draft Total Maximum Daily Load (TMDL) for Nutrients in the Upper/Middle Charles River, Massachusetts (CRWA, 2009).

This Plan is the result of that project. It demonstrates the feasibility of complying with regulations and managing stormwater runoff using a combination of small scale local practices with larger scale, regional stormwater projects. Franklin town officials worked closely with CRWA throughout the development of this plan, helping identify areas and types of designs that would be most feasible. The biggest challenges for the Town remain financial: funding a town wide stormwater management program, including the construction of numerous stormwater projects, will take time and will require public outreach and education. However, as this project affirms, it is technically feasible and would help Franklin not only to meet its regulatory requirements but also to increase groundwater recharge, reduce flooding, and improve the public realm.

COMMUNITY SETTING

Franklin is a residential community in the ex-urban area surrounding Boston. The Town originally developed around industrial uses driven by the availability of hydro-power, and the Town continues to support commerce and industry today. This community is of particular interest to CRWA because of new stormwater regulations proposed by EPA to require existing large industrial, commercial and high-density residential developments to effectively manage stormwater runoff from their properties to ensure they are complying with the requirements of the Upper/Middle Charles River Nutrient TMDL. Presently, this municipality is subject to EPA's Phase II MS4 General Stormwater Permit.

SUBWATERSHED SELECTION

CRWA's first task was to identify and select an appropriate subwatershed for which we would develop a stormwater management plan. Our goal was to select an area that met the following criteria:

- An appropriate size for stormwater modeling;
- Mixed land uses, somewhat representative of the Town of Franklin as a whole;
- Included some private properties that will be subject to EPA's new stormwater permitting program;
- Included public property;
- Drained to a single point where water quality and flow measurements could be estimated (or measured if additional resources became available); and
- Provided retrofit design opportunities of varying types and at different scales.

The first phase of the selection process involved extensive use of geographic information systems (GIS) to assess how various subwatersheds matched with our selection criteria. The following information was compiled for each possible subwatershed:

- Size
- Population
- Soil type
- Land use (1999)
- Parcel sizes within the subwatershed
- Permitted water withdrawal and discharge points (Franklin supplies public drinking water from groundwater wells)
- Schools and other public sites
- Open space

Based on the initial assessment, CRWA narrowed down the number of possible subwatersheds based on the criteria listed above. CRWA then conducted site visits of the remaining potential subwatershed study areas to further evaluate existing conditions, as well as restoration potential and challenges.

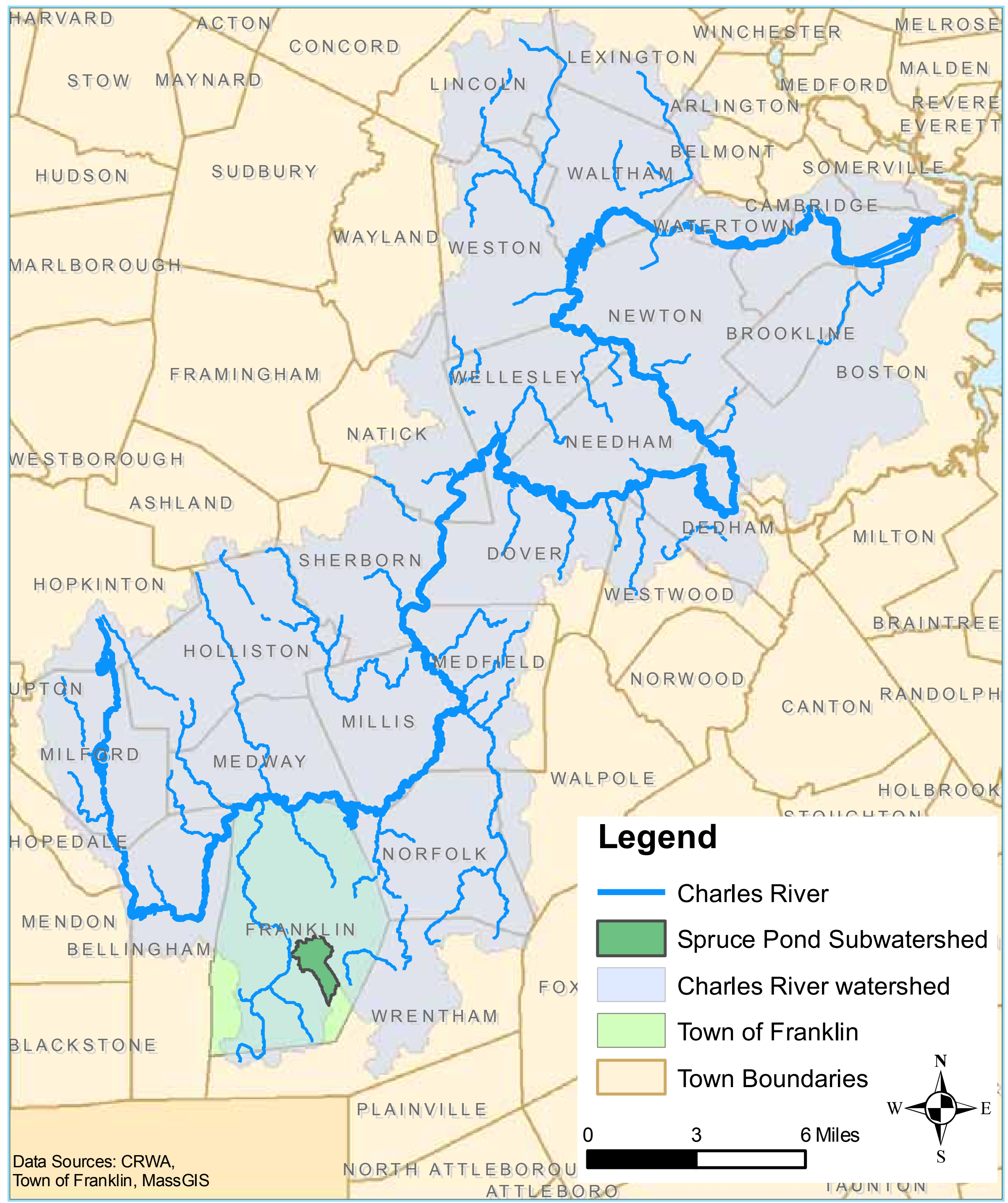


Figure 1. Spruce Pond Brook subwatershed , Franklin MA.

Following this assessment process, CRWA met with the Town Administrator, the Director of Public Works and several members of his staff to select the final study area. Town personnel provided important input regarding the municipality's plans and priorities for the various areas.

Spruce Pond Brook subwatershed was selected as the study area because it closely matched with all of our selection criteria (see Figure 1). The Subwatershed Analysis Summary Report which details the process leading to the selection of this subwatershed can be found on the project website: www.charlesriver.org/projects/blue_franklin.html.

EXISTING CONDITIONS ANALYSIS

Methodology

After selecting the Spruce Pond Brook subwatershed as our study area, CRWA collected detailed information on this subwatershed to help select, locate and design environmental restoration techniques and stormwater Best Management Practices (BMPs). This assessment included analysis of the Spruce Pond Brook subwatershed in the following areas:

- Topology
- Hydrological features
- Infrastructure (stormwater, water and sewer)
- Soil type
- Land use and zoning
- Land cover
- Assessor's parcels
- Open space
- Drinking water resource areas
- Water budget for Mine Brook subwatershed
- Historic water resources and land uses
- CRWA's previous investigation in this area, including an optimal stormwater recharge investigation
- Existing and new stormwater regulatory programs
- Water quality data
- State water quality assessment categories and listings
- Estimated existing phosphorus load
- Target phosphorus reduction

Analysis was conducted using GIS data obtained from the Town and MassGIS, through site visits and communications with Town personnel, review of CRWA's past data and reports, and review of state and federal water quality assessments and studies, including the Draft TMDL for Nutrients in the Upper/Middle Charles River (CRWA,2009).

Results: Project Area Description

The study area is a small subwatershed located in the southeastern corner of Franklin (Figure 1). The subwatershed is approximately 1.1 square miles; the estimated population based on the 2000 Census is 4,186 people (USCB 2000). This subwatershed is the drainage area of a small tributary, referred to by CRWA and the Town of Franklin as Spruce Pond Brook. Spruce Pond Brook flows north into Mine Brook, a major tributary to the Charles River. Approximately 1,000 feet of the Brook is culverted and flows under an industrial section of Franklin; the remaining Brook system flows primarily through open channels. The majority of the subwatershed is developed land that is drained by underground stormwater drain pipes.

Land use in the subwatershed is primarily residential and forested but includes a variety of uses (See Figure 3). The target phosphorus reduction for the subwatershed was calculated using the 1999 land use categories[1] from MassGIS and the land-use based target reductions determined in the Upper/Middle TMDL section on load allocations (CRWA, 2009). This calculation yielded a target TMDL reduction for phosphorus for Spruce Pond of 41.37% which CRWA rounded up to an even 42%. The calculation uses a weighted average of land use area; because this subwatershed has a relatively high percentage of forested land, which has a 0% removal target, this calculation results in a slightly lower percent reduction target than if a straight land area calculation was used, essentially giving additional credit to the existing green infrastructure (See Table 1).

For additional information on CRWA's existing conditions assessment see our Existing Conditions Report which can be found on the project website: www.charlesriver.org/projects/blue_franklin.html.

PRELIMINARY DESIGN: DIVIDING THE SUB-WATERSHED

Methodology

Following the existing conditions assessment, CRWA subdivided the study area into subareas based on stormwater drainage patterns and stormwater regulations. Industrial, commercial and high-density residential properties with greater than 2 acres impervious area were identified as properties likely to be subject to EPA's pilot stormwater permitting program[2]. Each of these properties was defined as its own drainage area as the permitting process is designed to encourage owners of these properties to treat their stormwater runoff on-site. The remaining drainage areas were defined by stormwater infrastructure and natural topography. Drainage areas were originally delineated using GIS and further refined based on site visits, consultation with Town personnel and stormwater drainage maps, and preliminary conceptual designs for stormwater BMP placement.

[1]For the modeling phase of the project CRWA switched to 2005 Land Use for the subwatershed as this data was made public in the middle of the project period. Based on 2005 Land Use for this subwatershed the existing phosphorus load is 358.8 pounds. Our target reduction was set at 42%. (See Appendix B for details).

[2]For more information about EPA's pilot stormwater permit, see CRWA's website: www.charlesriver.org/projects/stormwater/swregs.html

The subwatershed was divided into 49 drainage areas (See Figure 4).

CRWA conducted site visits of 45 of the 49 drainage areas. Site visits were conducted in coordination with Horsely Witten Group; site assessment methodology was based on Center for Watershed Protection's (CWP) Manual 3: Urban Stormwater Retrofit Practices in the Urban Subwatershed Restoration Manual Series. Field staff collected data using CWP datasheets, large scale maps, and digital cameras. Information was compiled in a multi-page matrix and library of digital photos.

CRWA then selected 12 priority drainage areas (see Figure 5, page 20) for which we would develop full conceptual designs. Priority drainage areas were chosen as a representative subset of the total 49 drainage areas. These drainage areas were selected based on the following criteria:

- Size variability
- Land use variability
- Variability in existing stormwater management (BMP present vs. no BMP present)
- Preference for areas draining to town owned land

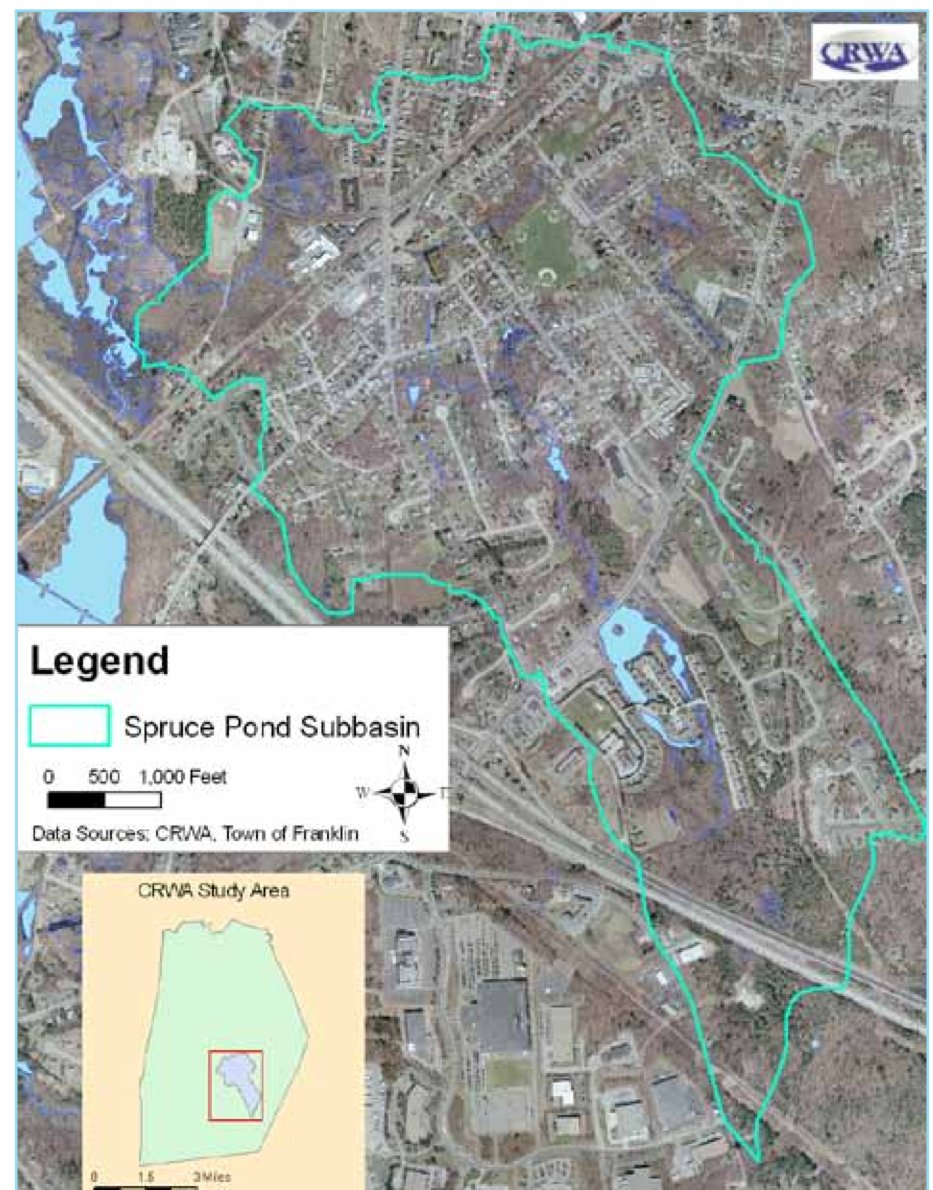


Figure 2. An aerial photograph of the Spruce Pond Brook subwatershed

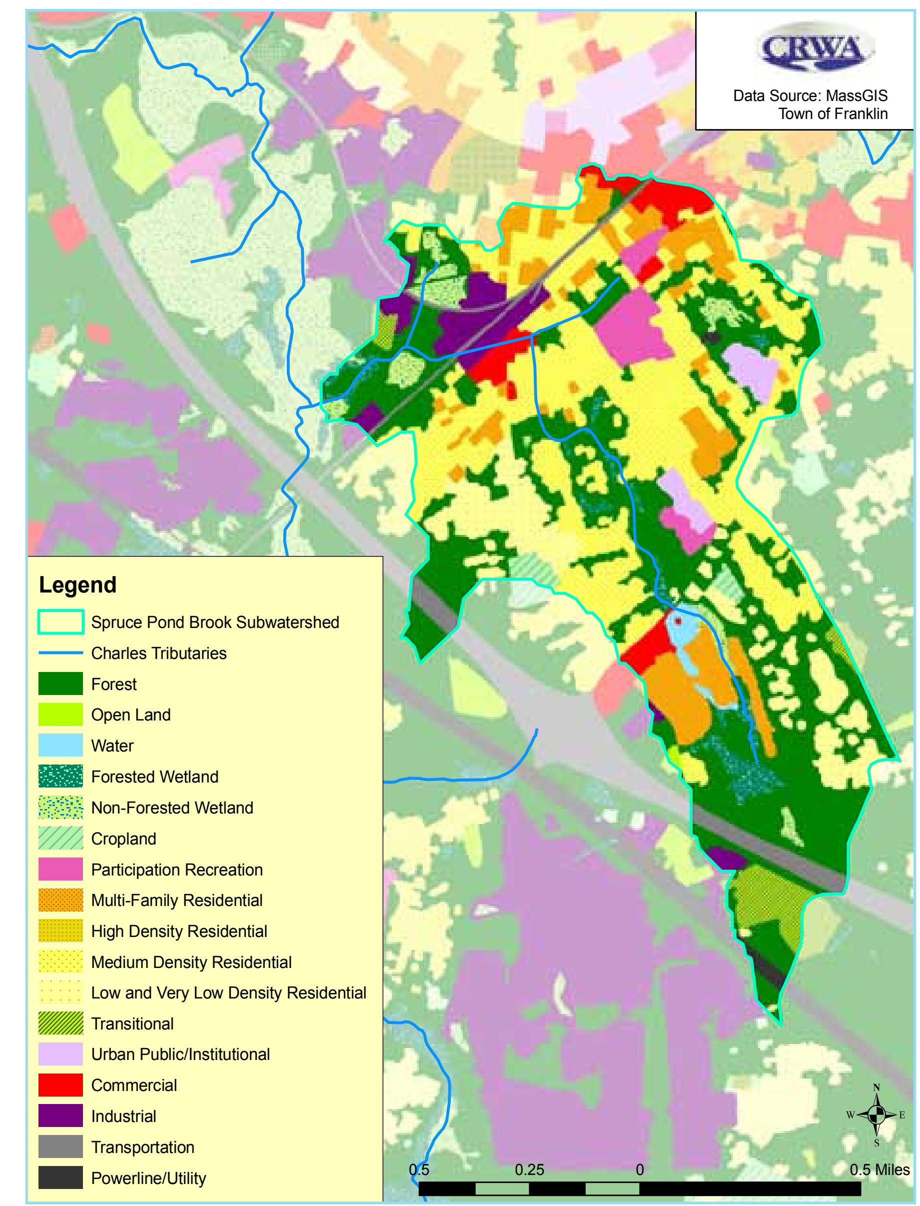


Figure 3. Land use in the Spruce Pond Brook subwatershed.

- Preference for areas with a strong public education component (i.e. schools, recreational fields, etc.)
- Exclusion of sites likely subject to EPA's pilot stormwater permitting program

Information from the existing conditions analysis and the preliminary design phase of the project were then combined to produce an existing site conditions analysis for each of the priority drainage areas.

Stormwater management opportunities were also identified for the remaining sites, although conceptual designs were not developed for these sites. See the Modeling Analysis section of this plan for further details.

Results

The maps, tables and photos in this section summarize much of the information obtained through the existing conditions and preliminary design analysis for each of the 12 priority drainage areas.

The following 12 pages show the existing conditions of each of the 12 priority sites. Details include drainage area, existing infrastructure, land use, soil type, impervious cover, estimated phosphorus load, and typical site photos.

Table 1. Target Phosphorus Reduction for Spruce Pond Brook Subwatershed based on Area Weighted Land Use

Land Cover/Source Category	1999 Land Use Area (square miles)	Existing Phosphorus Loading by Land Use (lbs/yr/sq mi)	Existing Phosphorus Loading in Subbasin by Land Use (lbs/yr)	Percent Load Reduction (As determined by TMDL)	Percent of Total Subwatershed	Percent Load Reduction Based on Weighted Average of Land Use Area
Commercial	0.037	967.37	35	65%	3.39%	2.21%
Industrial	0.073	838.08	61	65%	6.79%	4.41%
Higher Density Residential	0.054	644.62	35	65%	5.03%	3.27%
Medium Density Residential	0.395	322.54	127	65%	36.63%	23.81%
Low Density Residential	0.100	25.90	3	45%	9.25%	4.16%
Agriculture	0.013	287.99	4	35%	1.16%	0.41%
Forest	0.311	74.23	23	0%	28.88%	0.00%
Open Space	0.096	19.55	2	35%	8.88%	3.11%
Total	**1.1**		**290**			**41.37%**

Table 2. Summary of Possible Target Reductions for Spruce Pond Brook

Scenario	Target Reduction
Required stormwater reductions by land use (using a land use weighted average) in selected subwatershed	42%
Required stormwater reduction at Watertown Dam	48%
Required stormwater reduction for Town of Franklin	54%

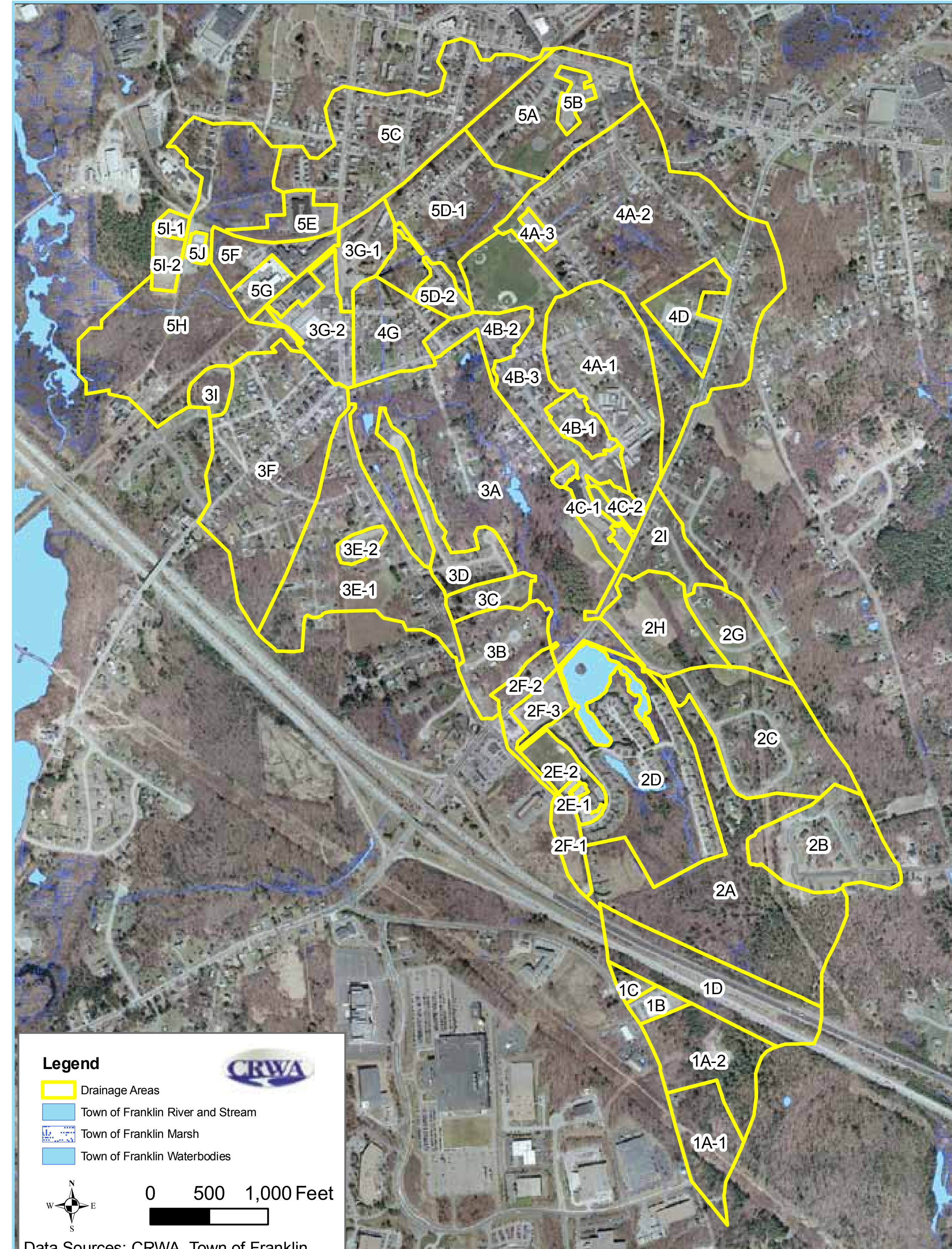
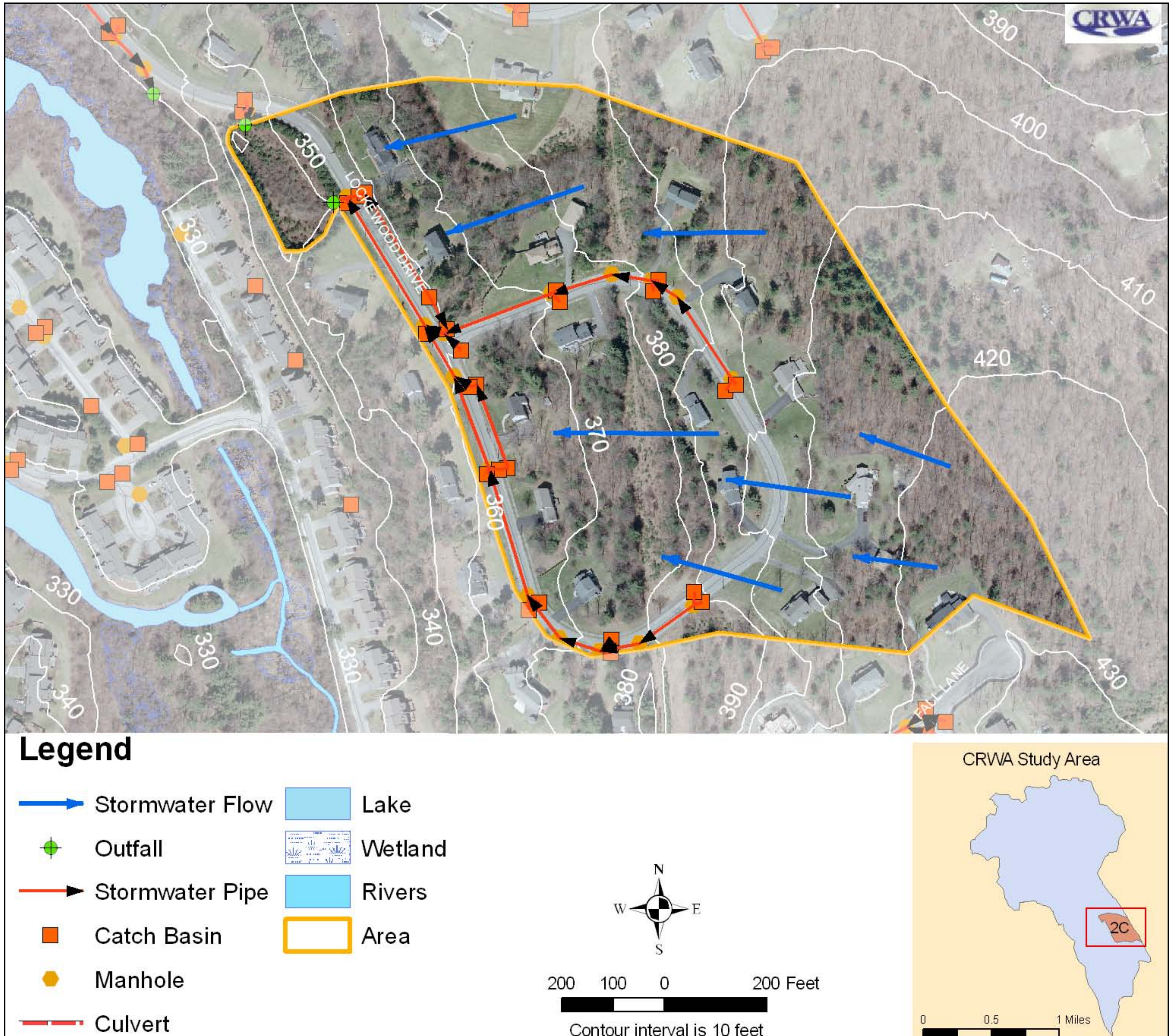


Figure 4. Drainage areas in the Spruce Pond Brook subwatershed.

Existing Conditions of Drainage Area 2C - Lockewood Drive South

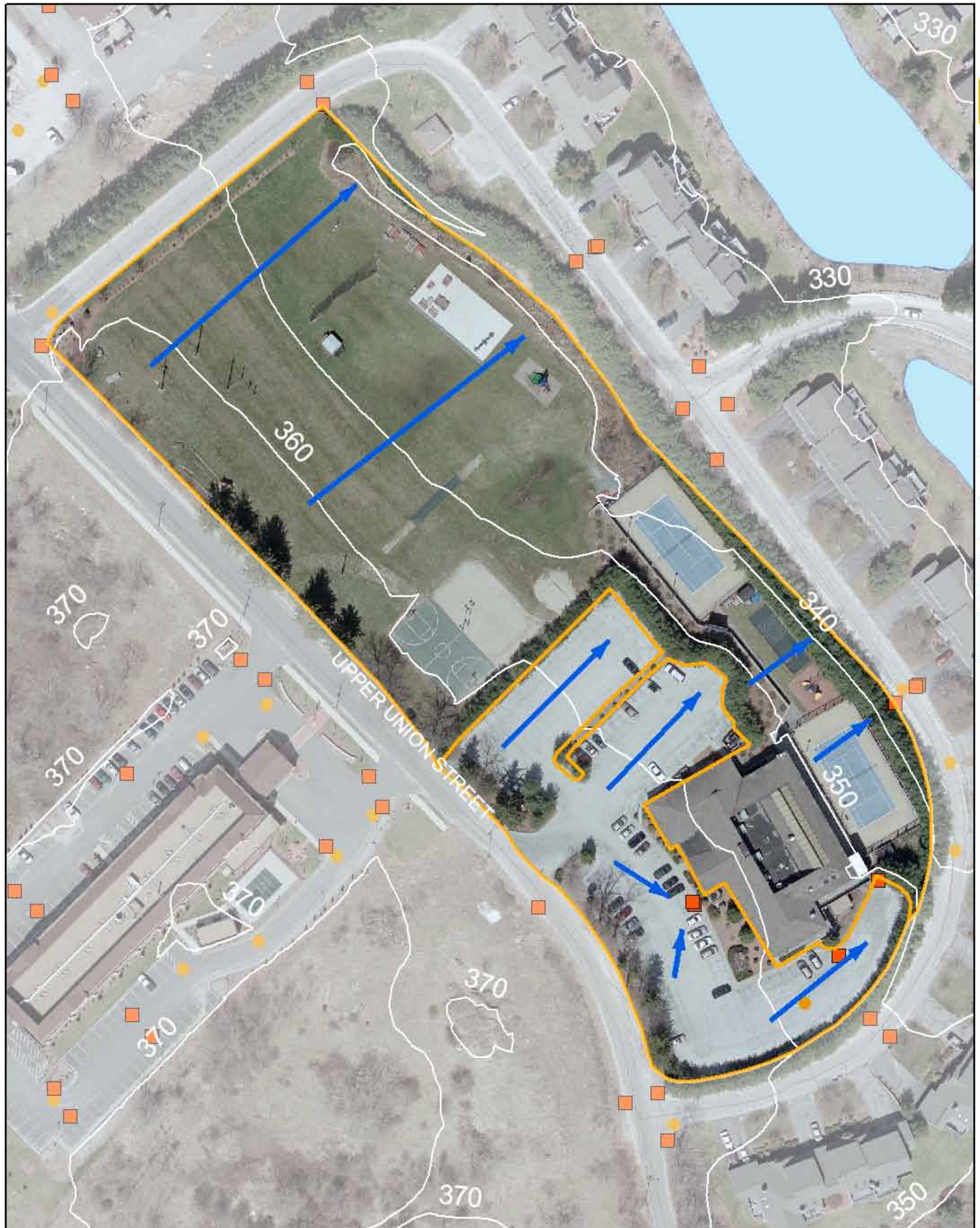


Inflow pipe

Aerial of existing BMP

Drainage Area (acres)	24.4
Impervious Area (acres)	3.4
Land Use	Forest/Low Density Residential
Hydrologic Soil Group (at proposed BMP site)	B
Existing Phosphorus Load (kg/year)	2.6

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA



Legend

- Drainage Area
- Stormwater Flow
- Outfall
- Catch Basin
- Manhole
- Stormwater Pipe
- Culvert
- Lake
- Wetland
- River

N W E S

100 50 0 100 Feet

Contour interval is 10 feet

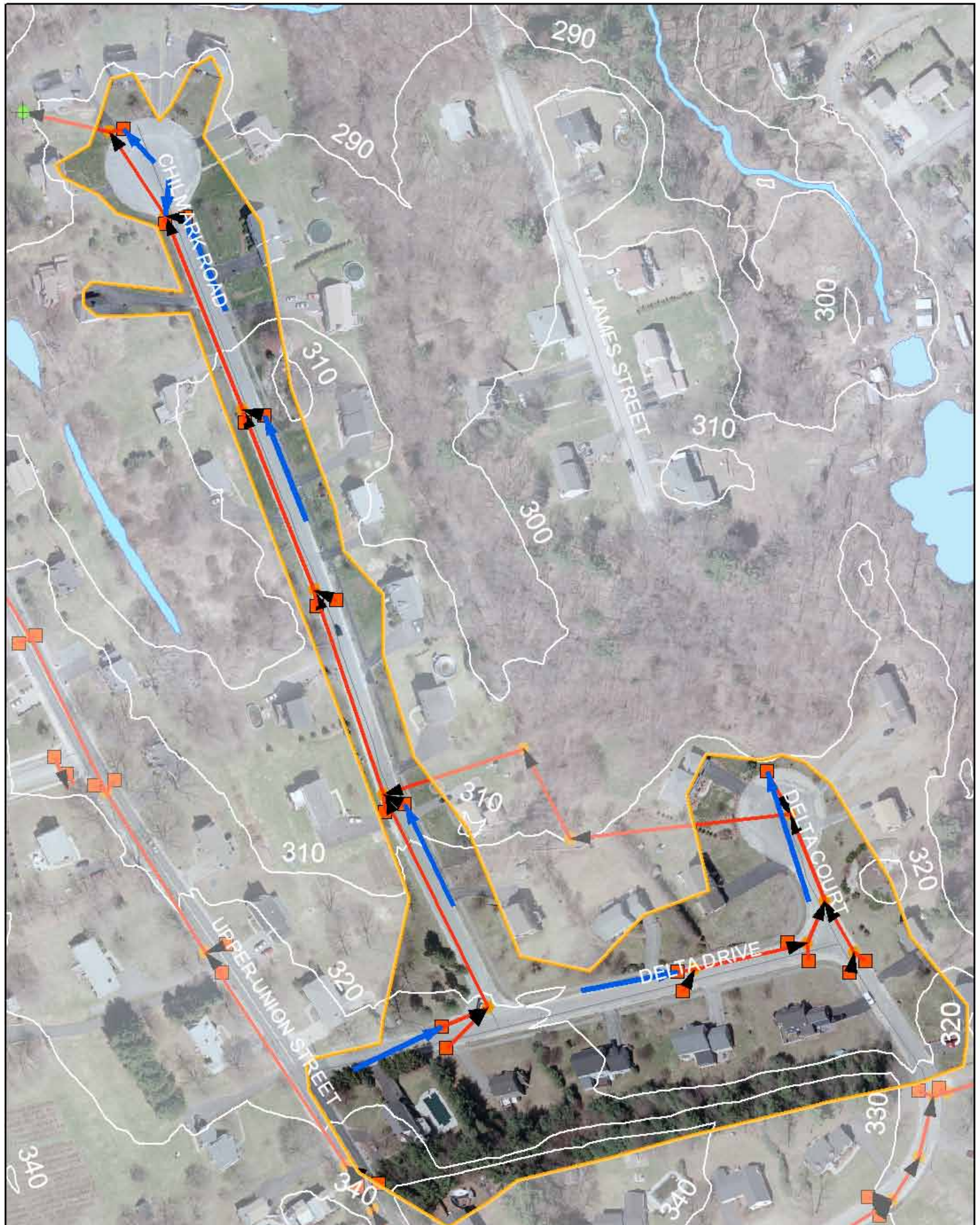
End of parking lot on southeast side of the building

Front of Boston Sports Club

Drainage Area (acres)	5.9
Impervious Area (acres)	1.9
Land Use	High Density Residential
Hydrologic Soil Group (at proposed BMP site)	C
Existing Phosphorus Load (kg/year)	1.4

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA

Existing Conditions for Drainage Area 3D - Chilmark Road

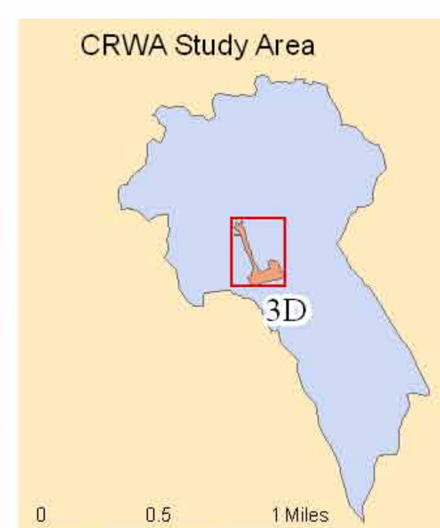


Legend

- Drainage Area
- Stormwater Flow
- Outfall
- Catch Basin
- Manhole
- Stormwater Pipe
- Culvert
- Lake
- Wetland
- River

150 75 0 150 Feet

Contour interval is 10 feet



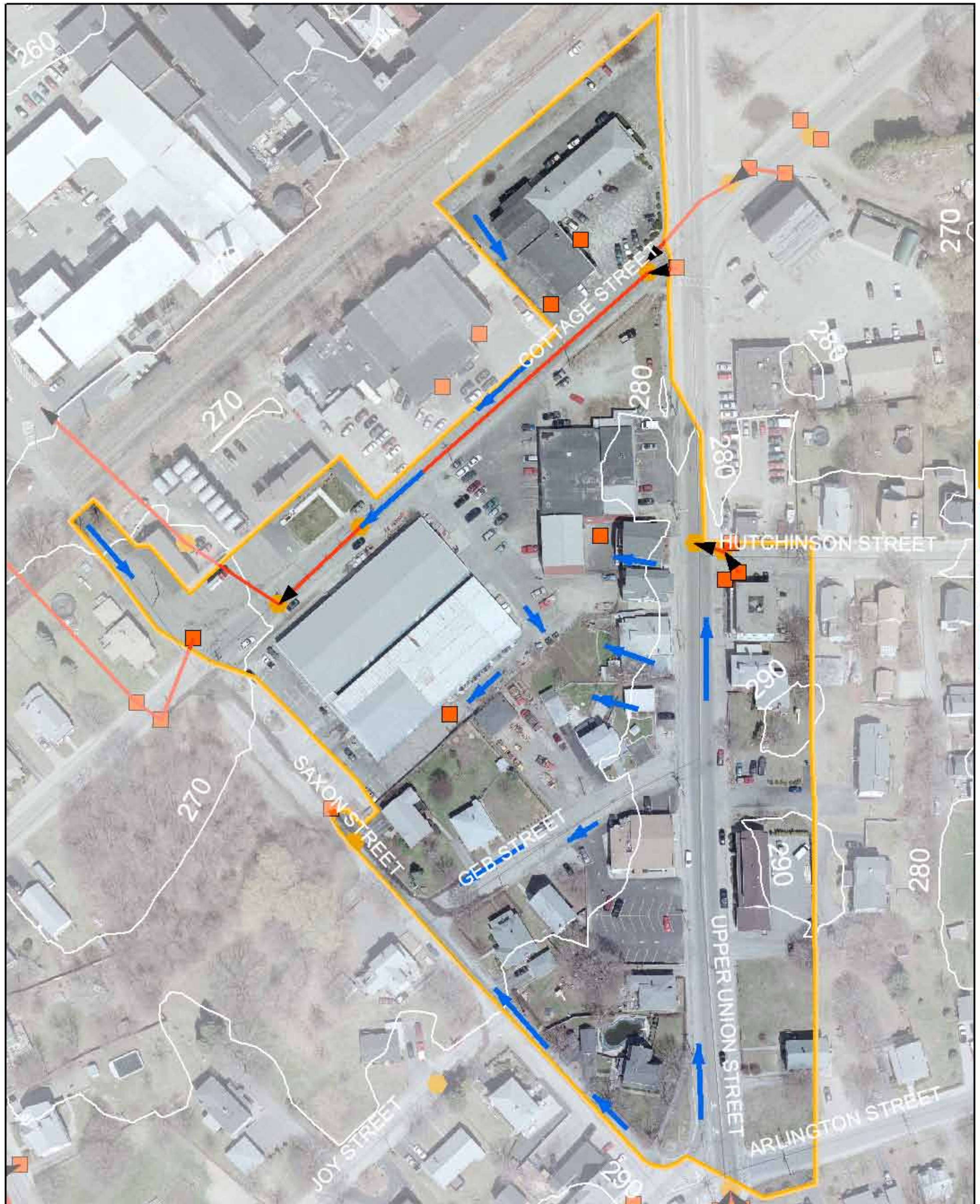
Outflow pipe from Chilmark Road into existing pond

Chilmark Road

Drainage Area (acres)	8.4
Impervious Area (acres)	2.8
Land Use	Medium Density Residential
Hydrologic Soil Group (at proposed BMP site)	A/B
Existing Phosphorus Load (kg/year)	2.1

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA

Existing Conditions for Drainage Area 3G - Cottage and Union Streets



Legend

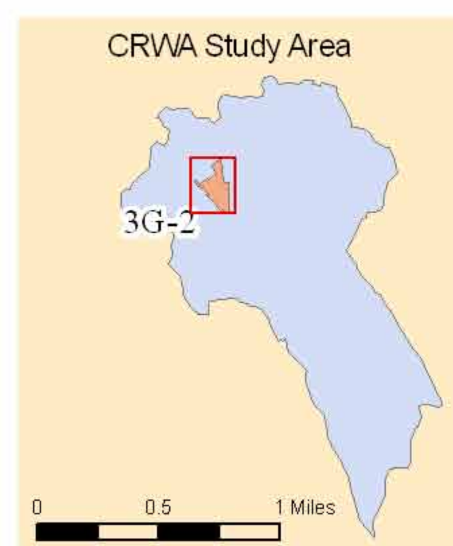
CRWA

- Stormwater Flow
- Outfall
- Catch Basin
- Manhole
- Stormwater Pipe
- Culvert
- Drainage Area
- Lake
- Wetland
- River

N W E S

120 60 0 120 Feet

Contour interval is 10 ft



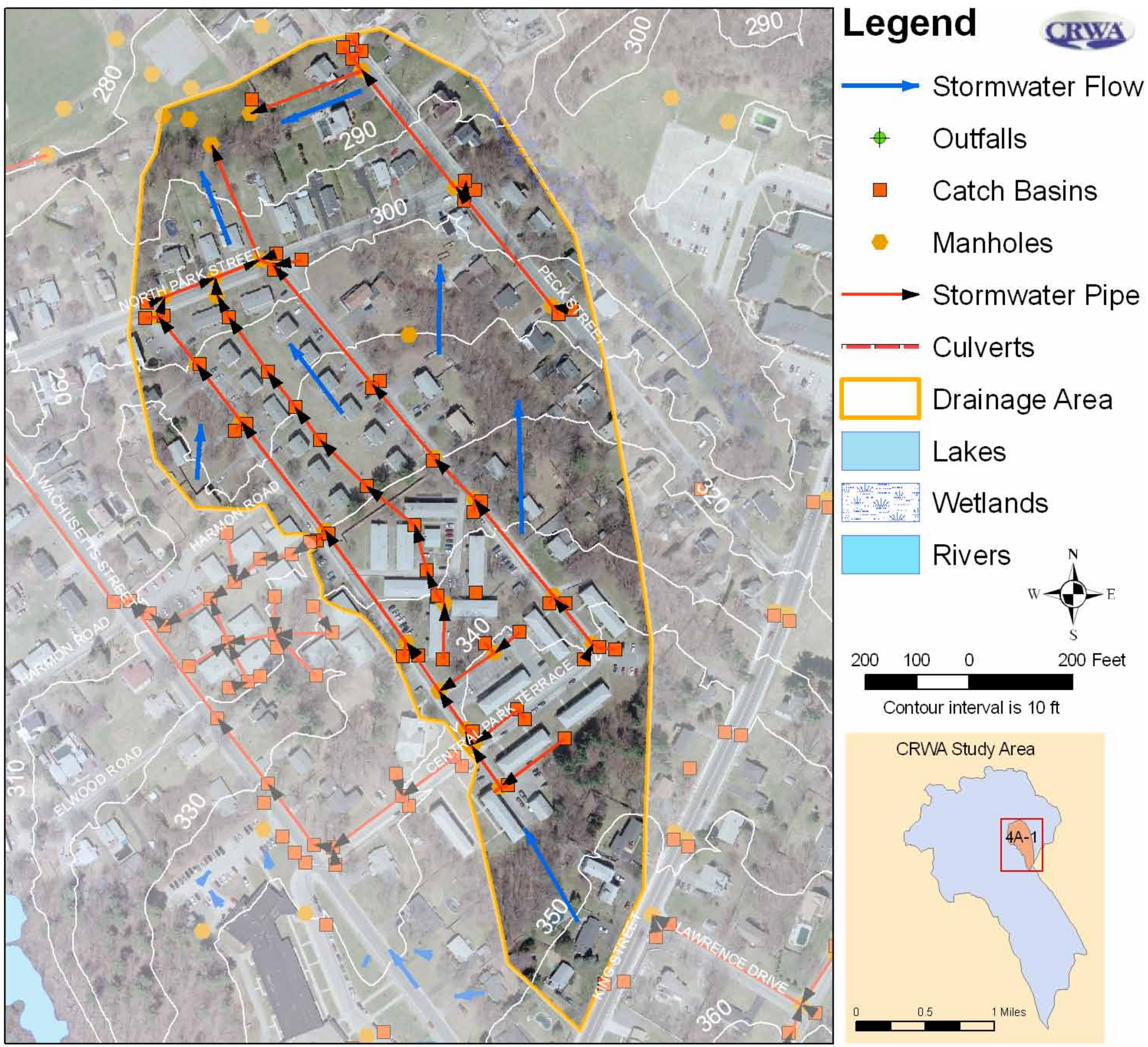
Aerial of hardware store site

View down Cottage Street

Drainage Area (acres)	8.5
Impervious Area (acres)	6.3
Land Use	Commercial/Medium Density Residential/Industry
Hydrologic Soil Group (at proposed BMP site)	Unknown
Existing Phosphorus Load (kg/year)	5.7

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA

Existing Conditions for Drainage Area 4A-1 - FHA Peck Street



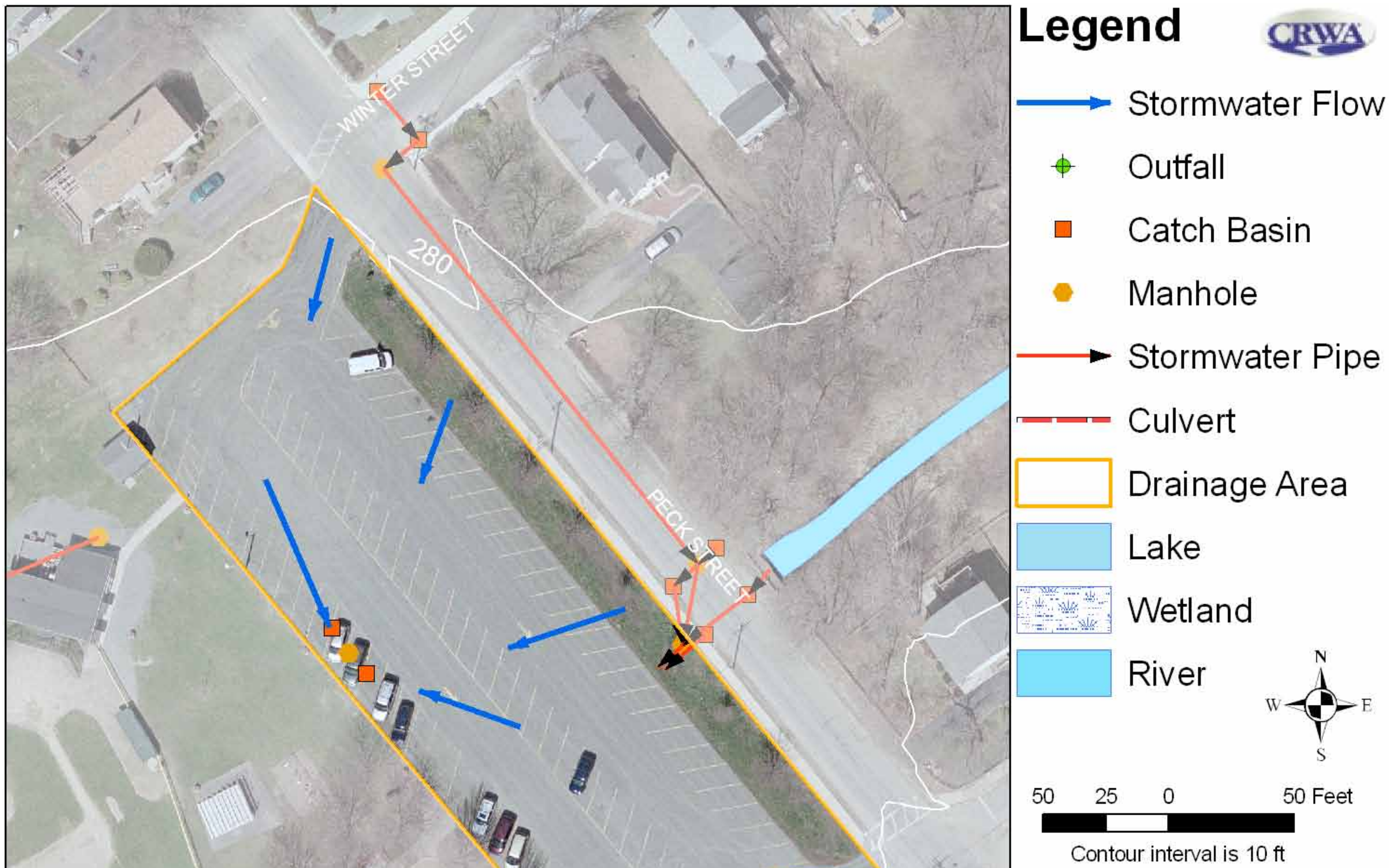
Corner of Fletcher Field

Catch basin in Fletcher Field

Drainage Area (acres)	25.2
Impervious Area (acres)	8.1
Land Use	Medium/High Density Residential
Hydrologic Soil Group (at proposed BMP site)	A
Existing Phosphorus Load (kg/year)	7.9

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA

Existing Conditions for Drainage Area 4A-3 Fletcher Field Large Lot



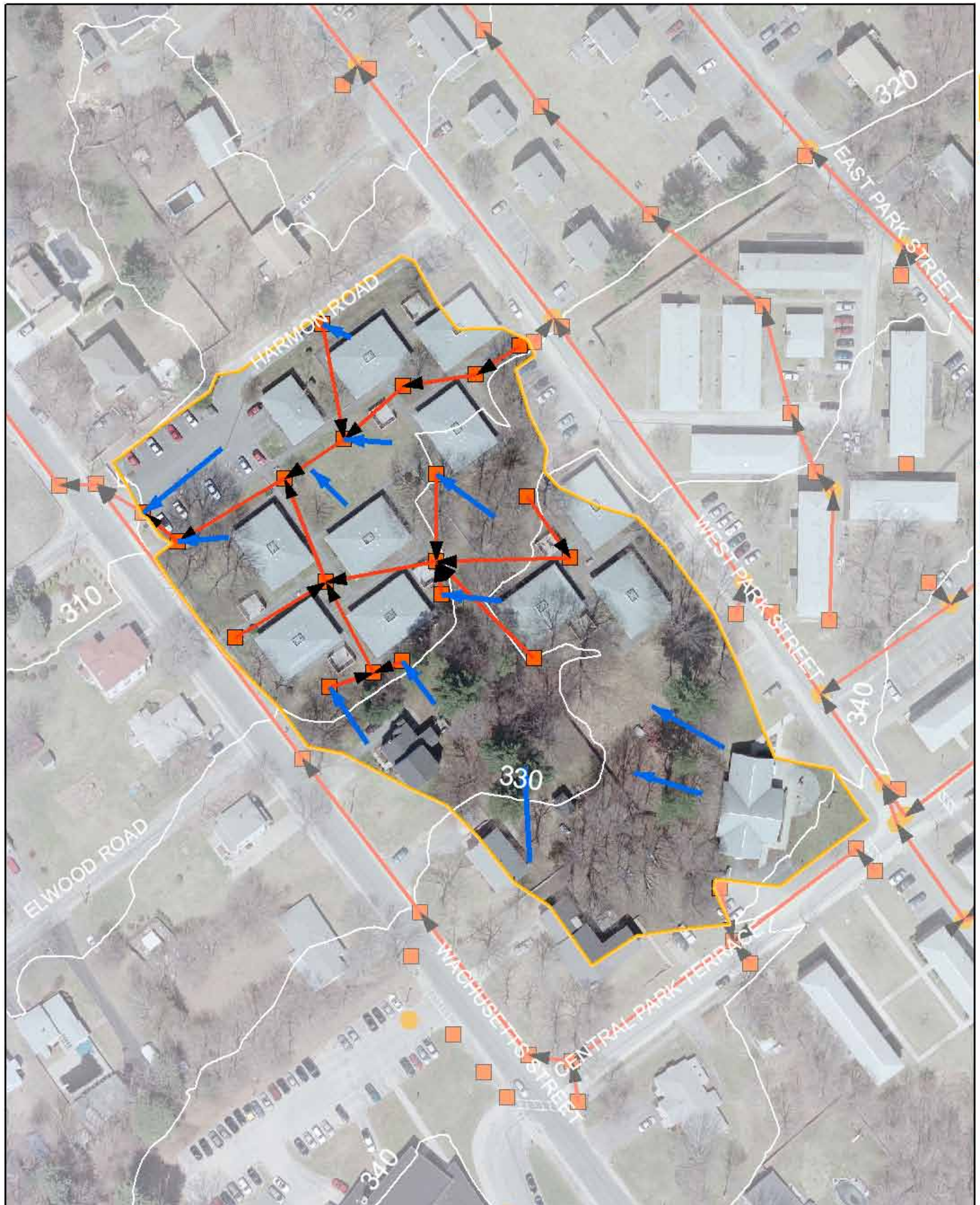
Parking lot

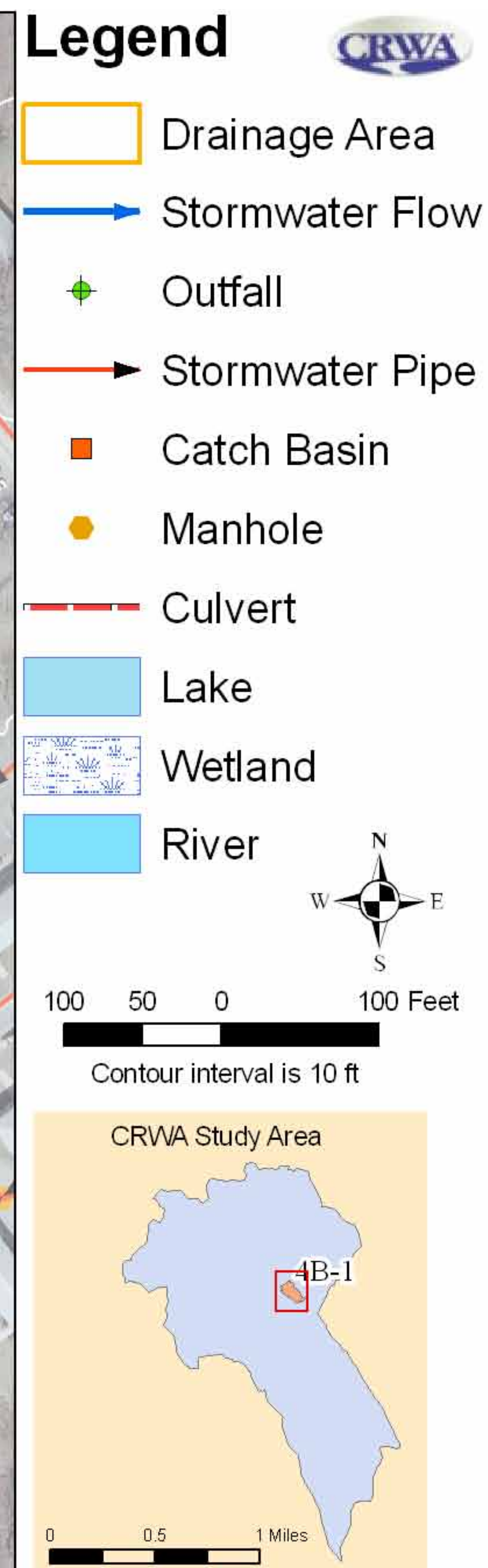
Parking lot

Drainage Area (acres)	1.0
Impervious Area (acres)	0.8
Land Use	Low Density Residential
Hydrologic Soil Group (at proposed BMP site)	B
Existing Phosphorus Load (kg/year)	0.3

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA

Existing Conditions for Drainage Area 4B-1 - FHA Housing Site





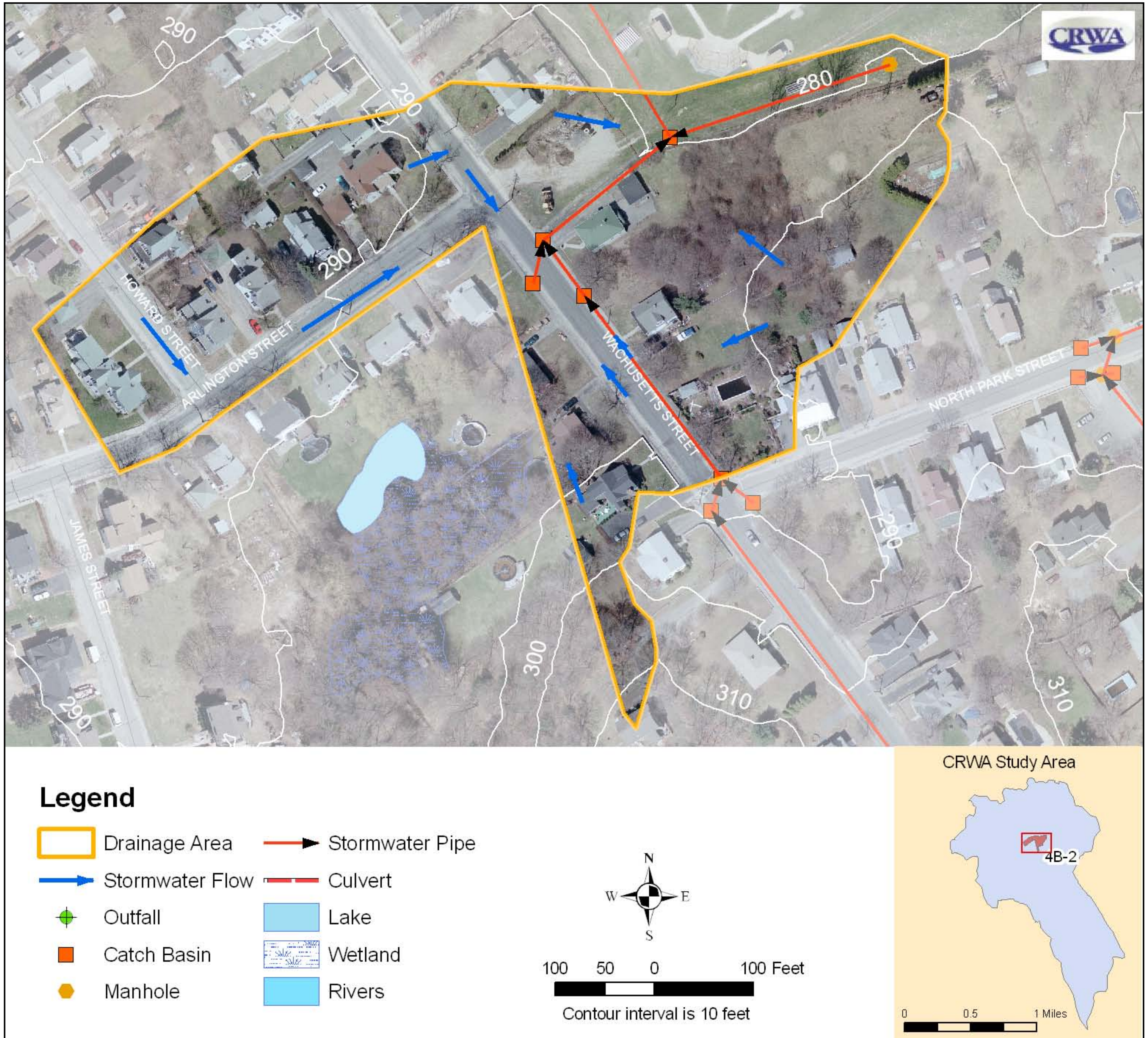

Looking down into existing courtyard


Corner of parking lot

Drainage Area (acres)	3.9
Impervious Area (acres)	1.2
Land Use	Medium Density Residential
Hydrologic Soil Group (at proposed BMP site)	B
Existing Phosphorus Load (kg/year)	1.1

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA

Existing Conditions for Drainage Area 4B-2 - Fletcher Field Small Lot



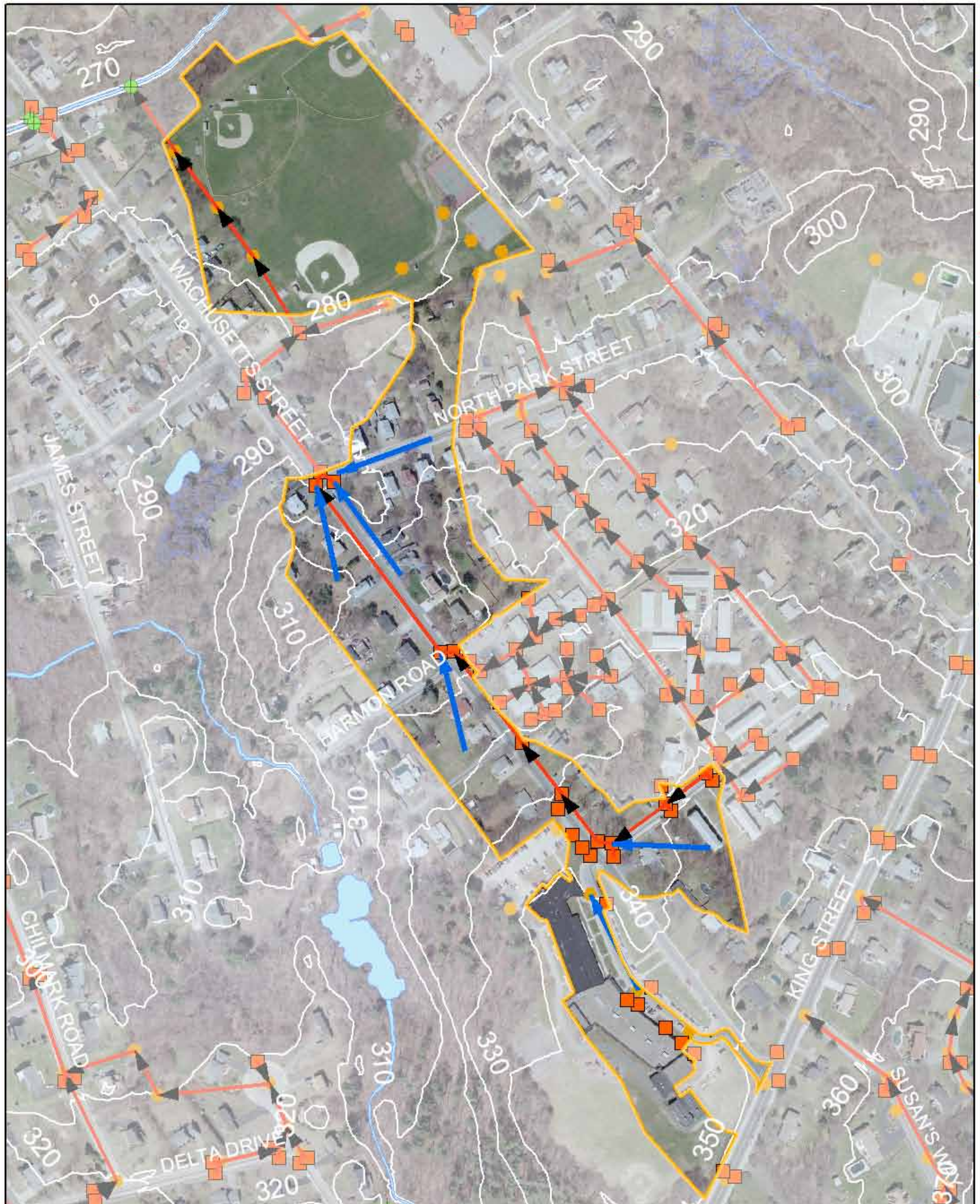

Corner of parking lot and existing swale


Parking lot, view from Wachusett Street

Drainage Area (acres)	5.8
Impervious Area (acres)	1.9
Land Use	Medium Density Residential
Hydrologic Soil Group (at proposed BMP site)	B
Existing Phosphorus Load (kg/year)	1.6

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA

Existing Conditions for Drainage Area 4B-3 - Fletcher Field Gravel Wetland

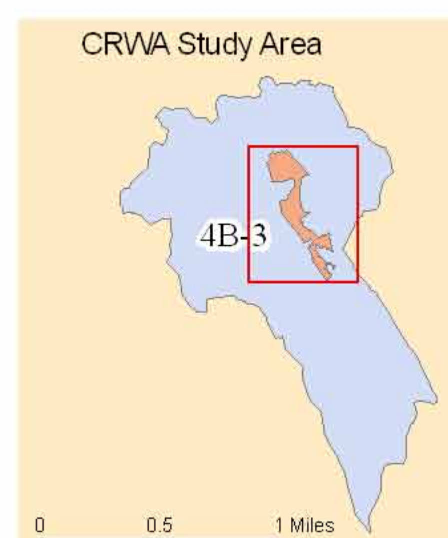


Legend

- Stormwater Flow
- Outfall
- Catch Basin
- Manhole
- Stormwater Pipe
- Culvert
- Drainage Area
- Lake
- Wetland
- River

300 150 0 300 Feet

Contour interval is 10 ft

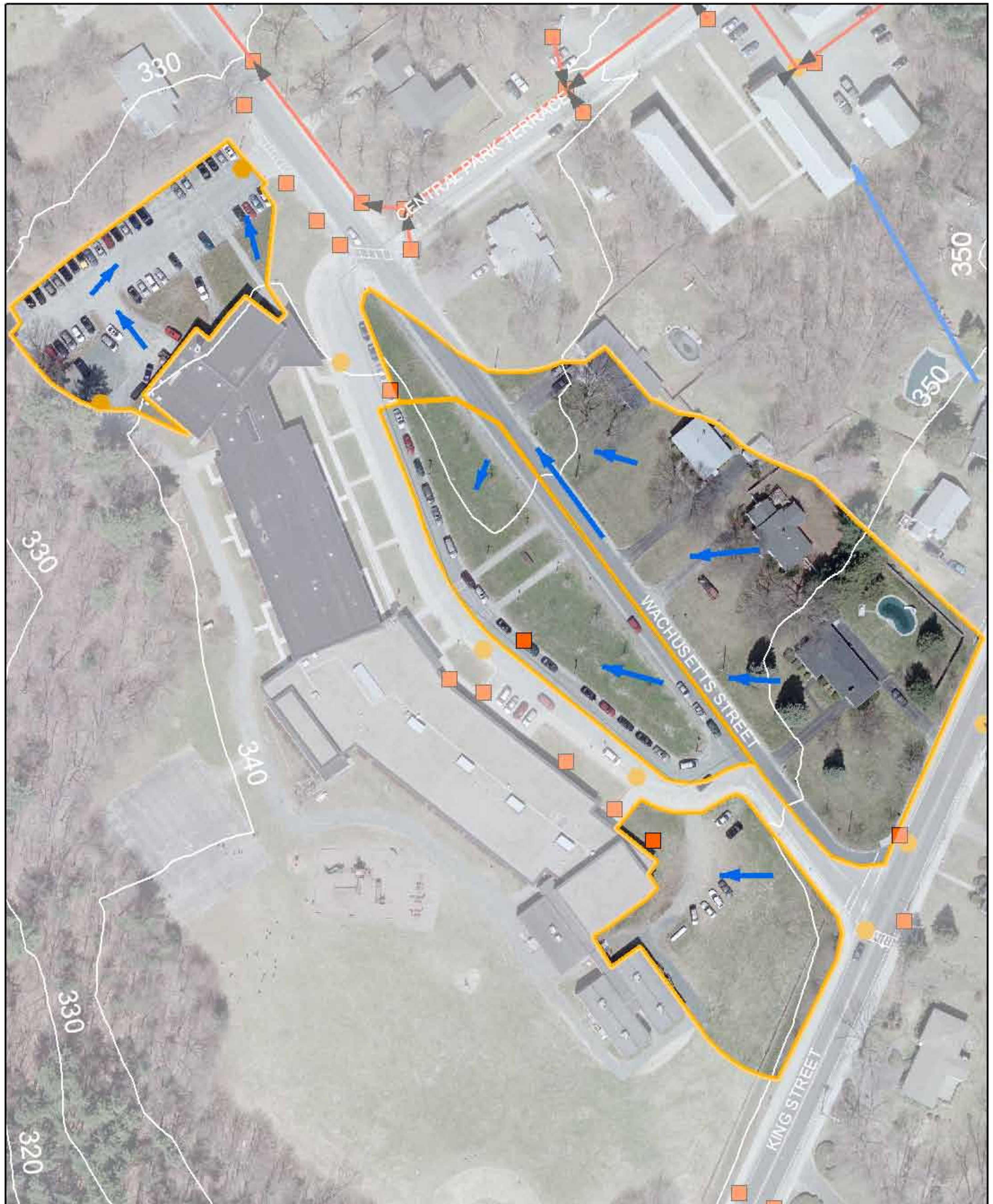


Gravel wetland site

Corner of baseball field

Drainage Area (acres)	24.9
Impervious Area (acres)	6.4
Land Use	Medium/Low Density Residential
Hydrologic Soil Group (at proposed BMP site)	B
Existing Phosphorus Load (kg/year)	6.4

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA



Legend

CRWA

- Stormwater Flow
- Outfalls
- Catch Basins
- Manholes
- Stormwater Pipe
- Culverts
- Drainage Area
- Lakes
- Wetlands
- Rivers

N W E S

100 50 0 100 Feet

Contour interval is 10 ft

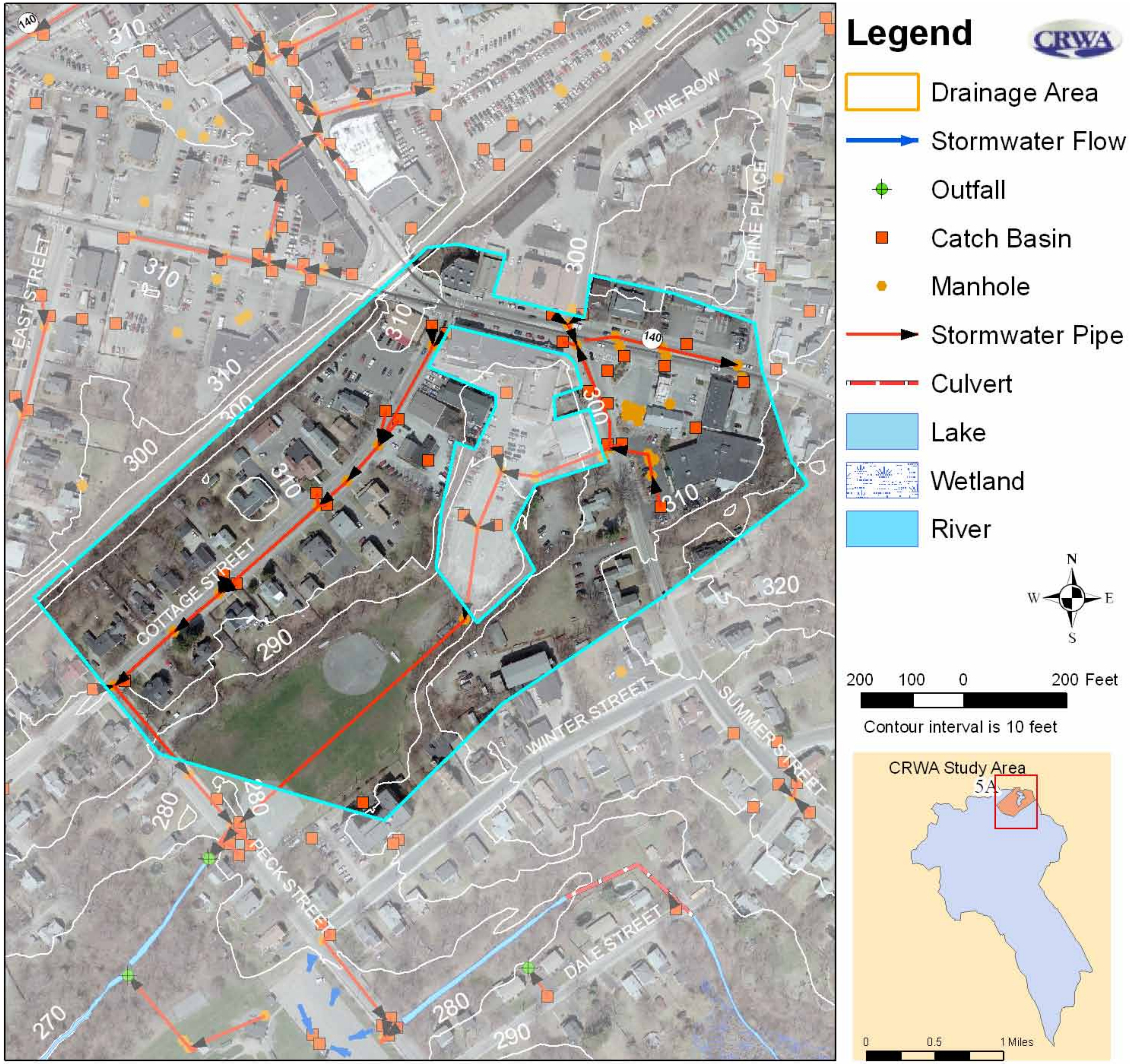

Parking lot on northwest side of the school


Grass depression at southeast corner of the school

Drainage Area (acres)	4.0
Impervious Area (acres)	1.7
Land Use	Commercial/Medium Density Residential
Hydrologic Soil Group (at proposed BMP site)	B/C
Existing Phosphorus Load (kg/year)	1.7

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA

Existing Conditions for Drainage Area 5A - Pisani Field



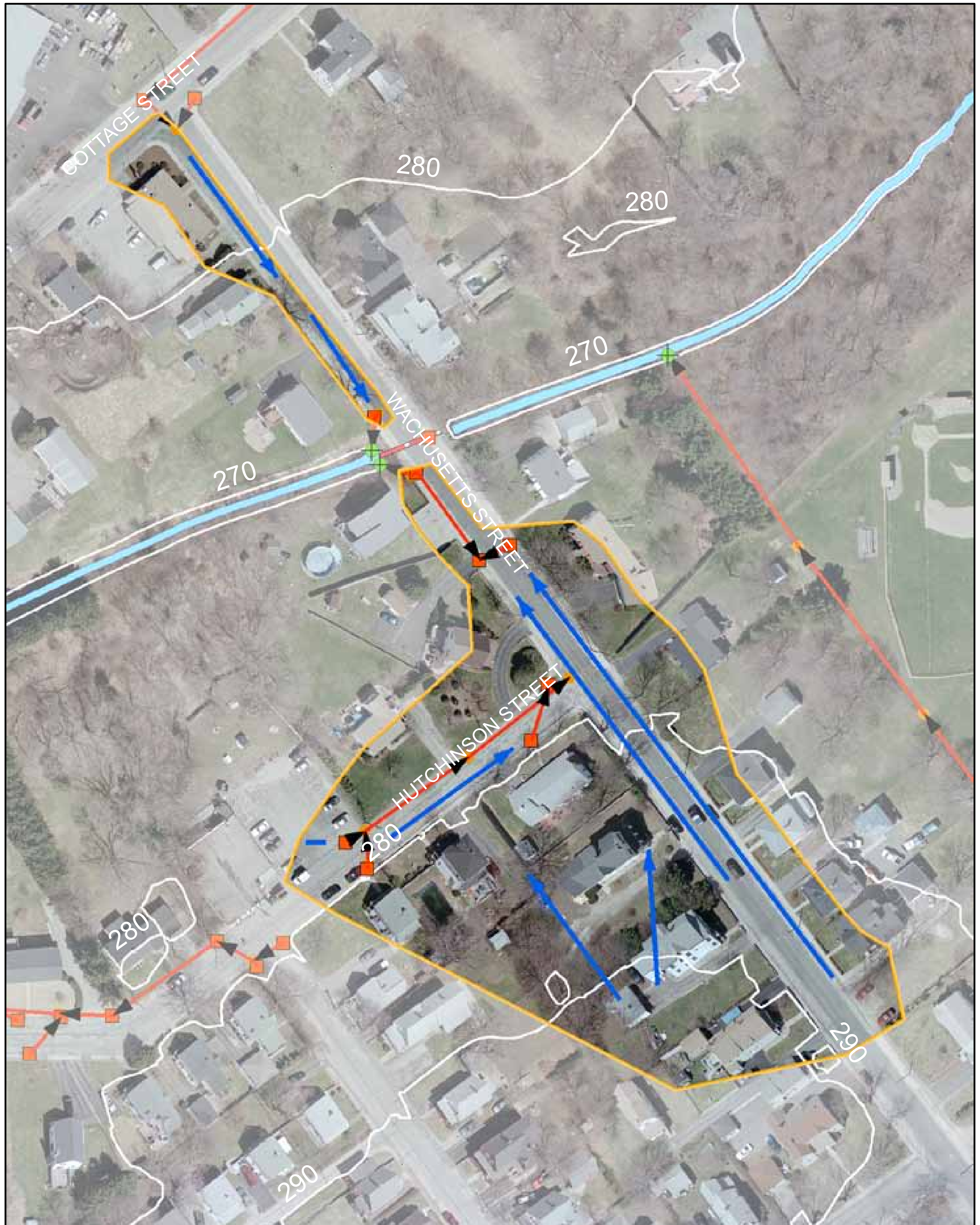
Corner of field

Parking lot in front of field

Drainage Area (acres)	19.6
Impervious Area (acres)	8.6
Land Use	Commercial/Medium Density Residential
Hydrologic Soil Group (at proposed BMP site)	A/B
Existing Phosphorus Load (kg/year)	8.7

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA

Existing Conditions for Drainage Area 5D2 - Wachusett Street North



Legend

- Drainage Area
- Stormwater Flow
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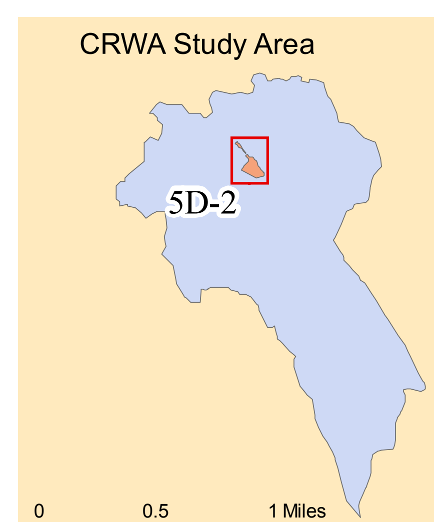
- River

100 50 0 100 Feet

Contour interval is 10 feet



Wachusett Street

Hutchinson Street intersection

Drainage Area (acres)	3.4
Impervious Area (acres)	1.5
Land Use	Medium Density Residential
Hydrologic Soil Group (at proposed BMP site)	C
Existing Phosphorus Load (kg/year)	1.1

Data Sources: MassGIS, Town of Franklin, CRWA, NRCS, EPA

PROPOSED STORMWATER MANAGEMENT DESIGN

Methodology

To develop the subwatershed stormwater management plan, CRWA developed conceptual designs for selected priority drainage areas and used computer modeling to assess the phosphorus reduction potential of various design scenarios for the entire subwatershed. For the purpose of this study, CRWA's stormwater management control techniques were limited to structural BMPs[3]. A stormwater BMP was selected for each developed drainage area from the following suite of low impact development BMPs:

- Infiltration chamber
- Infiltration basin
- Bioretention system
- Green street design (using bioretention systems)
- Gravel wetland
- Rain garden

Sample schematic designs of these systems are included in Appendix C.

BMPs were selected, sited and sized based on soil conditions (soil profile and water table depth), existing property use, space constraints, stormwater pipe locations and depths, slope, and neighborhood character.

CRWA modeled two stormwater management scenarios, our "best professional judgment" scenario (Scenario 0) and our optimized scenario (Scenario 2) (See Modeling Analysis section for details).

Results

The following section contains CRWA's conceptual designs for the 12 priority sites for the best professional judgment scenario. Non-priority sites are discussed further in the Modeling Analysis section.

This section shows the proposed stormwater retrofit designs for each of the 12 priority sites. Specific practices were selected to meet Town goals, and are based on soil conditions, existing infrastructure and phosphorus reduction capability.

[3]In reality, communities will likely rely on a mix of structural and non-structural BMPs. Non-structural BMP options include street sweeping, catch basin cleaning and banning fertilizers that contain phosphorus. It is possible that communities will get as much as 15% removal credit from non-structural best management practices.

Before and after scenario for the entrance of Boston Sports Club.

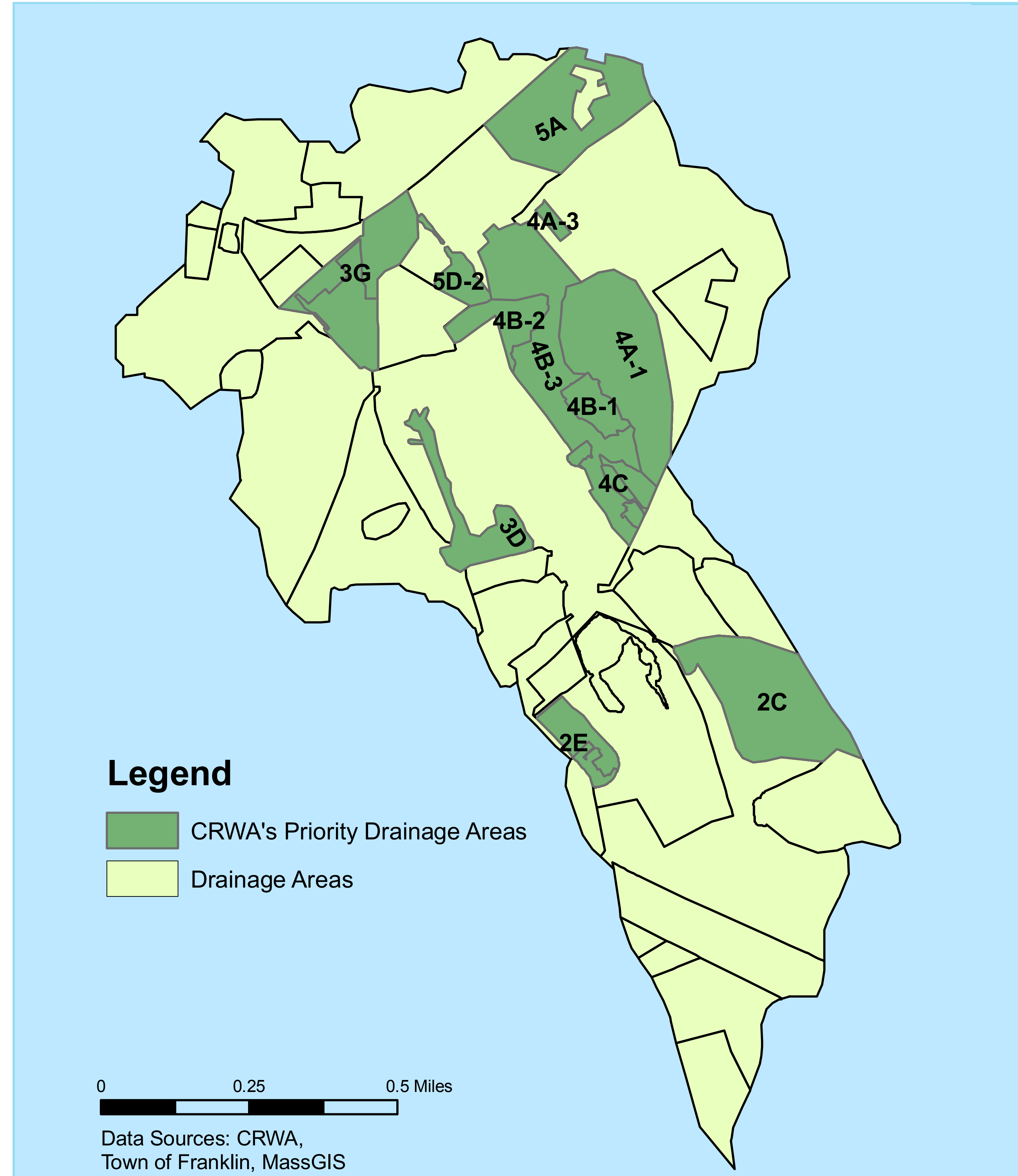
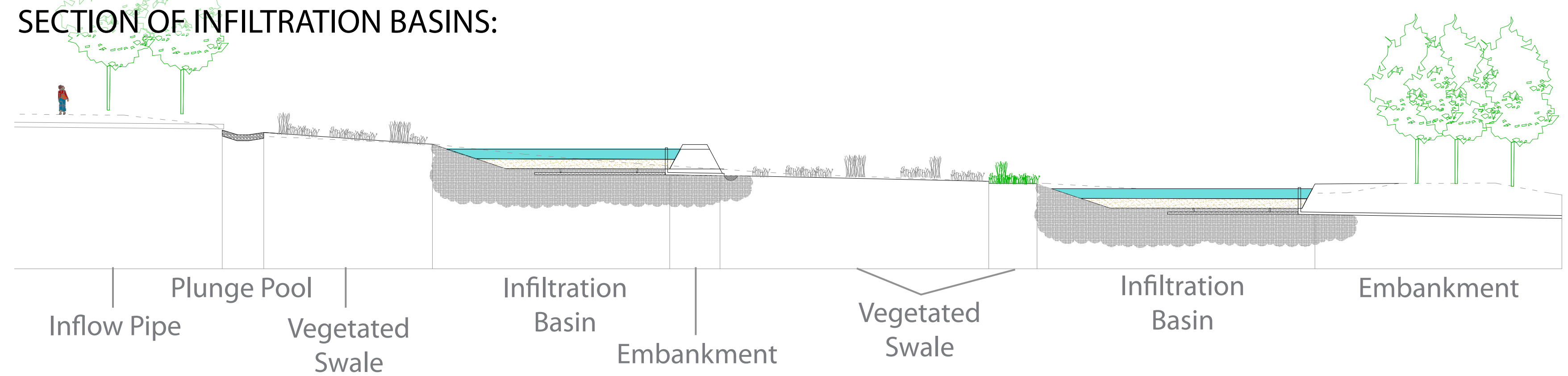


Figure 5. Priority drainage areas in the Spruce Pond Brook subwatershed.

Terraced infiltration basin. Photo source: Horsley Witten Group

Infiltration basin. Photo source: Horsley Witten Group

SECTION OF INFILTRATION BASINS:



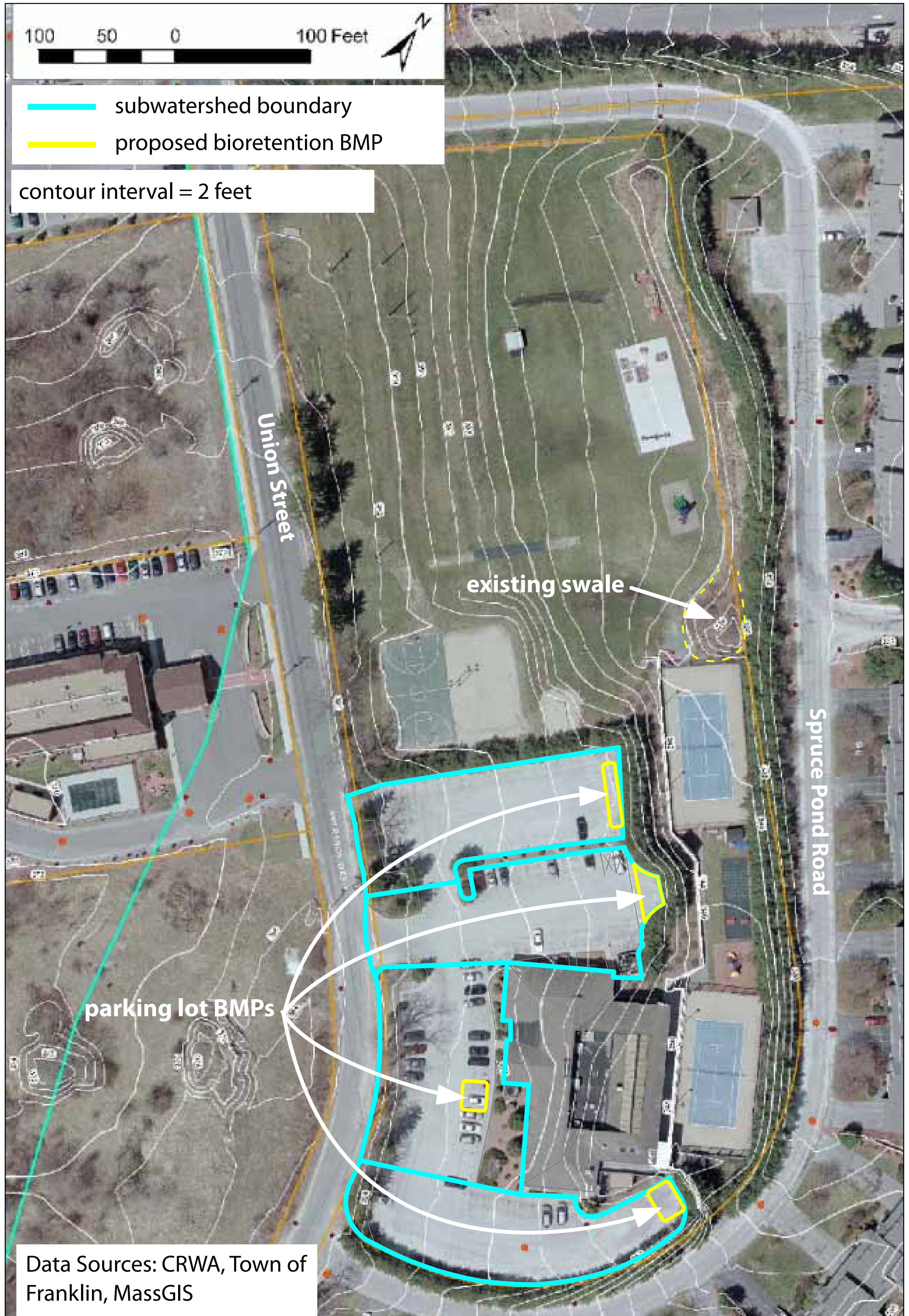
BMP DESCRIPTION

The existing dry detention basin will be retrofitted to provide infiltration and decrease the scouring that is currently occurring. At the inflow pipe there will be a forebay/plunge pool to dissipate the energy of the water before it flows into a vegetated, terraced infiltration system. Vegetated channels connect the basins and carry baseflow.

INFILTRATION BASIN SIZING- 1" storm

DRAINAGE AREA TOTAL	1,061,136	sq. ft.
IMPERVIOUS AREA	148,908 (14%)	sq. ft.
PERVIOUS AREA	912,229 (86%)	sq. ft.
PONDING HEIGHT	2	ft.
MEDIA DEPTH	2	ft.
BMP SURFACE AREA	7,348	sq. ft.

Proposed Designs for Drainage Area 2E - Boston Sports Club



BEFORE: Photo of existing end of northwest parking lot

AFTER: Visualization of proposed bioretention area

BMP DESCRIPTION

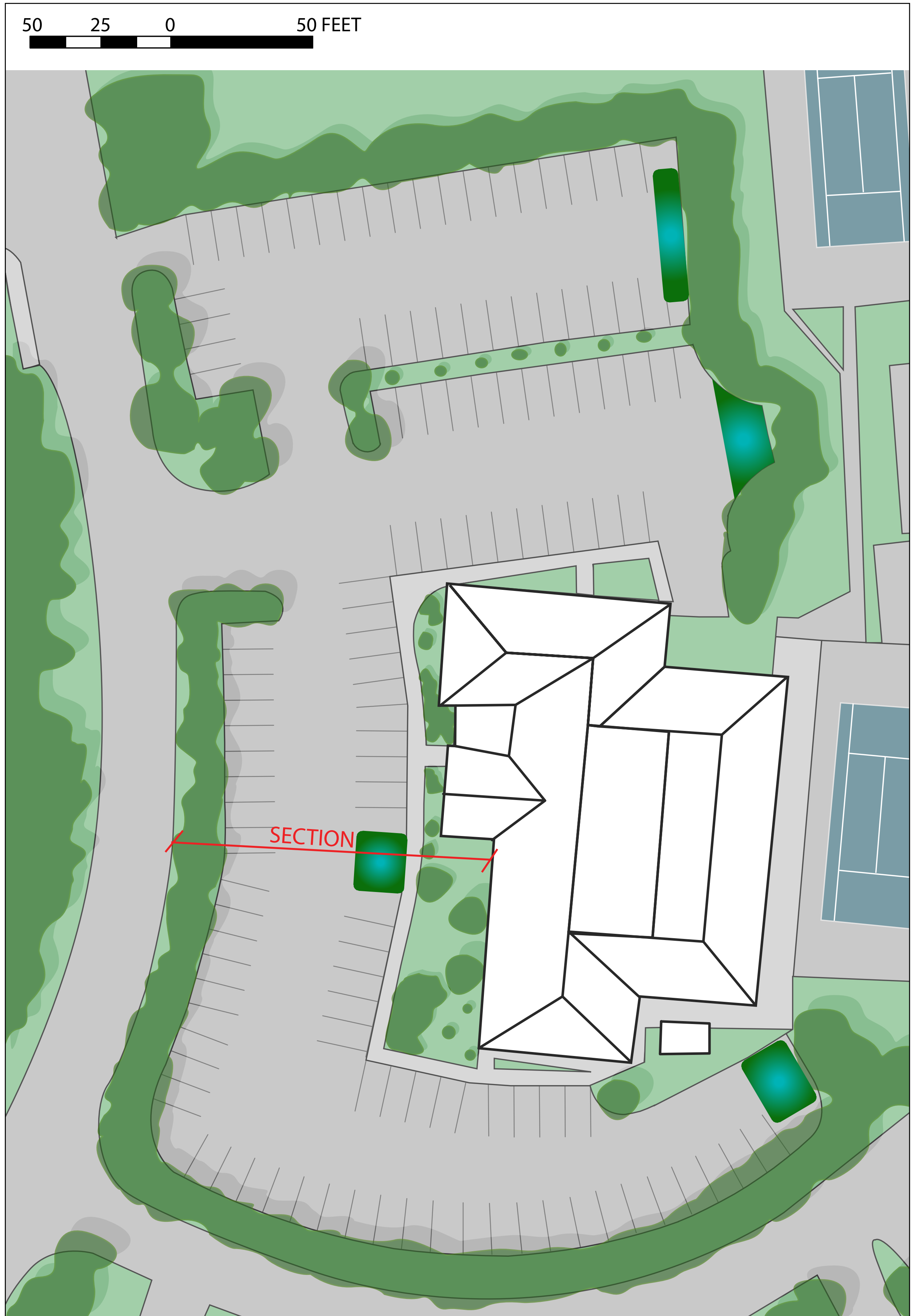
The existing swale at the edge of the field will continue to capture the drainage from the field. Drainage from the parking areas around the Boston Sports Club will be intercepted in four bioretention areas, within each parking lot area. The bioretention area by the front of the building will enhance the entryway and could promote education about stormwater management. Each bioretention area will be constructed over an existing catch basin that can be used as an overflow. The overflow pipe of the northern most parking lot will be redirected into the existing swale.

Source: http://picasaweb.google.com/buildgreeninfrastructure

BIORETENTION SIZING- 1" storm

DRAINAGE AREA TOTAL	60,789	sq. ft.
IMPERVIOUS AREA	41,850 (69%)	sq. ft.
PERVIOUS AREA	18,939 (31%)	sq. ft.
PONDING HEIGHT	0.75	ft.
MEDIA DEPTH	3	ft.
BMP SURFACE AREA	1,739	sq. ft.

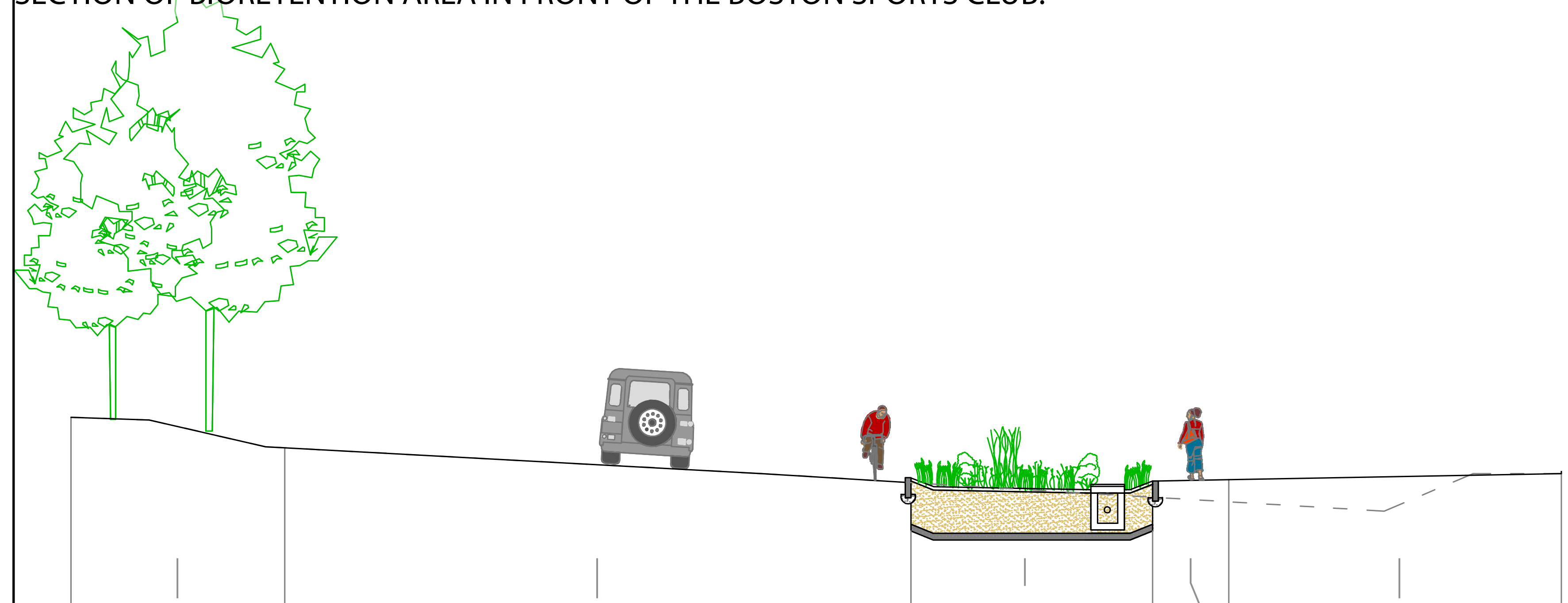
Proposed Designs for Drainage Area 2E - Boston Sports Club



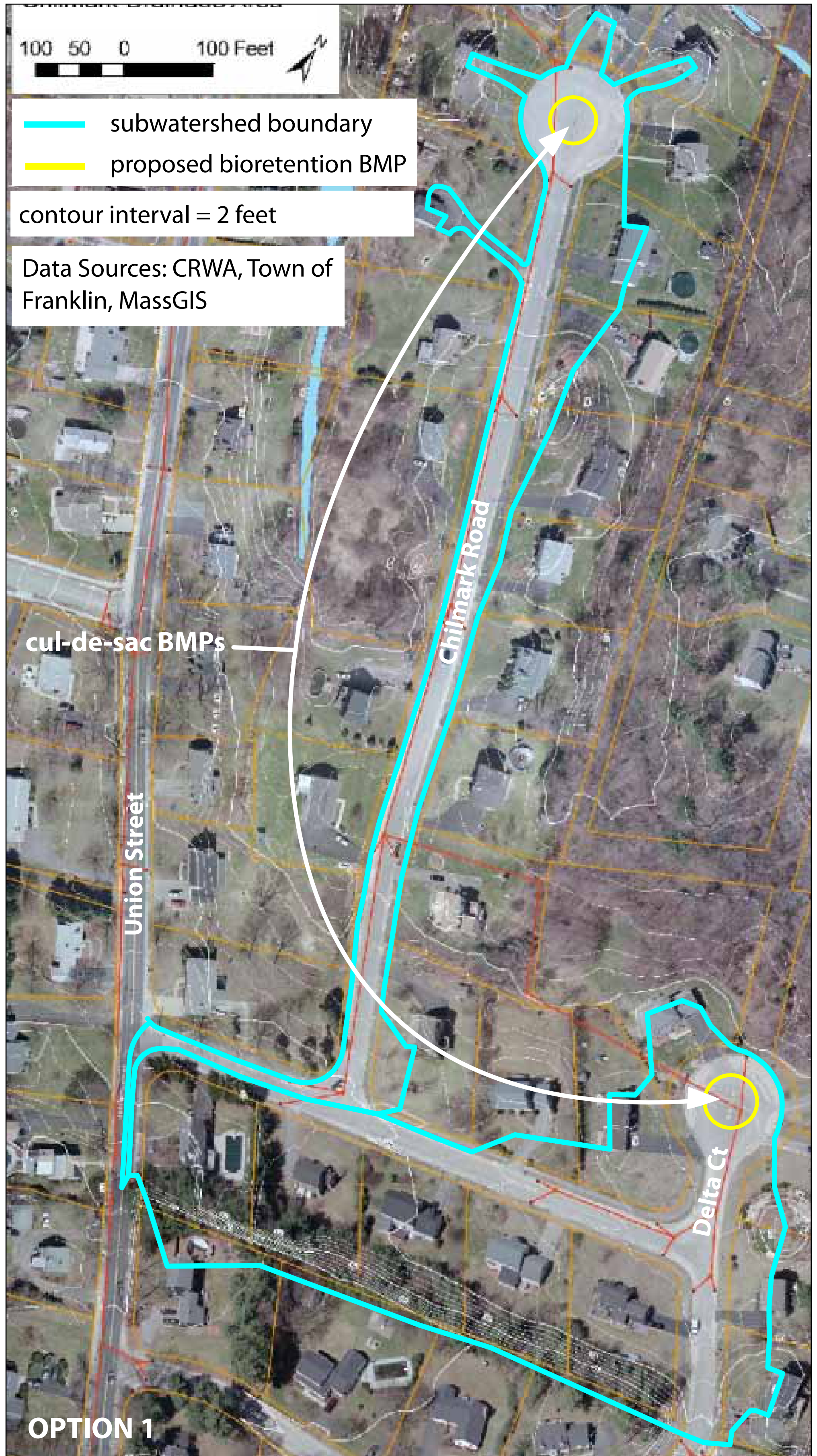
BEFORE: Photo of existing entrance of the Boston Sports Club

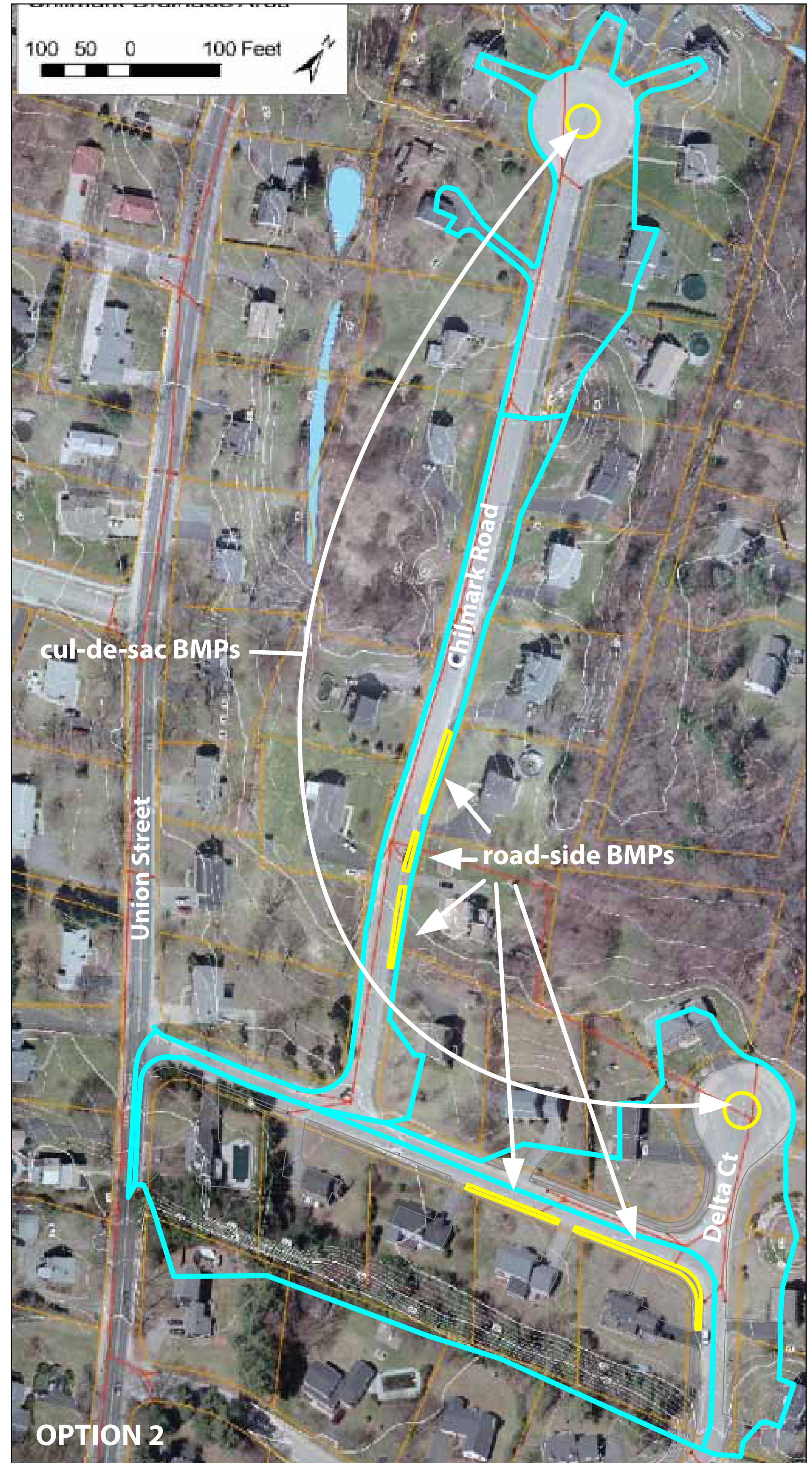
AFTER: Visualization of proposed bioretention area

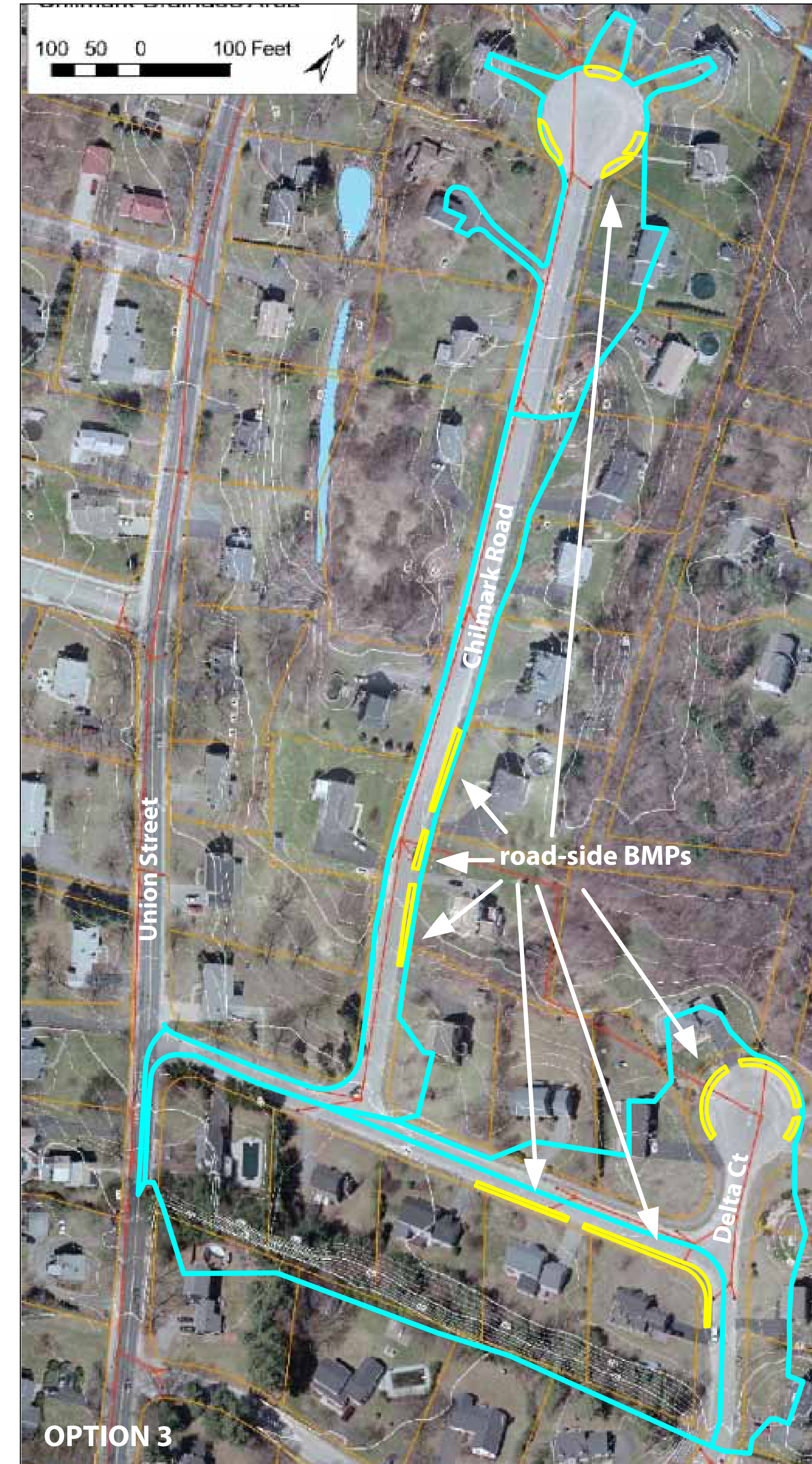
SECTION OF BIORETENTION AREA IN FRONT OF THE BOSTON SPORTS CLUB:



Proposed Designs for Drainage Area 3D - Chilmark Road







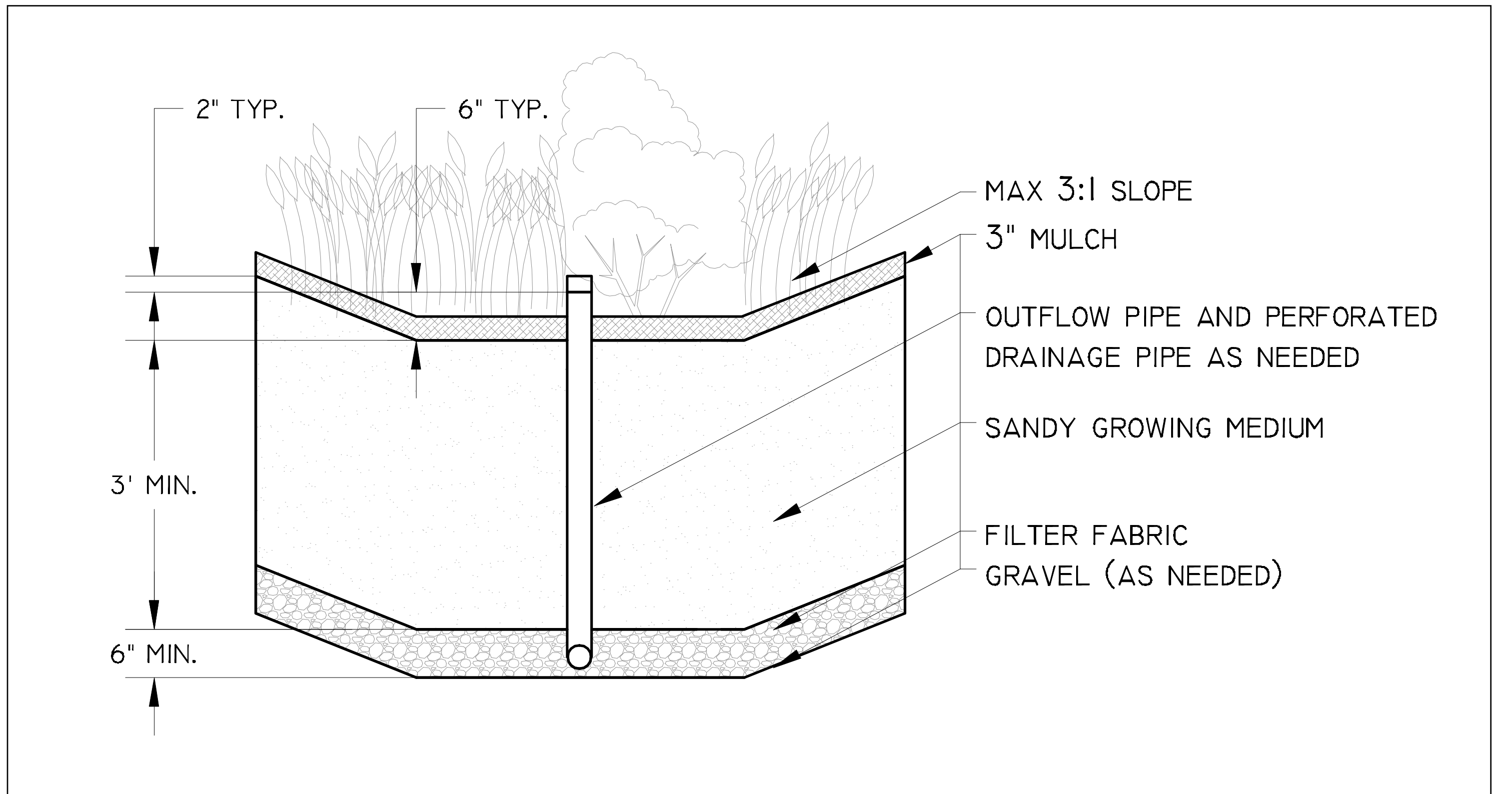
BMP DESCRIPTION

OPTION 1 - Retrofit the existing cul-de-sacs at the end of Chilmark Rd. and Delta Ct. with bioretention cells. Regrade cul-de-sacs so that they drain towards the middle, into the bioretention cells. Additionally, intercept the flow from the existing stormwater pipes and direct them into the bioretention areas. Install overflow pipes and connect them into existing stormwater pipes.

OPTION 2 - Retrofit existing cul-de-sacs with smaller bioretention cells that only take surface water runoff and do not intercept water from the existing stormwater pipes. Regrade cul-de-sacs so that they drain towards the middle, into the bioretention cells. Retrofit existing tree lawns with bioretention cells at low points along the street where the catch basin can be used as the overflow.

OPTION 3 - Build "bump-out" bioretention cells along the perimeter of the cul-de-sacs so regrading is not needed. As in Option 2, retrofit existing tree lawns with bioretention cells at low points along the street where the catch basin can be used as the overflow.

A green street in Portland, OR.
Photo source: Transportation Enhancements Image Library

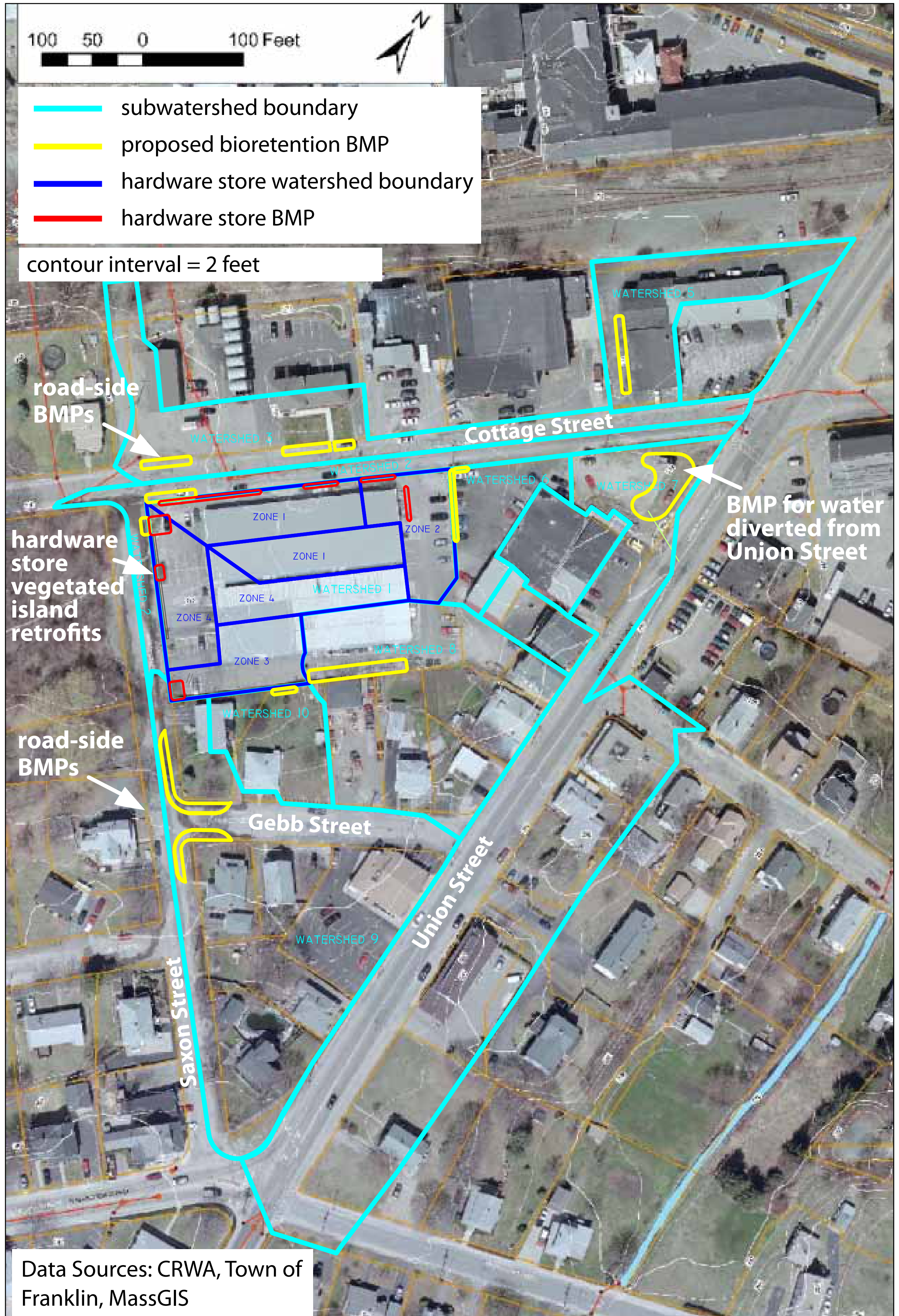


SCHEMATIC SECTION OF A BIORETENTION AREA
Typical of central cul-de-sac bioretention system

BIORETENTION SIZING - 1" storm

DRAINAGE AREA TOTAL	36,4543	sq. ft.
IMPERVIOUS AREA	119,878 (33%)	sq. ft.
PERVIOUS AREA	244,666 (67%)	sq. ft.
PONDING HEIGHT	0.75	ft.
MEDIA DEPTH	3	ft.
BMP SURFACE AREA	5,389	sq. ft.

Proposed Designs for Drainage Area 3G - Cottage and Union Streets



BEFORE: Photo of existing intersection of Geb and Saxon Streets

AFTER: Visualization of proposed road-side bioretention areas

Source: www.picasaweb.google.com/buildgreeninfrastructure

BMP DESCRIPTION

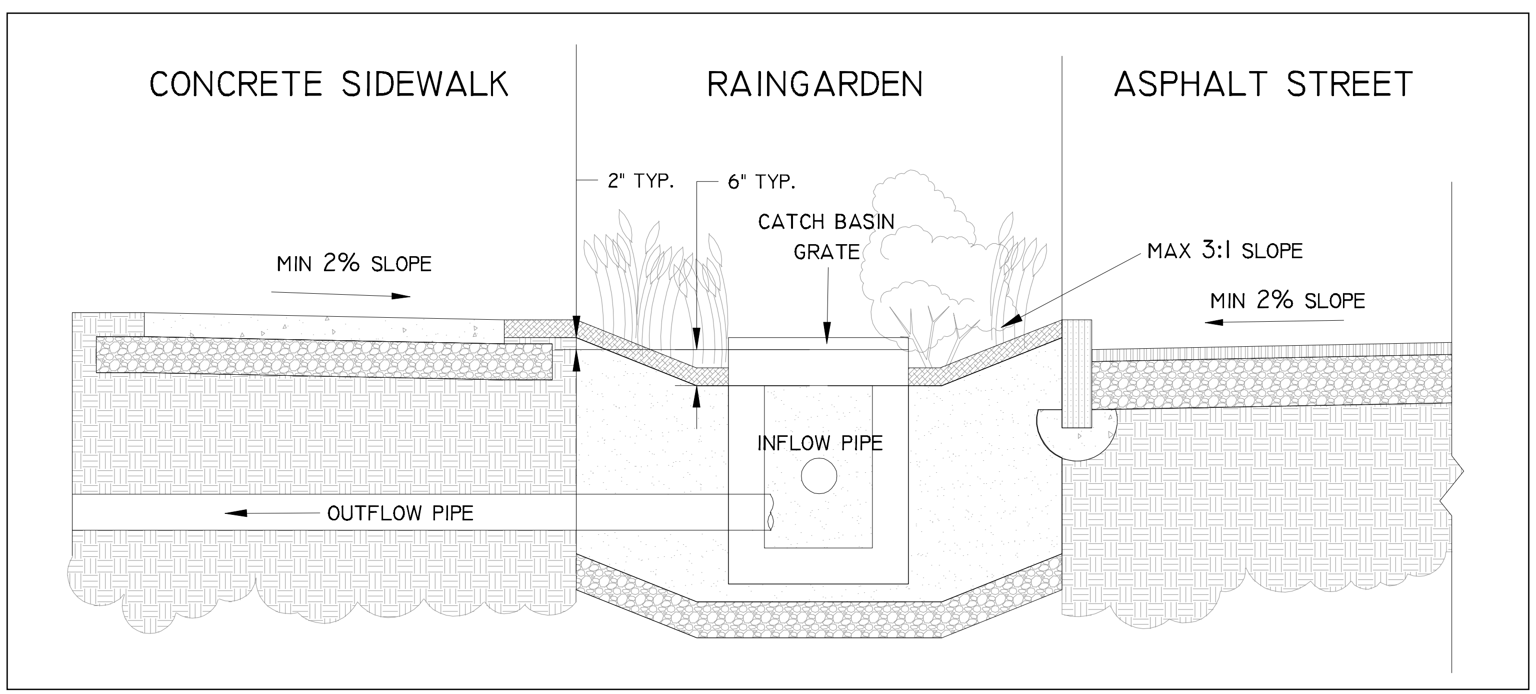
In this heavily developed area many dispersed bioretention areas capture the 1" storm within this subwatershed. These BMPs include:

- road-side bioretention areas along Cottage Street
- road-side biorention areas at the intersection of Geb and Saxon Streets
- pipe interception along Union Street that is diverted into a bioretention area at the corner of Union and Cottage Streets
- bioretention areas in existing parking lots

The hardware store site is broken into its own subwatersheds where on-site BMPs are proposed, including existing vegetated islands retrofitted as bioretention areas, and road-side bioretention areas.

BEFORE: Photo of existing view looking northeast on Cottage Street.

AFTER: Visualization of proposed road-side bioretention areas.



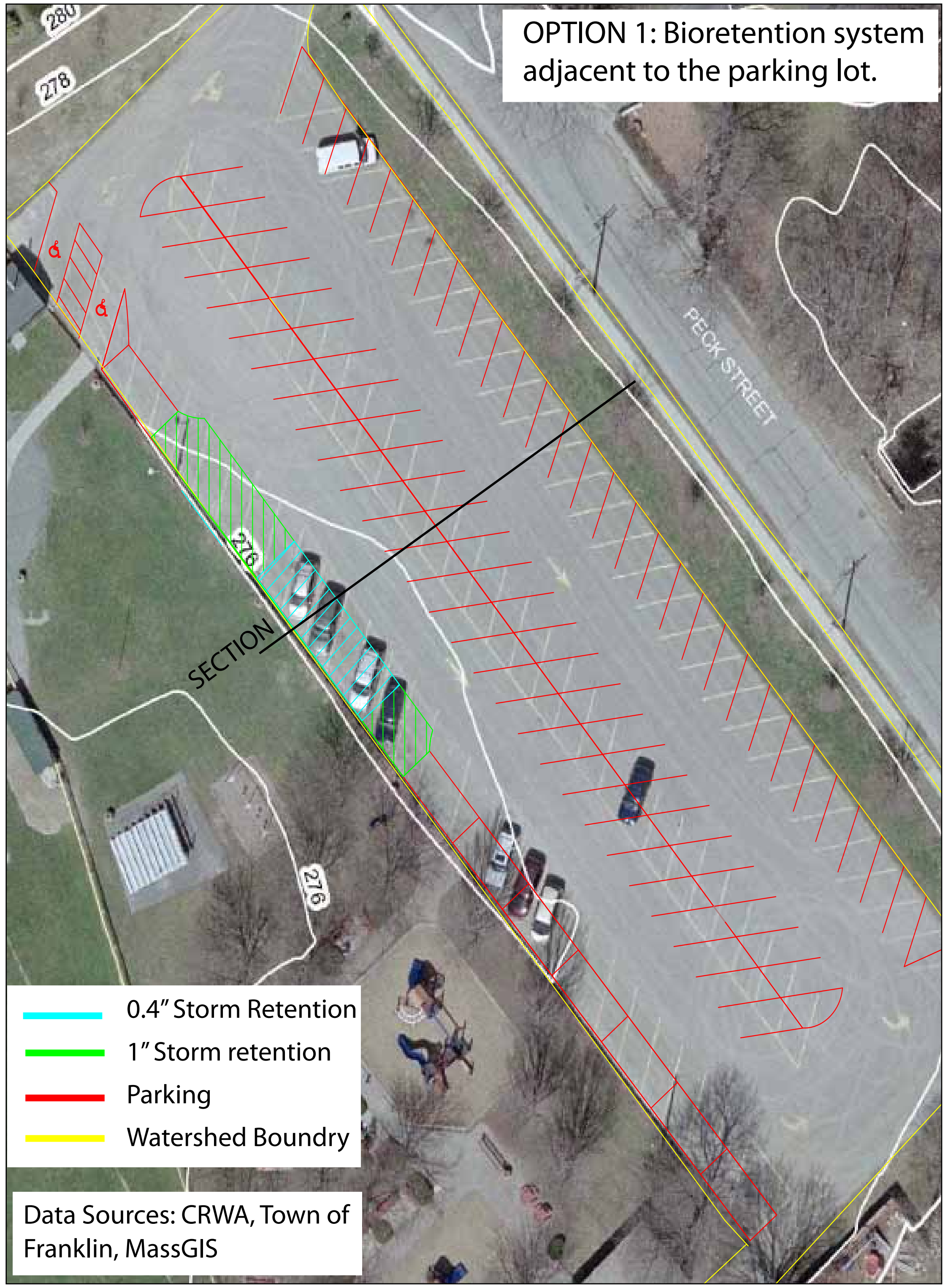
SCHEMATIC SECTION OF A BIORETENTION AREA WITH EXISTING CATCH BASIN
Typical of road-side retrofit

BIORETENTION SIZING - 0.7" storm*

DRAINAGE AREA TOTAL	369,393	sq. ft.
IMPERVIOUS AREA	274,501 (74.3%)	sq. ft.
PERVIOUS AREA	94,892 (25.7%)	sq. ft.
PONDING HEIGHT	0.5	ft.
MEDIA DEPTH	3	ft.
BMP SURFACE AREA	9,111	sq. ft.

* Design shown here differs from model output shown in matrix.

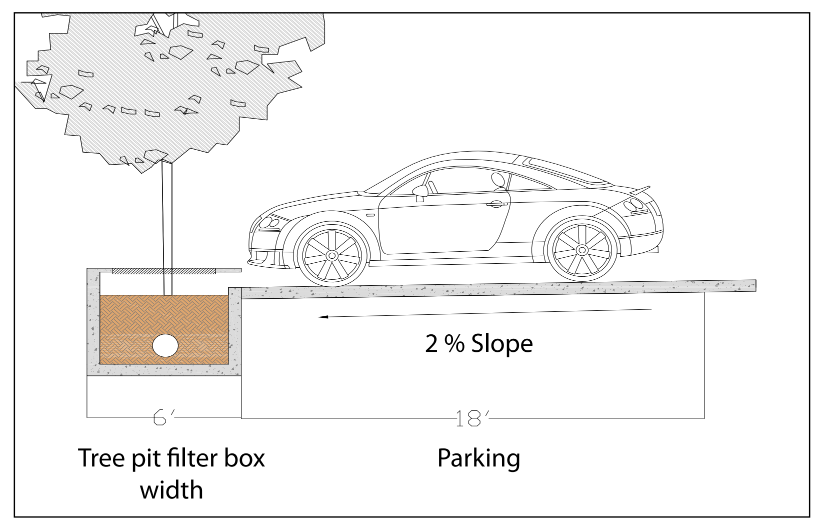
Proposed Designs for Drainage Area 4A-3 - Fletcher Field Large Parking Lot

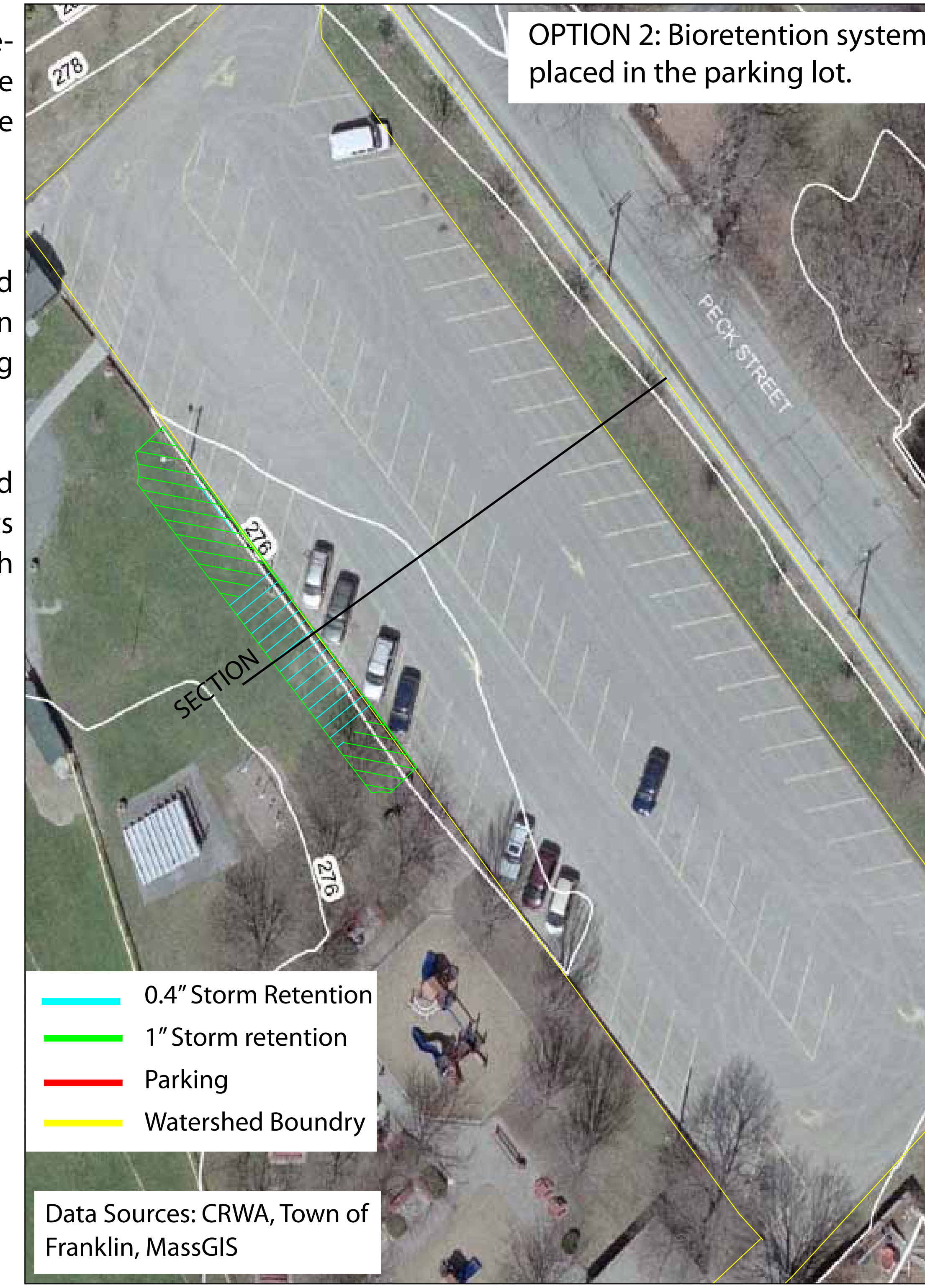


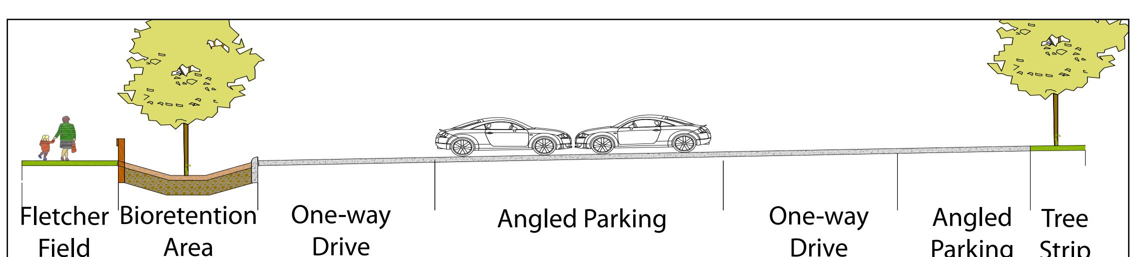
OPTION 1 - Bioretention area placed within re-organized parking lot. The reorganized lot will be designed to fit two one-way drives and will add nine parking spaces.
(See page 29 for site plan sizing details.)

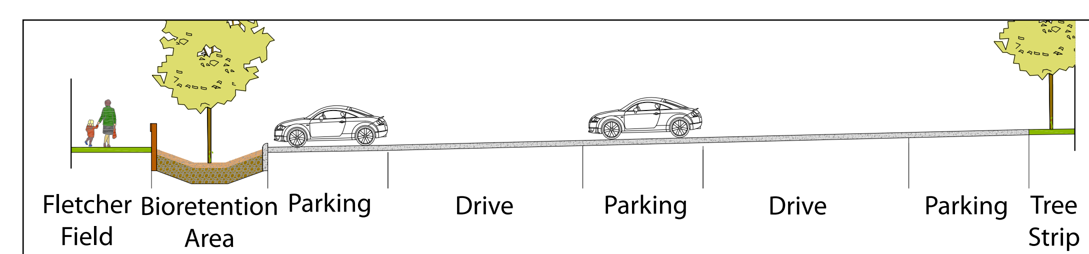
OPTION 2 - Bioretention system placed on field adjacent to the parking lot. Building the retention system in Fletcher Field will not require reorganizing the parking lot or removing any pavement.

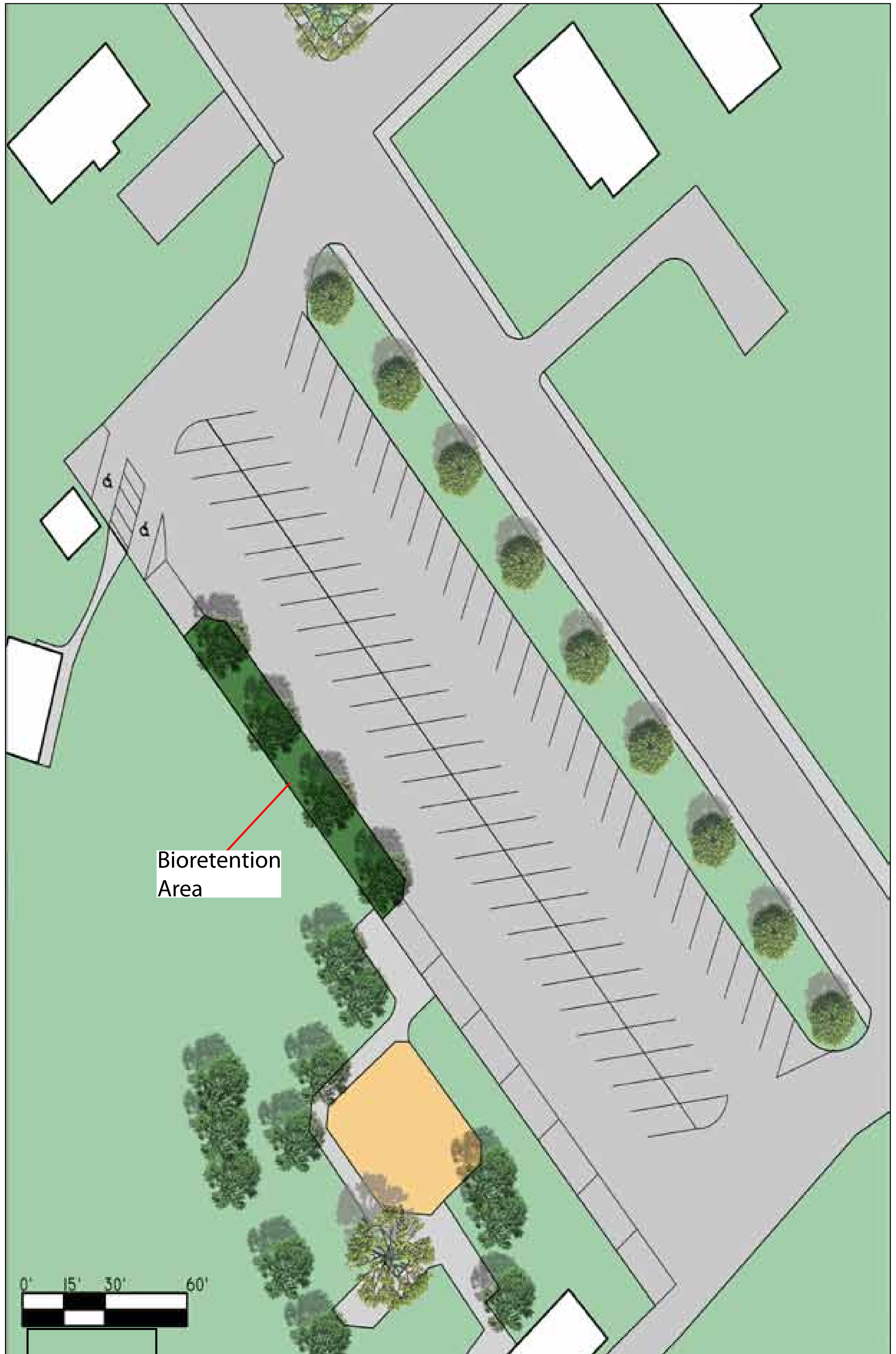
OPTION 3 (below) - The use of tree pit filters placed in the field next to the parking lot. These tree pits will filter water before draining to the existing catch basins.












BEFORE: Photo of existing parking lot.

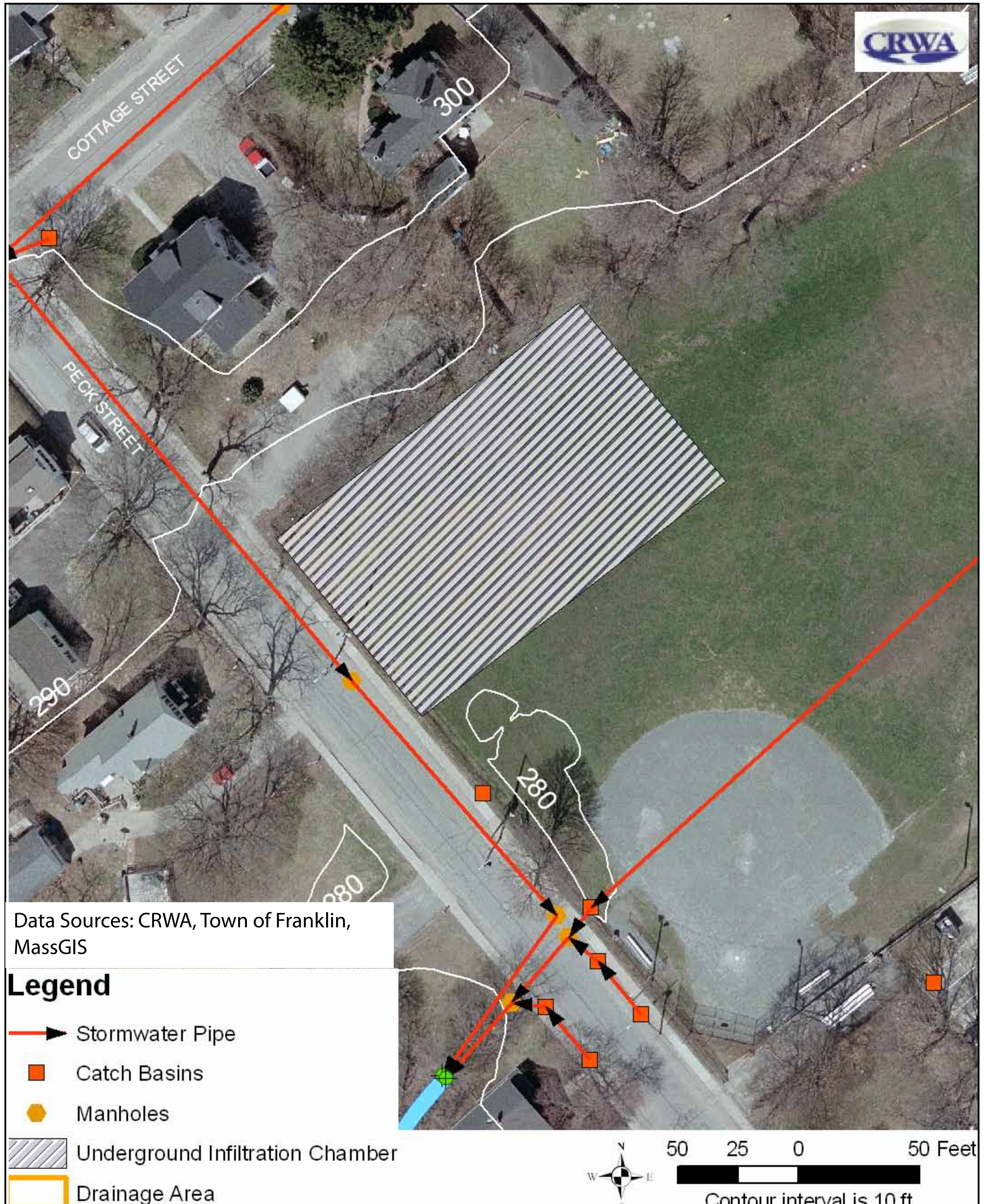

AFTER: Visualization of proposed bioretention area.

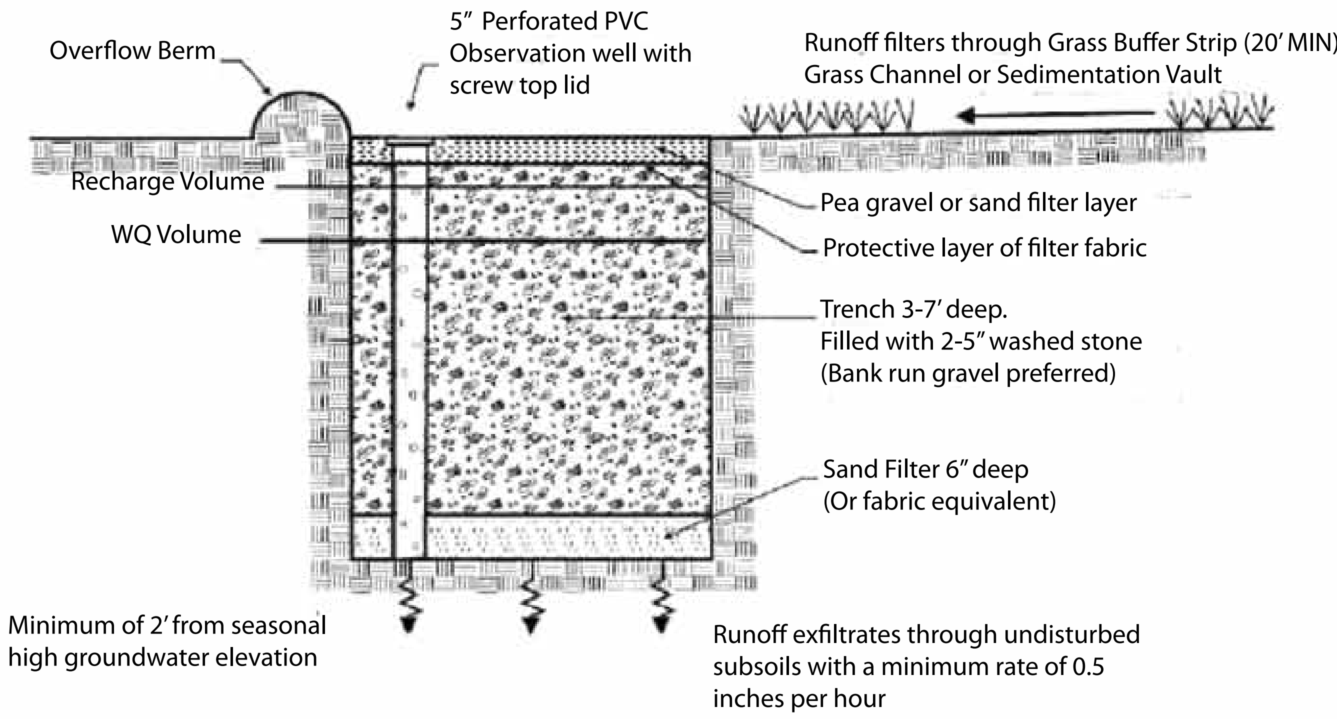
BMP DESCRIPTION

The proposed design will direct runoff to a vegetated bioretention area where it will be cleaned by plants before being recharged into the ground. Overflow of this system will drain into the raised catch basins connected to the existing stormwater infrastructure. The rearranged parking lot will be more efficient and create nine extra spots and reduce underutilized impervious surface.

BIORETENTION SIZING - 0.4" storm

DRAINAGE AREA TOTAL	41,468.0	sq. ft.
IMPERVIOUS AREA	33,239.0 (80%)	sq. ft.
PERVIOUS AREA	8,229.0 (20%)	sq. ft.
PONDING HEIGHT	0.5	ft.
MEDIA DEPTH	3	ft.
BMP SURFACE AREA	627	sq. ft.





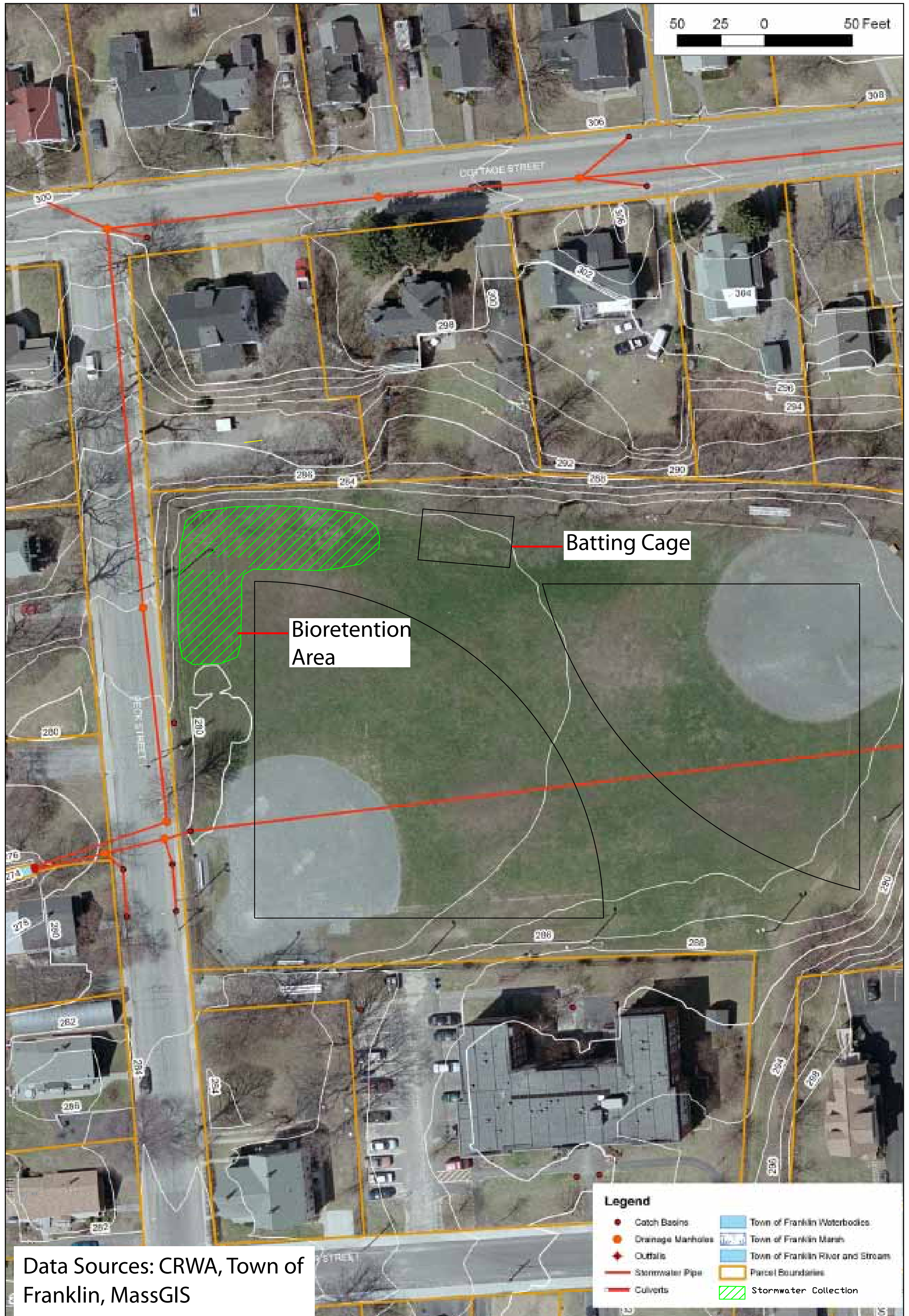
A schematic section of an infiltration trench.
Source: Tetra Tech

BMP DESCRIPTION

OPTION 1 - An underground infiltration trench designed to infiltrate a 1" storm.

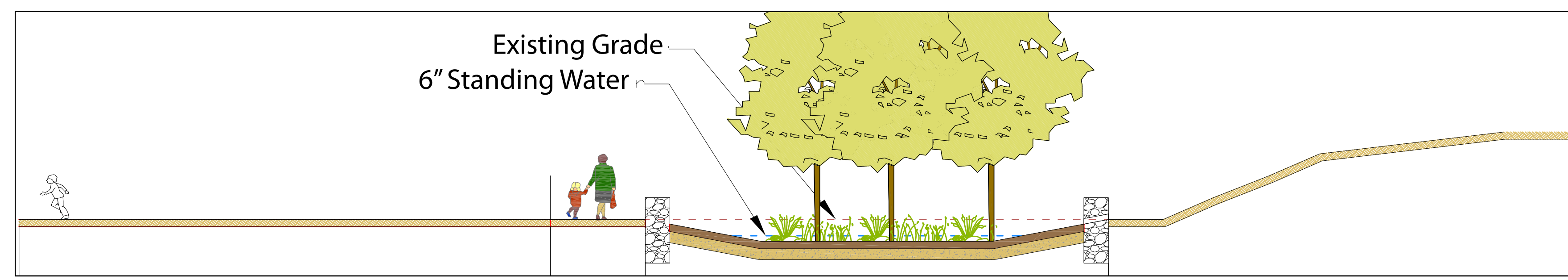
INFILTRATION TRENCH SIZING - 1" storm

DRAINAGE AREA TOTAL	853,994.7	sq. ft.
IMPERVIOUS AREA	373,550.7 (44%)	sq. ft.
PERVIOUS AREA	480,444.0 (56%)	sq. ft.
STORAGE DEPTH	2.1	ft.
MEDIA DEPTH	4	ft.
BMP SURFACE AREA	15,032	sq. ft.



BEFORE: Photo of northwest corner of the field.

AFTER: Visualization of a possible bioretention area.



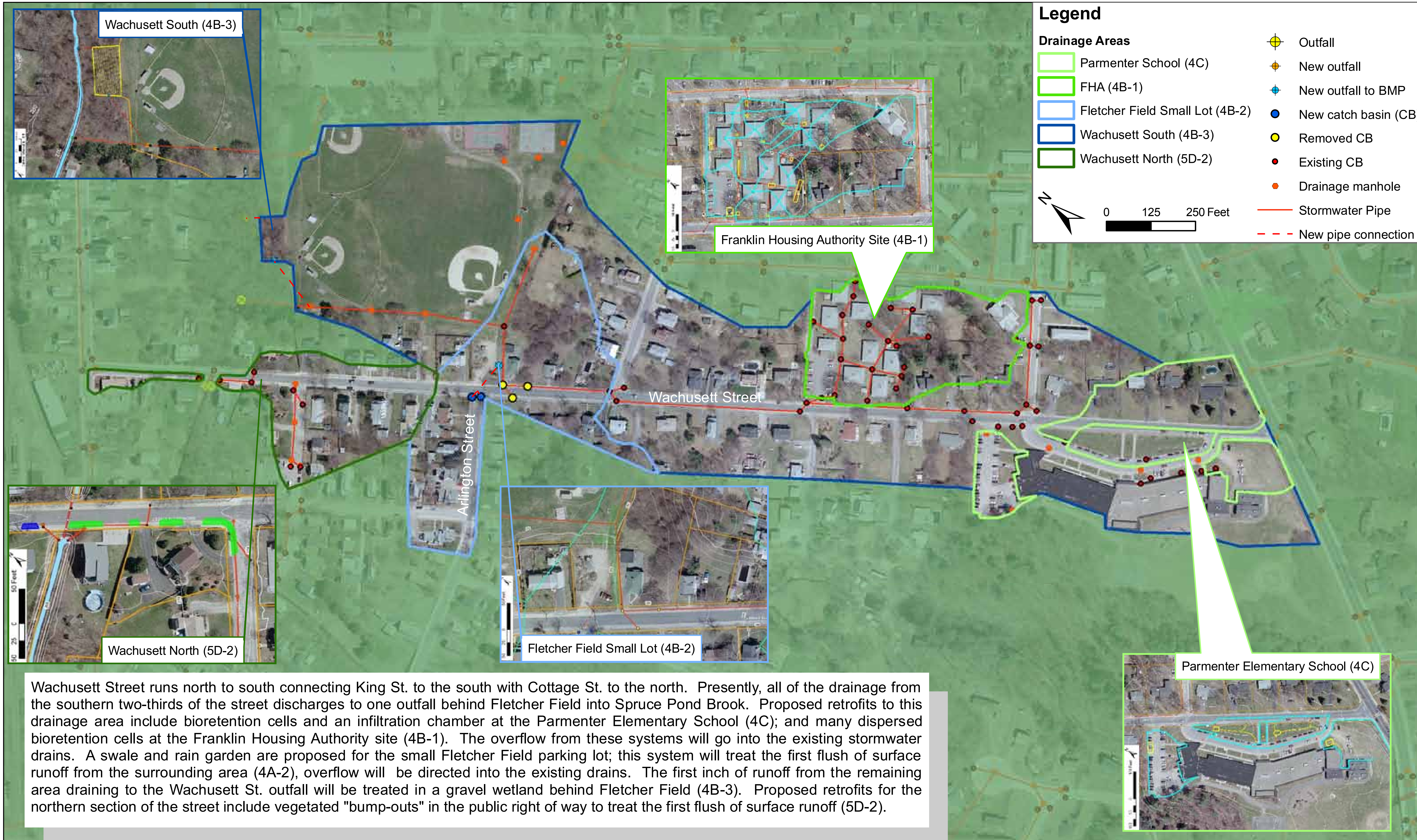
BMP DESCRIPTION

OPTION 2 - If the drainage area was reduced so that surface BMPs could fit above ground, the resulting system would create an aesthetically functional bioretention area along the edge of Pisani Field.

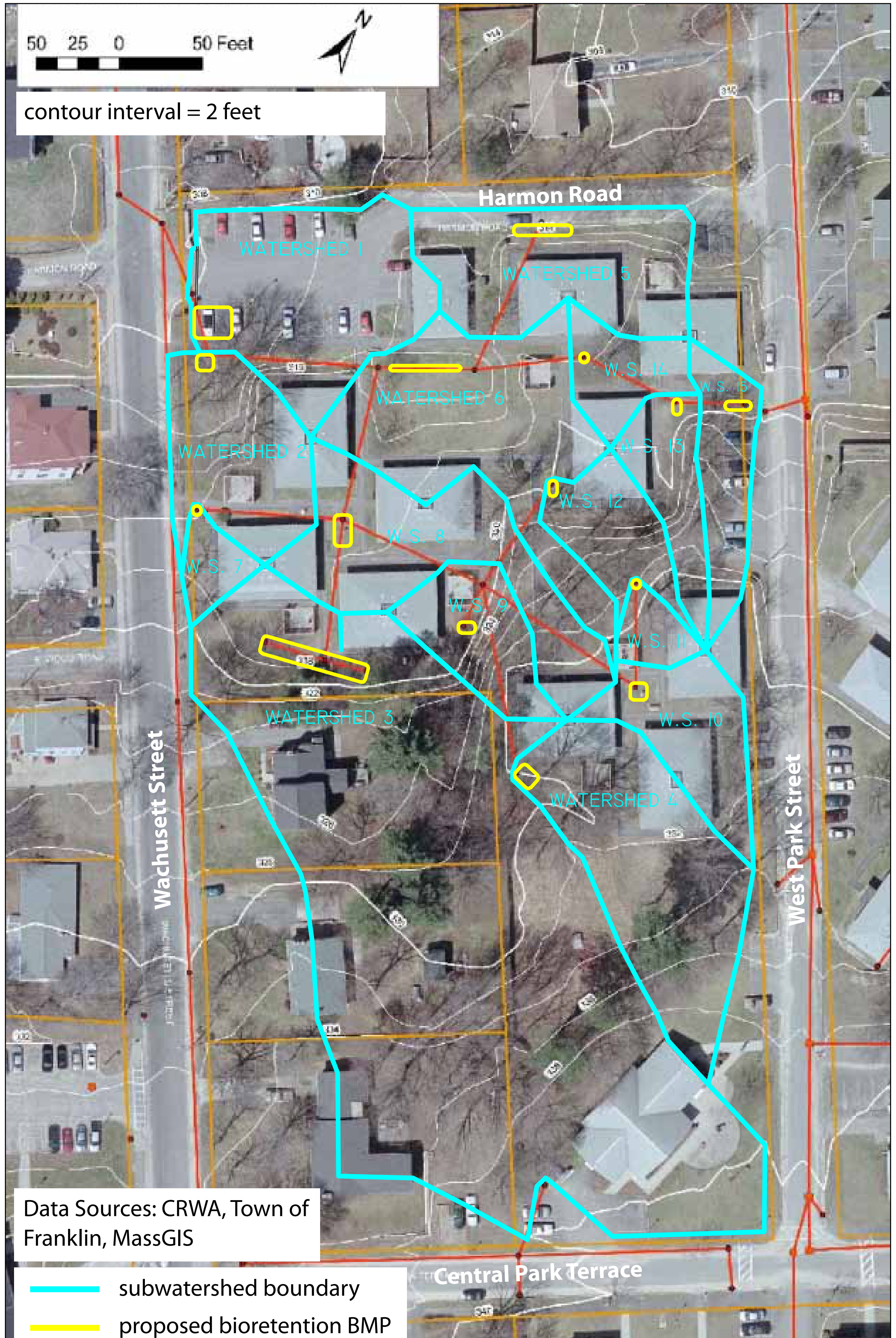
BIORETENTION SIZING - 0.4" storm

DRAINAGE AREA TOTAL	853,994.7	sq. ft.
IMPERVIOUS AREA	373,550.7 (44%)	sq. ft.
PERVIOUS AREA	480,444.0 (56%)	sq. ft.
PONDING HEIGHT	0.75	ft.
MEDIA DEPTH	3	ft.
BMP SURFACE AREA	6,477	sq. ft.

Overview of Proposed Designs for Wachusett Street



Wachusett Street runs north to south connecting King St. to the south with Cottage St. to the north. Presently, all of the drainage from the southern two-thirds of the street discharges to one outfall behind Fletcher Field into Spruce Pond Brook. Proposed retrofits to this drainage area include bioretention cells and an infiltration chamber at the Parmenter Elementary School (4C); and many dispersed bioretention cells at the Franklin Housing Authority site (4B-1). The overflow from these systems will go into the existing stormwater drains. A swale and rain garden are proposed for the small Fletcher Field parking lot; this system will treat the first flush of surface runoff from the surrounding area (4A-2), overflow will be directed into the existing drains. The first inch of runoff from the remaining area draining to the Wachusett St. outfall will be treated in a gravel wetland behind Fletcher Field (4B-3). Proposed retrofits for the northern section of the street include vegetated "bump-outs" in the public right of way to treat the first flush of surface runoff (5D-2).




BEFORE: Photo of existing catch basin in existing courtyard.


AFTER: Visualization of proposed bioretention area with catch basin retrofit.

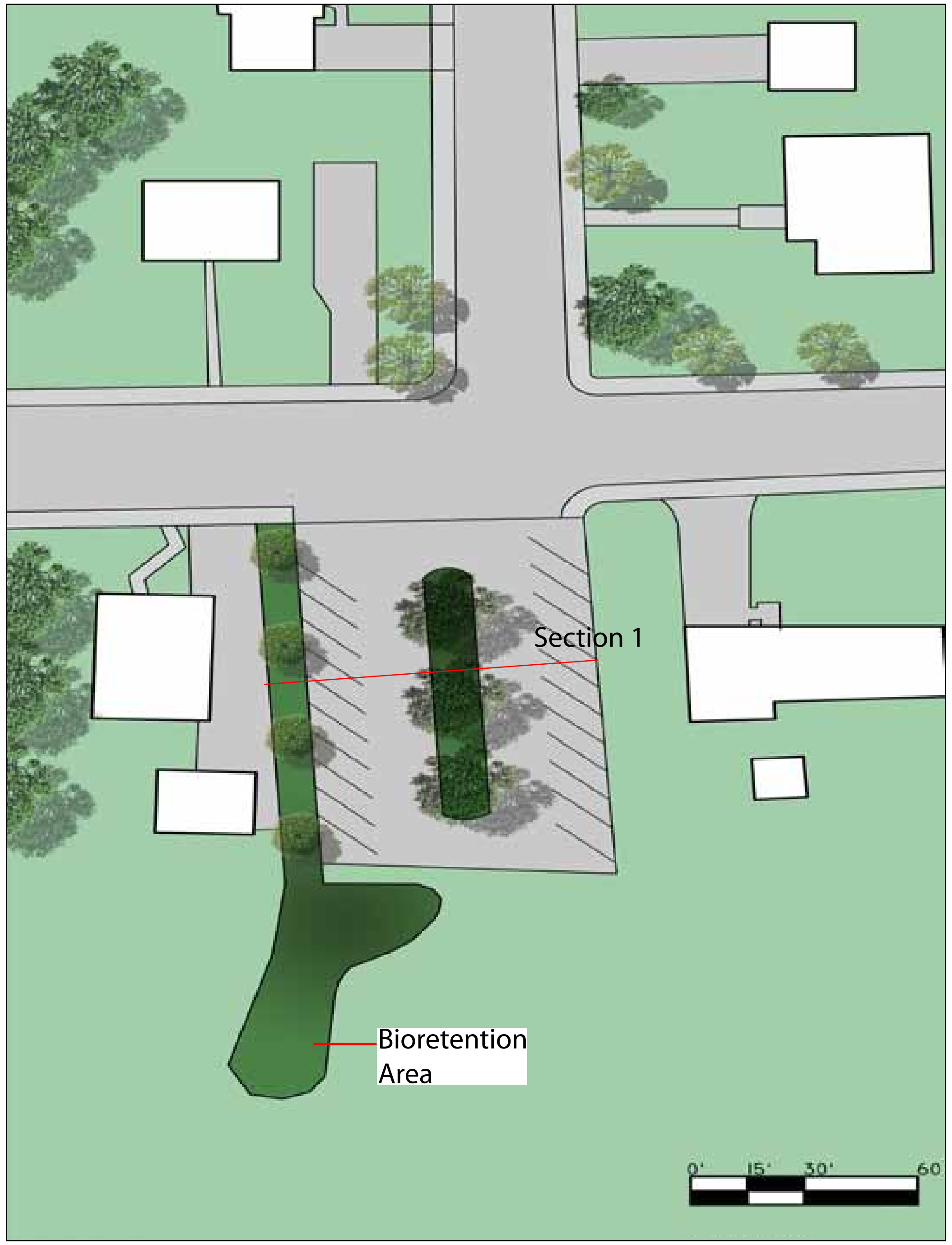
BMP DESCRIPTION

The drainage area for the site is broken up into many subwatersheds. Many dispersed bioretention areas capture and treat the 1" storm. Each bioretention area is located where there is an existing catch basin that can be raised up to serve as the system overflow. The bioretention areas will add beauty and character to this housing complex.

BIORETENTION SIZING - 1" storm

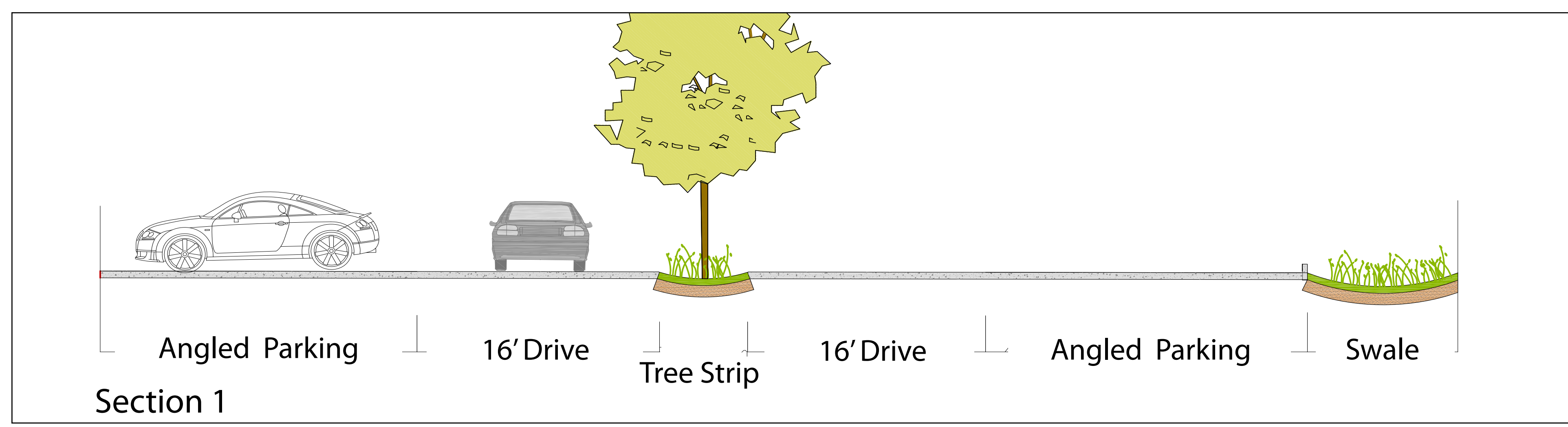
DRAINAGE AREA TOTAL	169,875.3	sq. ft.
IMPERVIOUS AREA	53,166.6 (31%)	sq. ft.
PERVIOUS AREA	116,708.7 (69%)	sq. ft.
PONDING HEIGHT	0.5	ft.
MEDIA DEPTH	2	ft.
BMP SURFACE AREA	2,204	sq. ft.

Proposed Designs for Drainage Area 4B-2 - Fletcher Field Small Parking Lot



BEFORE: Photo of existing concrete swale on western edge of small parking lot.

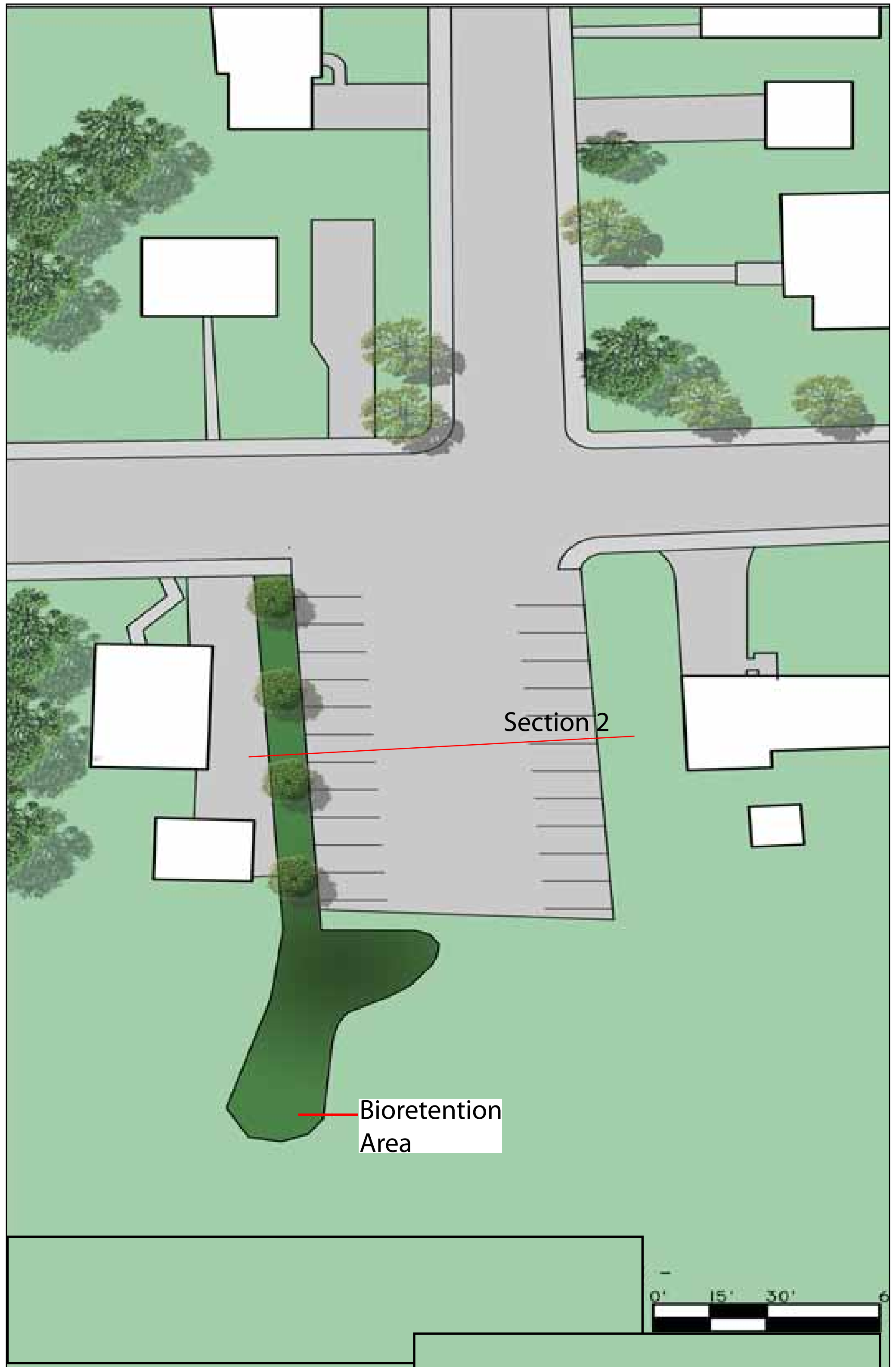
AFTER: Visualization of the vegetated swale.



OPTION 1 - Includes angled parking, one way drive and a centered tree strip to provide shade and reduce the amount of impervious surface.

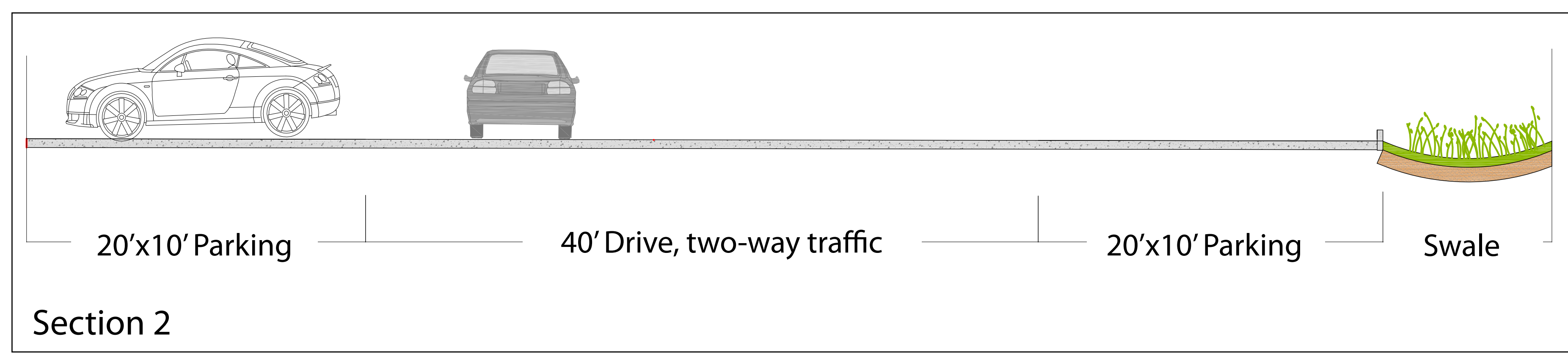
BMP DESCRIPTION

The proposed retrofit for the smaller Fletcher Field parking lot will treat drainage from Wachusett Street and Arlington Street being redirected by new catch basins placed at the end of Arlington. The drainage will travel through a vegetated swale into a bioretention area located in the field. This design will not only create a lush greenscape but provide a vital educational tool for stormwater management.



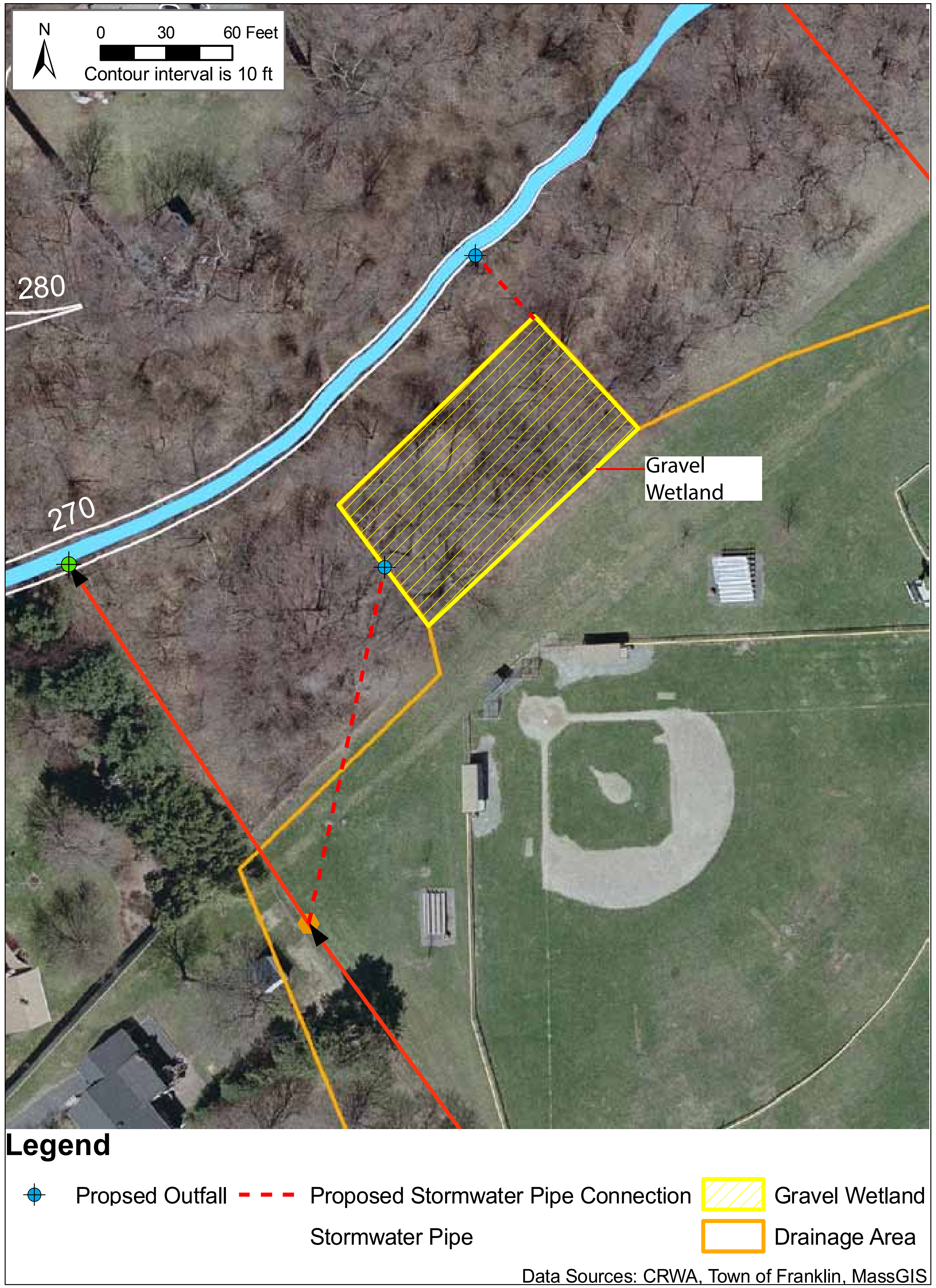

BEFORE: Photo of eastern corner of field.

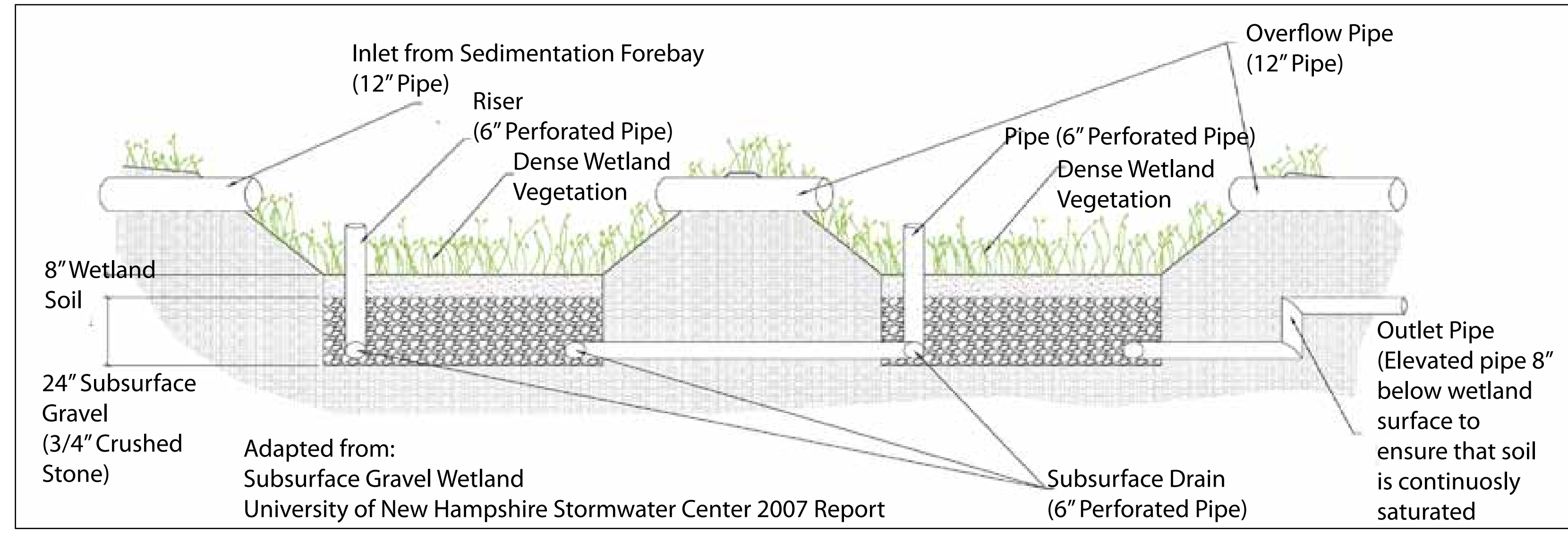

AFTER: Visualization of proposed bioretention area.



OPTION 2 - Includes retaining the configuration of the existing parking lot while constructing a vegetated swale leading to the bioretention area.

Proposed Designs for Drainage Area 4B-3 - Fletcher Field Gravel Wetland





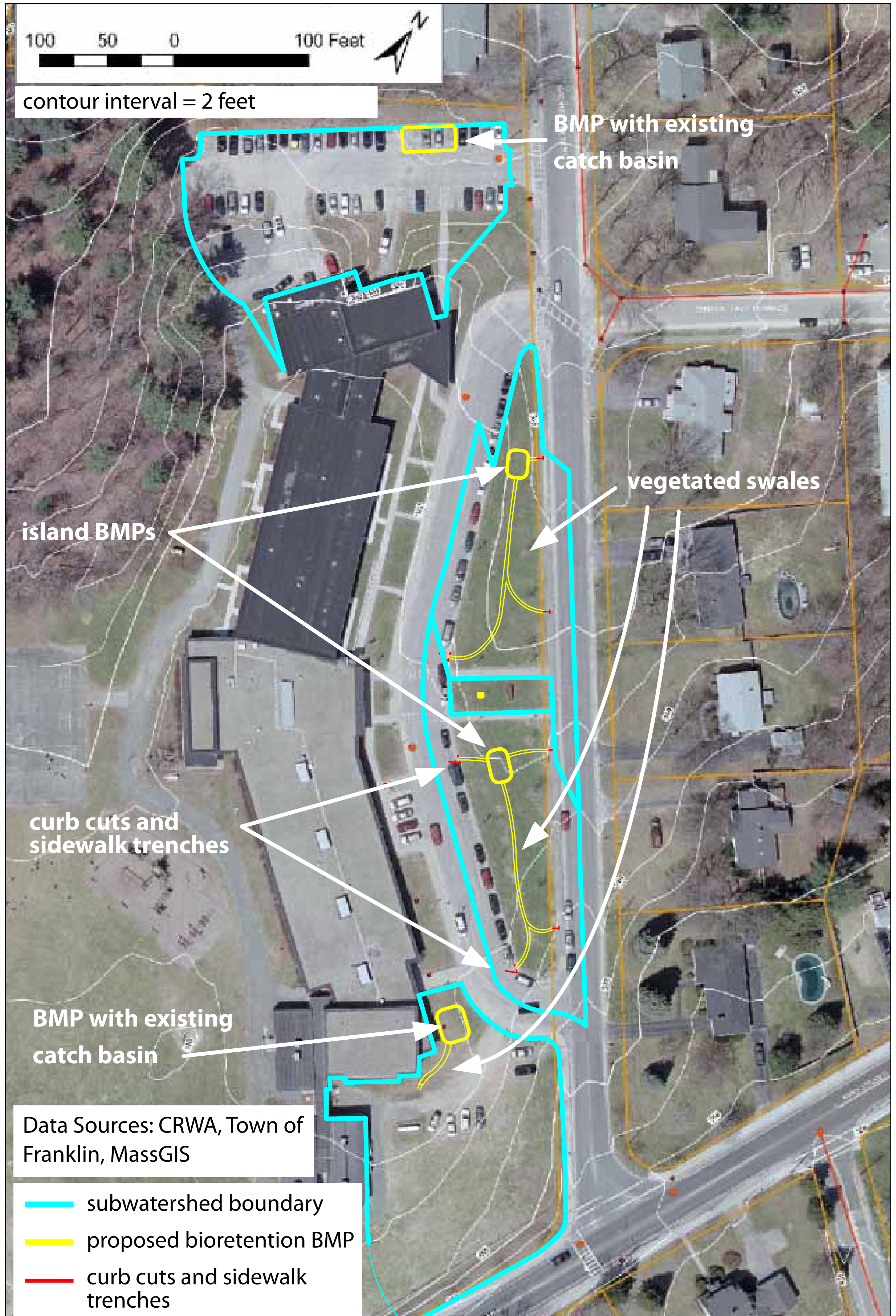
Gravel wetland in use at the University of New Hampshire Stormwater Center.

BMP DESCRIPTION

This site provides the perfect opportunity to construct a gravel wetland that will clean and retain a large volume of water. The system is designed to constantly stay saturated with retention areas which will treat up to a 1" storm. The wetland will also provide habitat for migratory and local birds and a variety of wetland plants.

HORIZONTAL WETLAND SIZING - 1" storm

DRAINAGE AREA TOTAL	1,085,851	sq. ft.
IMPERVIOUS AREA	282,321(26%)	sq. ft.
PERVIOUS AREA	803,530(74%)	sq. ft.
PONDING HEIGHT	2.2	ft.
MEDIA DEPTH	2	ft.
BMP SURFACE AREA	8,570	sq. ft.




BEFORE: Photo of the existing islands in front of the school.


AFTER: Visualization of proposed bioretention areas.

BMP DESCRIPTION

The proposed plan includes bioretention areas that treat the parking lot runoff on the southeast and northwest sides of the school. These systems would include retrofit catch basins used as overflow pipes. The plan also includes bioretention areas in the islands in front of the school which will have overflow pipes installed and tied into existing stormwater pipes. The runoff from the roads surrounding the islands is directed into the bioretention areas through curb cuts and trenches through the sidewalks. Within the islands, the water moves along vegetated swales to get to the bioretention areas.


Source: http://picasaweb.google.com/buildgreeninfrastructure

BIORETENTION SIZING - 1" storm

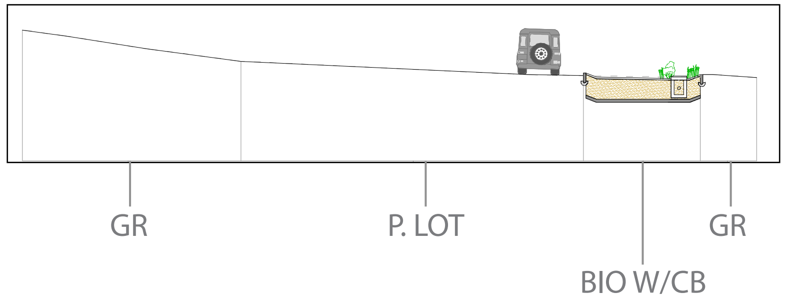
DRAINAGE AREA TOTAL	91,190	sq. ft.
IMPERVIOUS AREA	49,697 (54.5%)	sq. ft.
PERVIOUS AREA	41,494 (45.5%)	sq. ft.
PONDING HEIGHT	0.5	ft.
MEDIA DEPTH	3	ft.
BMP SURFACE AREA	2,416	sq. ft.

Proposed Designs for Drainage Area 4C - Parmenter School

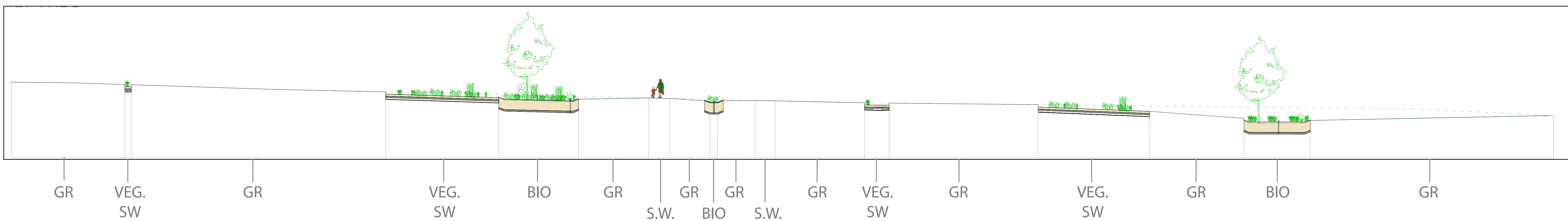
BEFORE: Photo of the existing islands from Wachusett Street.

AFTER: Visualization of proposed trench, swale, and bioretention.

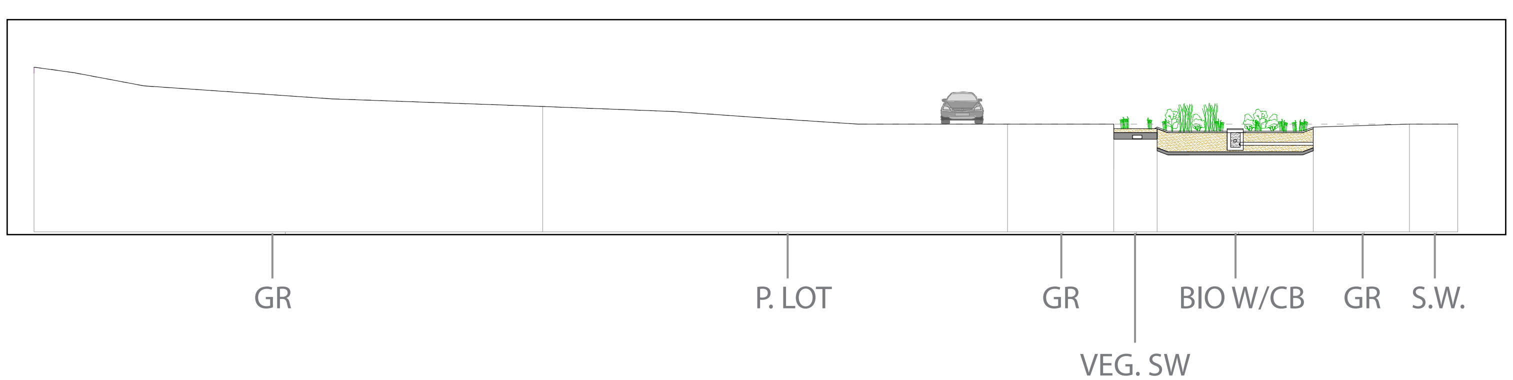
SECTION 1:
NORTHWEST PARKING LOT BIORETENTION AREA



SECTION 2:
ISLANDS IN FRONT OF SCHOOL



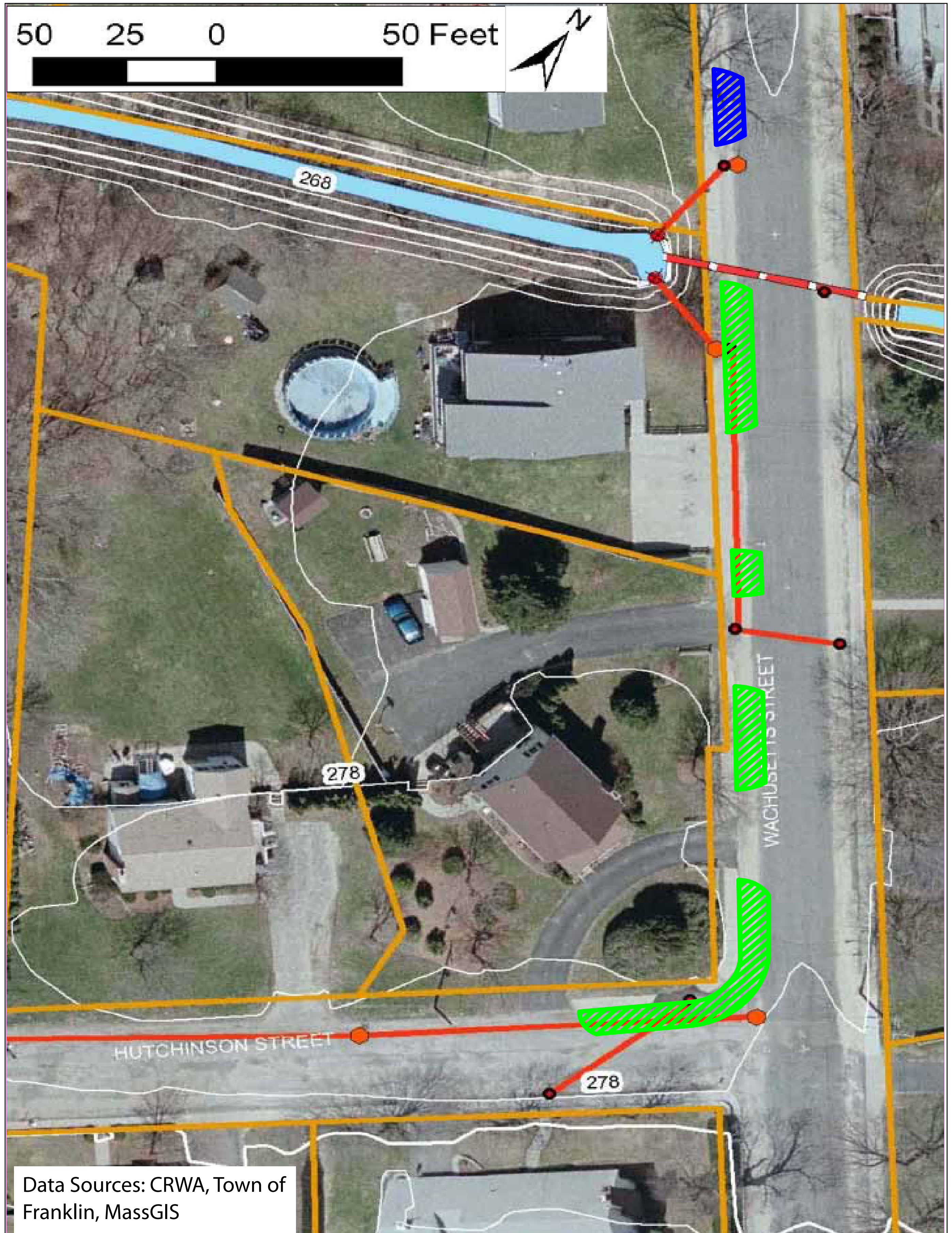
SECTION 3:
SOUTHEAST PARKING LOT BIORETENTION AREA



ABBREVIATIONS

VEG. SW.	VEGETATED SWALE
BIO	BIORETENTION
BIO W/CB	BIORETENTION WITH CATCH BASIN RETROFIT
GR	GRASS
P. LOT	PARKING LOT
S.W.	SIDEWALK

Proposed Designs for Drainage Area 5D-2 - Wachusett Street

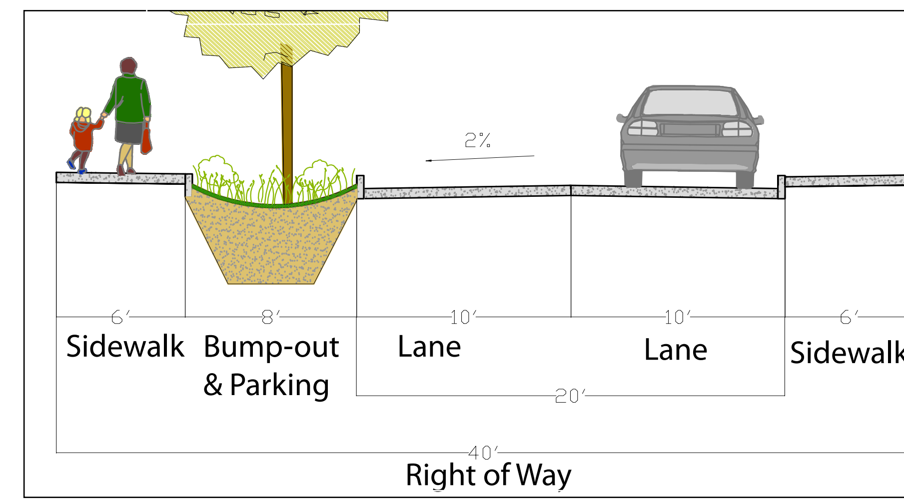


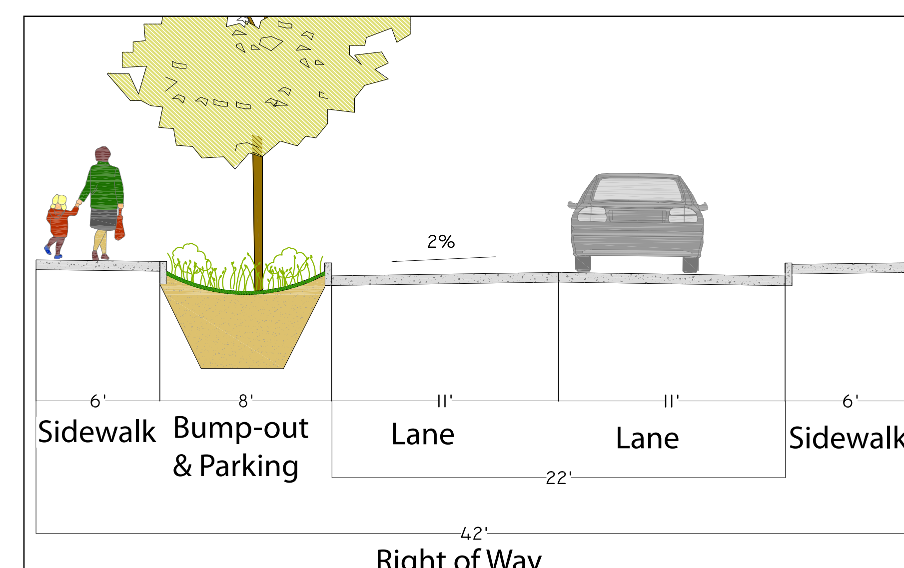
BEFORE: Photo of Wachusett Street.

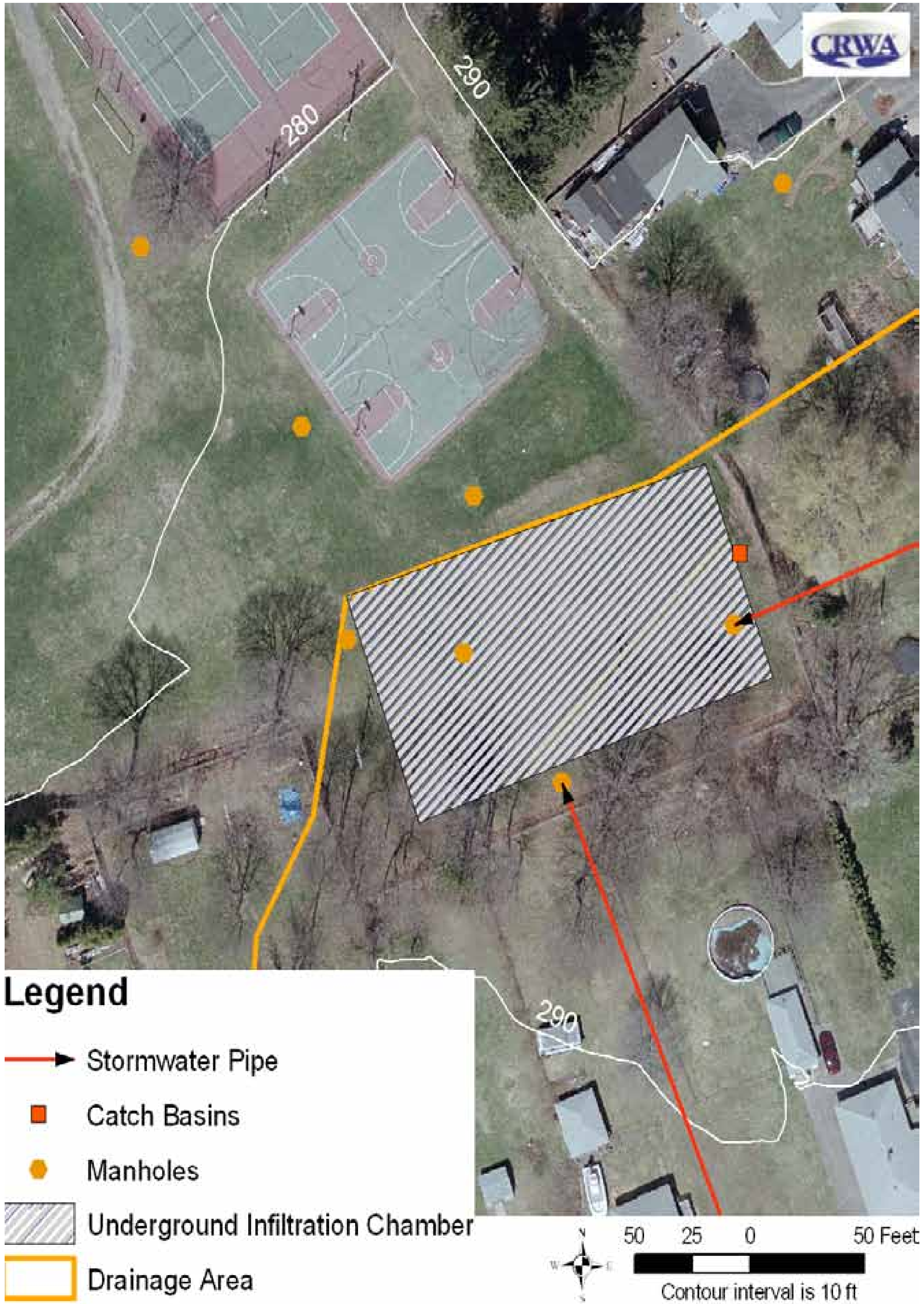
AFTER: Visualization of the proposed bump-outs.

BMP DESCRIPTION

The proposal of street "bump-outs" along Wachusett Street, between Hutchinson and Cottage Streets, will both clean stormwater and improve the aesthetic of the streetscape. The "bump-outs" are designed to capture and treat runoff from up to a 1" storm. The adjoining sections show how the "bump-outs" will be designed to fit within the street right of way which ranges from 40'-42' as the street runs north to south. They would be interspersed with parking spaces along the street.








Underground infiltration chamber. Photo source: Rainstay

Infiltration basin. Photo source: Horsley Witten Group

BMP DESCRIPTION

An underground infiltration trench/ chamber designed to infiltrate a 1" storm. Initially the site was being considered for an above ground bioretention system which would be aesthetically more desirable. However, since the drainage area is too large, and the space is constrained due to the location of a play area right next to the site, an underground trench or chamber is a more feasible option.

INFILTRATION TRENCH SIZING- 1" storm

DRAINAGE AREA TOTAL	1,096,682	sq. ft.
IMPERVIOUS AREA	351,614 (32%)	sq. ft.
PERVIOUS AREA	745,068 (68%)	sq. ft.
MEDIA DEPTH	3	ft.
BMP SURFACE AREA	14,775	sq. ft.

Data Sources: CRWA, Town of Franklin, MassGIS

MODELING ANALYSIS

Methodology

For each of the 49 drainage areas, CRWA calculated the existing phosphorus load in stormwater runoff based on the 2005 land use, impervious areas, and phosphorus loads developed by TetraTech (2009) specifically for the 2005 land use. Sites within the subwatershed with more than two acres of connected impervious cover that are likely to be subject to EPA's new draft stormwater permit were each defined as separate drainage areas. These residually designed or "RDA" sites were all assigned a phosphorus load reduction target of 65% that did not vary in the model runs.

CRWA modeled the six stormwater BMPs listed in the previous section. Phosphorus removal efficiencies were modeled based on annual curves developed by long-term modeling of BMP systems (TetraTech, 2010) using data collected at the University of New Hampshire's Stormwater Center (UNHSC, 2007). Removal efficiencies are based on the volume of water the BMP is designed to treat. The removal efficiency multiplied by the existing load gives the new phosphorus load. The overall phosphorus removal efficiency for Spruce Pond Brook subwatershed was determined and compared to the target value. Construction cost for each BMP was estimated using estimates of unit cost ($/sq. ft. treated) and the runoff volume treated by each BMP.

Optimization used a commercially available genetic algorithm for Excel to minimize the total construction cost by varying individual BMP design storms (measured in inches) with the constraint that the target phosphorus reduction of 42% must be equaled or exceeded. Optimization yields least-cost scenarios using different BMP sizes while still meeting the target phosphorus reduction.

Retrofit Plan Results

CRWA developed two retrofit plans: Scenario 0 and Scenario 2. Scenario 0 was based primarily on CRWA's site assessments and professional judgment regarding selection and location of BMPs. The second, Scenario 2 was developed through a cost optimization run. Preliminary cost estimates of the two scenarios ranged from $2.97-4.92 million dollars.

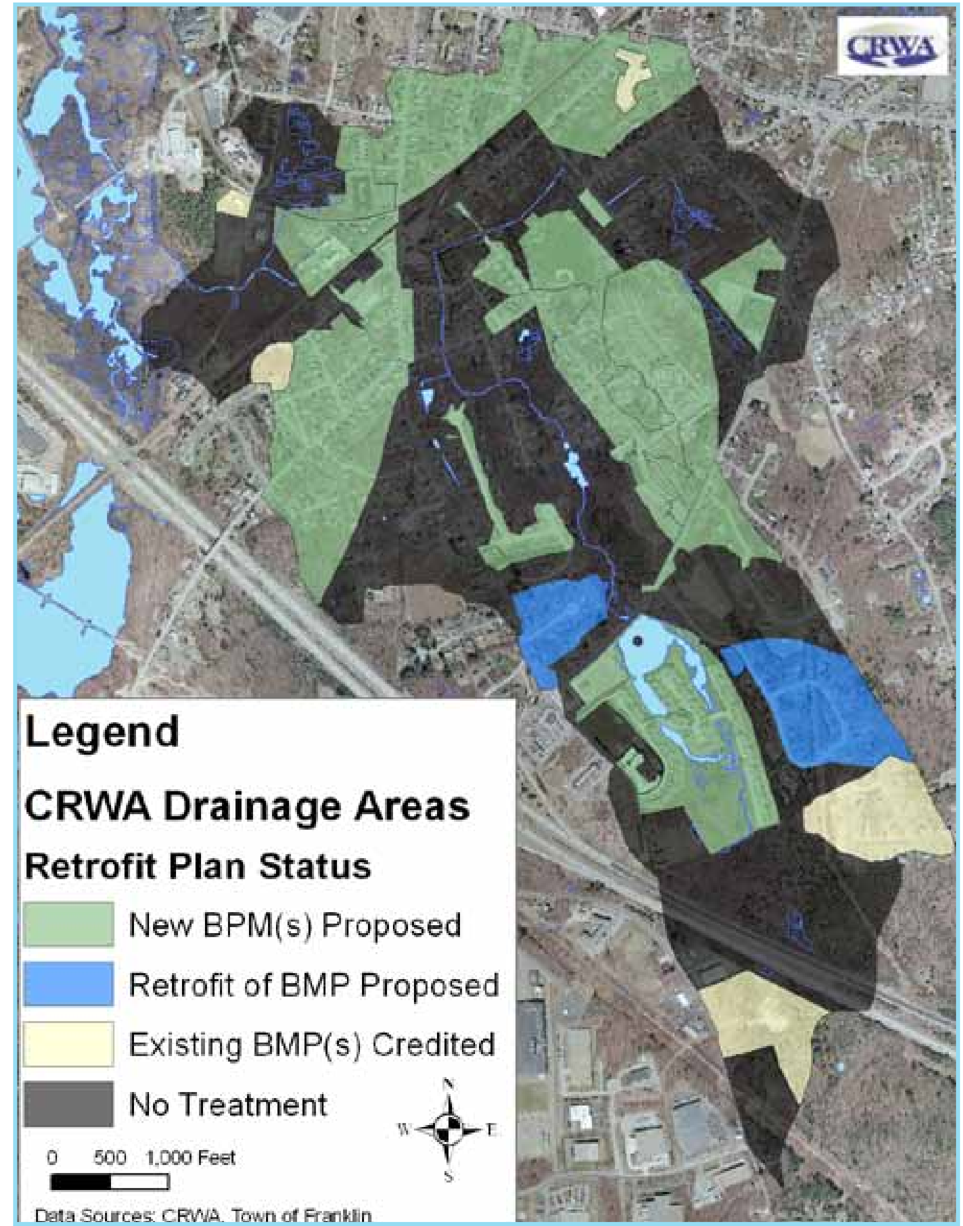


Figure 6. Retrofit plan status for Scenario 0.

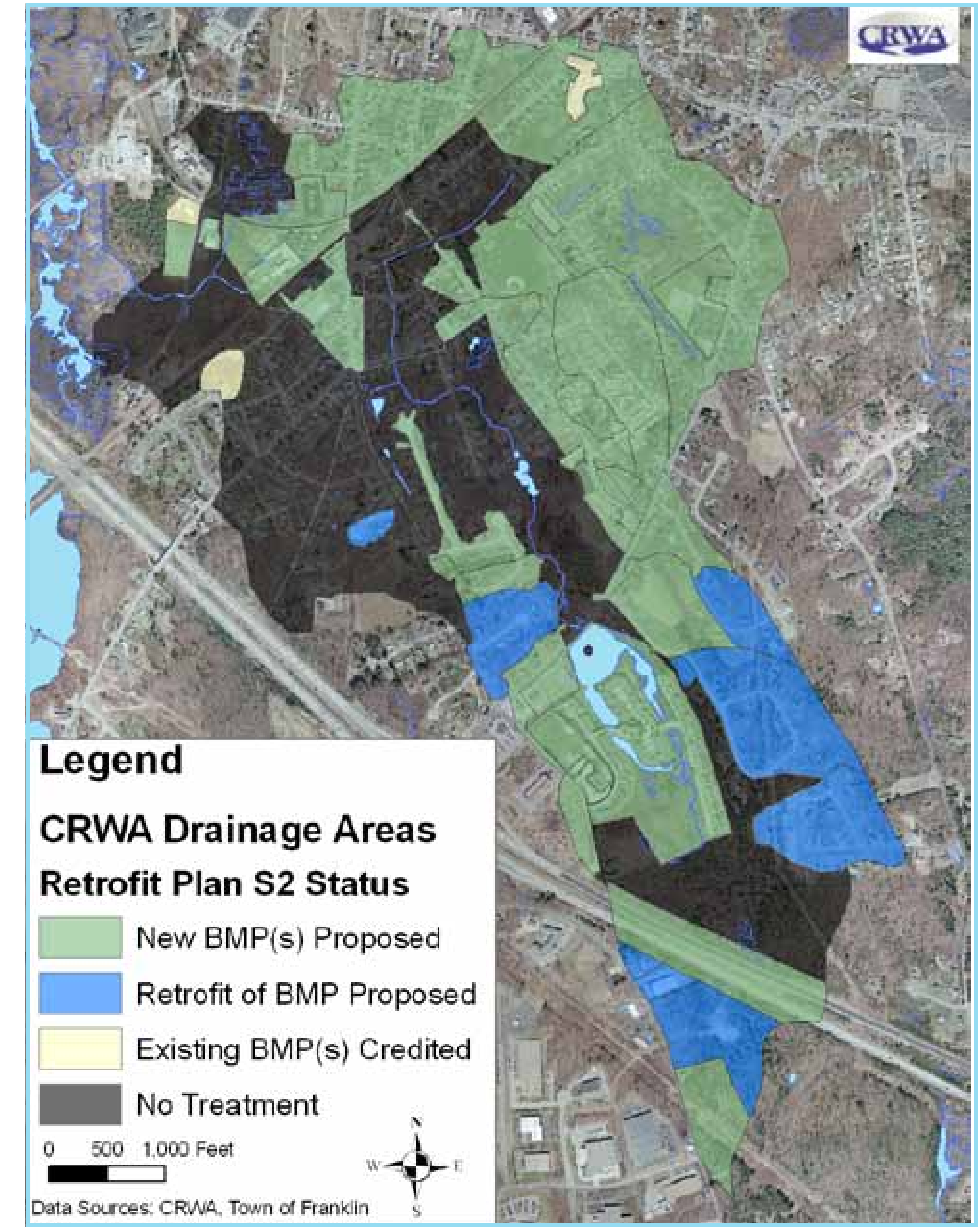


Figure 7. Retrofit plan status for Scenario 2.

Scenario 0: Initial Design Plan

CRWA selected sites and BMP types based on a thorough review of existing drainage, stormwater infrastructure, available land usage, soil conditions, pollutant removal efficiencies, BMP sizing constraints, discussions with Franklin officials, and estimated cost. CRWA targeted large drainage areas where logistical conflicts such as utilities, changes to the stormwater drainage system, land ownership, and space conflicts would be minimal.

The designed retrofit plan results in a 42.1% reduction in the phosphorus load in stormwater runoff with a cost of $4.9 million. Appendix A summarizes the complete results of this plan. Select priority site designs are shown in the previous section.

Scenario 2: Optimized Plan

Scenario 2 was created through a model optimization set to minimize costs while still meeting the target for phosphorus removal. The optimization varied the BMP design storm for the BMPs in each drainage area and lo ked for the best overall combination of BMP treatments. No upper or lower bounds were set on BMP treatment volumes. BMP type for each drainage area was fixed. The optimized retrofit plan results in a 43.8%[4] reduction in the phosphorus load in stormwater runoff at a cost of $2.97 million. Appendix A summarizes the results of this plan.

[4]Scenarios 0 and 2 differ in the consideration of existing BMPs constructed prior to 2000 which slightly affects the reduction target. See Appendix B for details.

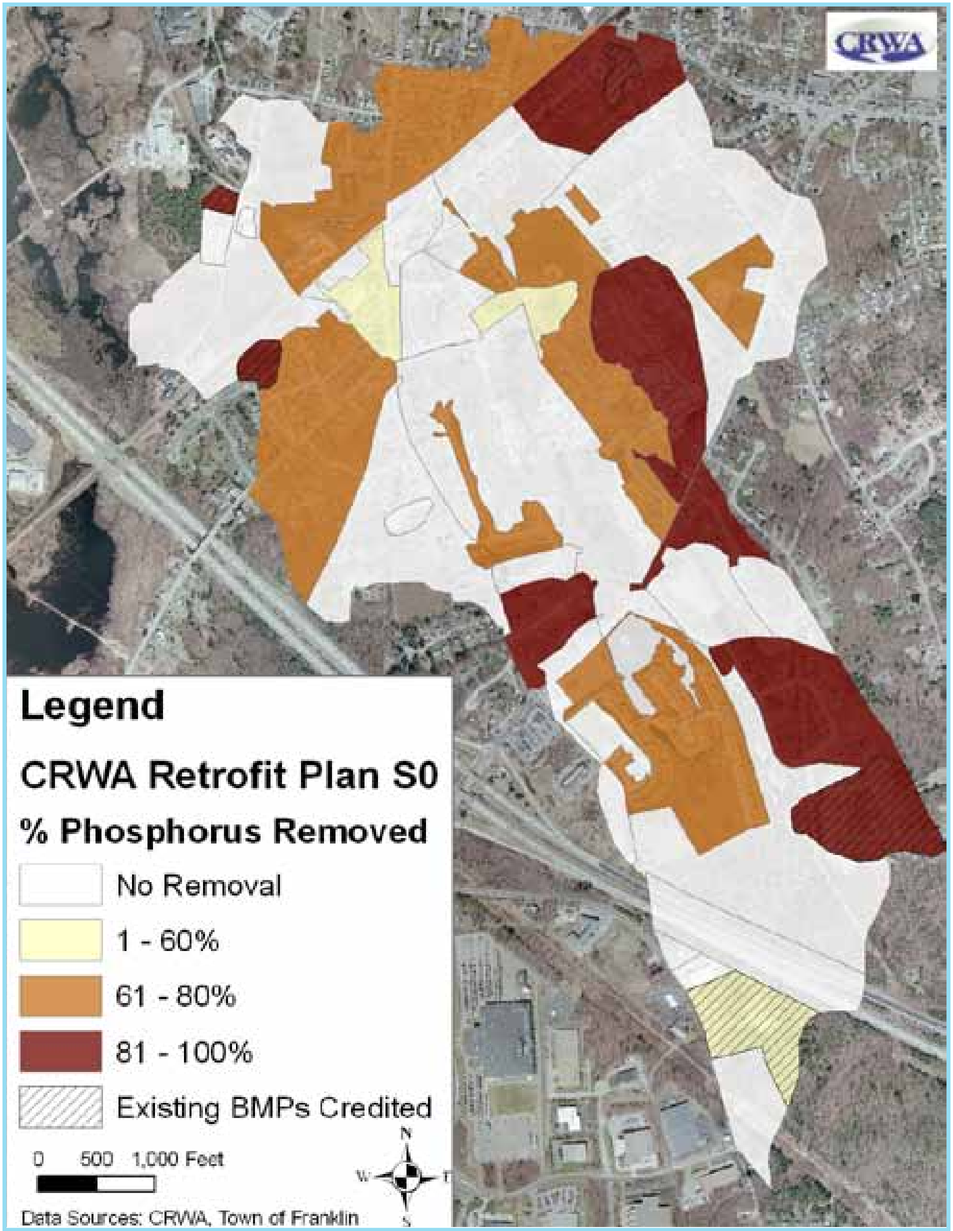


Figure 8. Percentage of phosphorus removed by drainage area in Scenario 0.

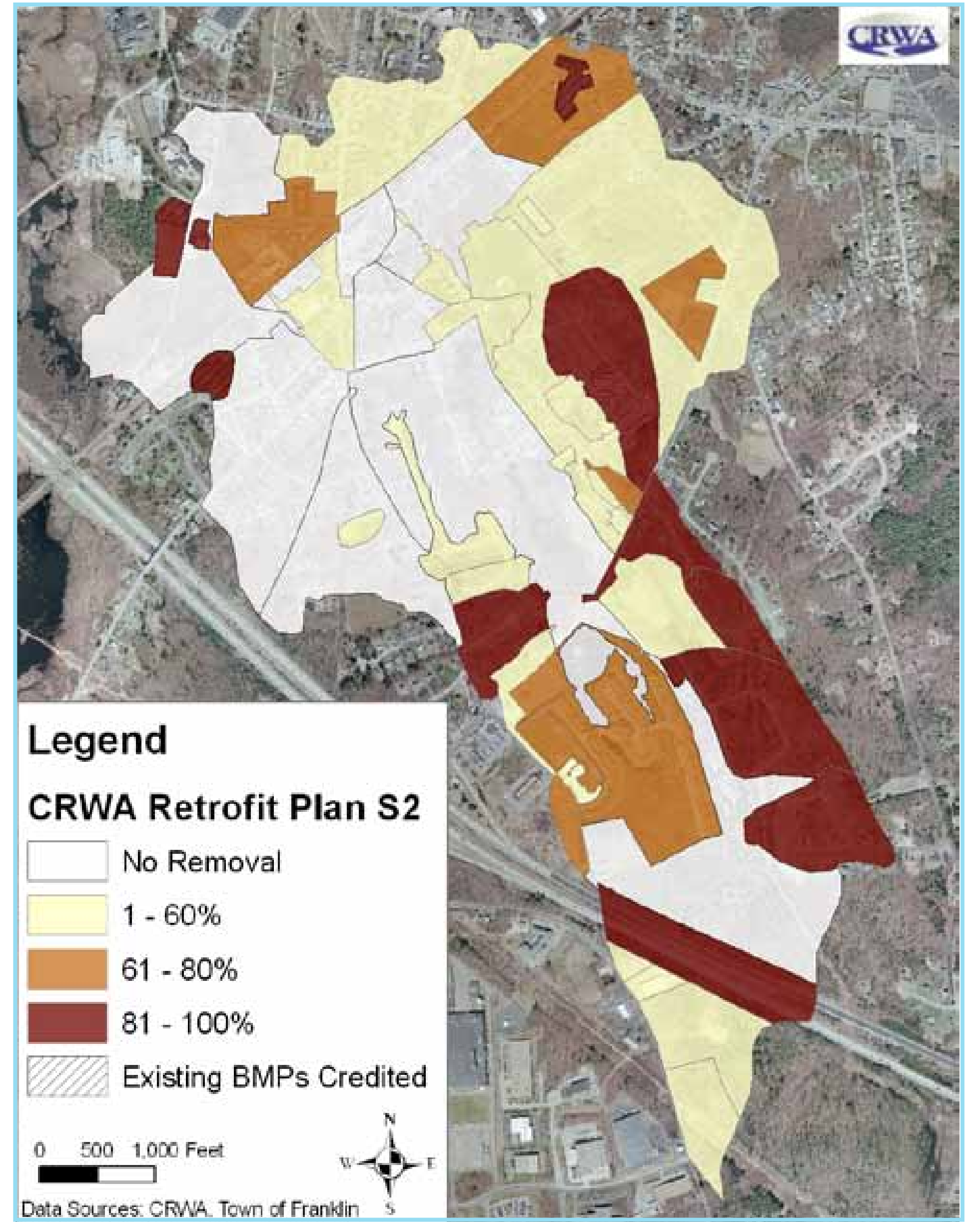


Figure 9. Percentage of phosphorus removed by drainage area in Scenario 2.

Discussion

Scenario 2 differed significantly from Scenario 0 in the number of drainage areas receiving stormwater runoff treatment. Scenario 2 includes more BMP systems than were originally proposed in Scenario 0. Scenario 0 has 21 drainage areas receiving no treatment versus only 8 in Scenario 2. Figures 8 and 9 highlight the fact that Scenario 2 includes many more systems providing phosphorus removal in the low range (<60% removal). In summary, this plan includes more systems treating smaller water quality volumes from more drainage areas. Since most BMPs in the results of Scenario 2 have a smaller treatment volume, they fall on a steeper part of the removal efficiency curve. By employing multiple BMPs, each treating small water quality volumes, the result is greater aggregate phosphorus removal across the subwatershed at a similar overall treatment volume, and a reduced cost per unit of phosphorus removed. This result is also consistent with the general principals of LID in which smaller, onsite systems are encouraged.

IMPLEMENTATION

The Town of Franklin plans to implement many of CRWA's suggested projects in the short term. In the summer of 2010 rain gardens will be constructed at two sites on Fletcher Field (Drainage Areas 4A-3 and 4B-2, see pages 28-29 and 34-35). Rain gardens will also be constructed in front of the Parmenter Elementary School on Wachusett St. (Drainage Area 4C, see pages 37-39). These sites will serve as pilot projects to educate the community about low impact development stormwater management practices and to help Town personnel become familiar with construction and maintenance of these types of systems.

Additional projects will be implemented as funding becomes available either through grant funding or through the Town's capital investment plan.

Proposed stormwater BMP for the Parmenter School.

Proposed green street BMPs for Center Street.

Project team assessing the Parmenter School site.

Project team member observing exixting drainage pattern.

CONCLUSION

This valuable study provides a model for municipalities throughout the Charles River watershed by clearly presenting how a small subwatershed can be brought into compliance with the Upper/Middle Charles River Nutrient TMDL using low impact development stormwater management treatment systems. CRWA's Spruce Pond Brook Stormwater Management Plan identifies multiple opportunity sites where stormwater BMPs can be sited to effectively treat stormwater runoff. Furthermore, the results of our model display how various sites can be designed to work together to achieve TMDL compliance on the subwatershed or watershed scale. By developing this plan and presenting it to the Town, the municipality can act on implementation opportunities as they arise, either through regularly scheduled capital investment projects or grant opportunities.

Next Steps

Moving forward CRWA and the Town of Franklin hope to continue to implement many of the BMP opportunities identified through this study. Additionally, if funding permits CRWA hopes to have the opportunity to revisit and refine our modeling results. In the initial project modeling phase, no lower bound was set on BMP treatment volumes when in reality, it may make sense to set a lower bound for constructed treatment units. CRWA would like the opportunity to run additional model optimizations with varying restraints and see how the outcome is affected. CRWA would also like to run optimizations with the phosphorus reduction goal set higher to explore the maximum, cost-efficient removal target for this subwatershed. Another obvious next step is to expand the scale of this assessment, design and modeling process to produce a town-wide or regional TMDL compliance plan, although currently neither the Town nor CRWA has the funding to conduct this work.

Lessons Learned

CRWA learned many valuable lessons throughout this process.

Coordination. Close coordination and cooperation with Town personnel was essential in making this project a success. CRWA worked hard to build successful working relationships with Town employees in many agencies. Additionally, CRWA met regularly with an advisory committee made up of representatives from planning, conservation, public works, engineering and the Town Administrator. We learned it was essential to be able to clearly explain our goals and process to multiple Town employees to achieve effective buy-in and cooperation from the various departments. Finally, we also had to be open and responsive to suggestions and feedback from the Town.

Importance of site visits. GIS maps were invaluable in this process, however, ground truthing data and conducting site visits were essential elements of our existing conditions assessment and preliminary design work phase.

Look for treatment opportunities wherever possible. The optimized model run reinforced the importance of treating runoff from all areas. Treating a large volume of water from one drainage area does not always compensate for leaving other large areas untreated. Treating the first flush and small storms is a necessary strategy to reduce nutrient loading in the Charles River watershed.

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STORMWATER MANAGEMENT PLAN FOR SPRUCE POND BROOK SUBWATERSHED - APENDICES

Modeling Results- Scenario 0

ID	Name	Total Area (ac)	Total Impervious Area (ac)	Land Use(s)	Existing Phosphorus Load (kg/yr)	RDA Site?	Assigned BMP Type	BMP Design Storm (inches)	Ponding Depth (inches)	Media Depth (feet)	BMP Area (sq. ft.)	BMP Treatment Volume (cu. ft.)	Phosphorus Reduction (%)	Phosphorus Load Removed (kg/yr)	Estimated BMP Cost	Estimated Land Cost	Total Cost	$/lb phosphorus removed	$/acres treated
1A-1	Union Place South	9.74	1.13	Forest, Low and High Density Residential	0.81	No	Infiltration Basin	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
1A-2	Union Place North	14.33	8.05	High Density Residential, Forest	8.74	No	Infiltration Chamber	0.13	N/A	3.50	2,214.0	7,748.8	45.1%	3.95	$45,068.53	$61,136.43	$106,204.96	$12,173.92	$7,412.27
1B	Beaulieu Business Park	2.09	1.47	Industrial, Forest	1.23	No	Infiltration Chamber	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
1C	Elemen-Tree House After School Care Program	1.41	0.40	Industrial, Forest	0.40	No	Infiltration Chamber	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
1D	I-495 East	19.24	7.22	Freeway, Forest	4.95	No	Infiltration Basin	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2A	Upper Spruce Pond	46.04	1.29	Forest, Low Density Residential, Medium Density Residential	2.56	No	None	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2B	Fall Lane	17.27	4.02	Low Density Residential, Forest	2.32	No	Infiltration Basin	1.45	12	N/A	22,785.9	22,785.9	96.7%	2.24	$9,439.79	$0.00	$9,439.79	$1,905.41	$546.47
2C	Lockewood Drive South	24.36	3.42	Forest, Low Density Residential, Medium Density Residential, Commercial	2.57	No	Infiltration Basin	2.00	24	N/A	14,697.5	29,395.0	99.3%	2.55	$62,357.99	$0.00	$62,357.99	$11,058.77	$2,559.82
2D	Spruce Pond Condos	33.57	7.93	High Density Residential, Forest, Commercial	9.79	Yes	Green Street	0.65	9	3.00	10,669.2	40,009.4	65.1%	6.37	$624,145.93	$0.00	$624,145.93	$44,323.72	$18,591.10
2E-1	Boston Sports Club (parking lot)	1.40	0.96	High Density Residential	1.02	No	Bioretention	1.00	9	3.00	1,739.5	6,523.2	75.2%	0.77	$67,840.88	$0.00	$67,840.88	$39,833.53	$48,613.17
2E-2	Boston Sports Club (open area)	4.50	0.95	High Density Residential	1.39	No	Bioretention	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2F-1	Upper Union Street	3.48	0.55	Forest, Commercial	0.60	No	Infiltration Basin	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2F-2	King Street West	4.49	2.16	Medium Density Residential, Commercial, Forest, High Density Residential	2.08	No	Gravel Wetland	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2F-3	King Street South Commercial Area	3.58	2.27	Commercial	2.46	Yes	Gravel Wetland	1.50	26	2.00	4,036.3	16,952.3	64.8%	1.59	$193,740.76	$0.00	$193,740.76	$55,054.14	$54,142.54
2G	Susan's Way	7.76	1.40	Medium Density Residential, Forest	1.43	No	Infiltration Basin	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2H	Lockewood Drive North	12.79	1.37	Forest, Low Density Residential, Medium Density Residential, Agriculture	1.65	No	Green Street	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2I	King Street East	8.79	2.91	Forest, Medium Density Residential, Low Density Residential	2.00	No	Infiltration Basin	0.50	12	N/A	4,951.0	4,951.0	83.3%	1.67	$22,207.63	$0.00	$22,207.63	$6,029.87	$2,527.54
3A	Middle Spruce Pond	69.67	6.46	Forest, Medium Density Residential, Low Density Residential, Commercial	7.33	No	None	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
3B	Odyssey Lane	11.22	2.34	Medium Density Residential, Forest	2.27	No	Infiltration Basin	0.50	12	N/A	4,314.1	4,314.1	83.3%	1.89	$1,935.09	$0.00	$1,935.09	$464.12	$172.43
3C	Loretta Road	4.14	0.84	Medium Density Residential, Forest	0.84	No	Gravel Wetland	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
3D	Chilmark Road	8.37	2.75	Medium Density Residential, Forest, Low Density Residential	2.12	No	Green Street	1.00	9	3.00	5,389.6	20,211.1	75.2%	1.59	$315,292.76	$0.00	$315,292.76	$89,688.06	$37,674.91
3E-1	Upper Union Street/Zachary Way	30.43	6.40	Low Density Residential, Forest, Medium Density Residential, Agriculture	4.86	No	Gravel Wetland	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
3E-2	Zachary Way	1.90	0.70	Low Density Residential	0.36	No	Infiltration Basin	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
3F	Saxon/Cottage/Washington Streets	40.95	10.90	Medium Density Residential, Forest, Low Density Residential	8.57	No	Gravel Wetland	1.00	26	2.00	14,348.6	60,264.1	61.0%	5.23	$430,457.71	$222,475.26	$652,932.97	$56,525.95	$15,943.76
3G-1	Cottage and Union Streets Industrial Area NE (no BMP proposed)	9.25	6.32	Industrial, Medium Density Residential, Commercial, Freeway	5.36	No	Green Street	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
3G-2	Cottage and Union Streets Industrial Area SW (BMP proposed)	8.48	6.30	Commercial, Medium Density Residential, Industrial	5.69	No	Green Street	0.17	6	3.00	2,212.7	7,744.4	29.7%	1.69	$112,846.34	$0.00	$112,846.34	$30,170.74	$13,307.18
3I	A Street Extention	2.72	0.67	Forest, Medium Density Residential	0.39	No	Infiltration Basin	2.00	12	N/A	3,088.3	3,088.3	100.0%	0.39	$21,545.01	$0.00	$21,545.01	$24,905.16	$7,914.87
4A-1	SE Fletcher Field (Park Street FHA/Peck Street)	25.18	8.07	Medium Density Residential, High Density Residential, Forest, Low Density Residential	7.94	No	Infiltration Chamber	1.00	N/A	3.00	14,775.4	44,326.1	98.8%	7.84	$464,108.27	$0.00	$464,108.27	$26,777.28	$18,434.29
4A-2	Winter/Summer/King/Lower Peck St @ NE Fletcher Field	64.02	14.22	Medium Density Residential, Forest, Commercial, Low Density Residential	12.85	No	Gravel Wetland	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
4A-3	Fletcher Field Large Parking Lot	0.95	0.76	Low Density Residential	0.32	No	Bioretention	1.00	6	3.00	1,568.1	5,488.2	75.2%	0.24	$39,985.60	$0.00	$39,985.60	$75,047.18	$42,002.47
4B-1	Franklin Housing Authority Development on Wachusett Street	3.93	1.23	Medium and High Density Residential	1.14	No	Bioretention	1.00	9	3.00	2,431.5	9,118.1	75.2%	0.86	$71,121.06	$0.00	$71,121.06	$37,554.40	$18,104.18
4B-2	Fletcher Field Small Parking Lot and Lower Wachusett/Arlington Streets	5.82	1.93	Medium Density Residential, Forest, Low Density Residential	1.58	No	Bioretention	0.50	6	3.00	2,165.7	7,579.9	58.1%	0.92	$55,225.13	$0.00	$55,225.13	$27,264.49	$9,492.11
4B-3	NW Fletcher Field (Upper Wachusett Street)	24.93	6.43	Medium Density Residential, Low Density Residential, Commercial, Forest, High Density Residential	6.39	No	Gravel Wetland	1.00	26	2.00	8,507.4	35,730.9	61.0%	3.90	$255,220.76	$0.00	$255,220.76	$29,624.69	$10,238.44
4C-1	Parmenter Elementary School (building and lawn area)	2.09	1.14	Commercial, Low Density Residential	1.22	No	Bioretention	1.00	6	3.00	2,416.0	8,456.1	75.2%	0.92	$61,608.52	$0.00	$61,608.52	$30,332.50	$29,429.17
4C-2	Parmenter Elementary School (roadway)	1.89	0.53	Medium Density Residential	0.49	No	Infiltration Chamber	1.00	N/A	4.00	1,075.9	4,303.4	95.4%	0.47	$37,208.36	$0.00	$37,208.36	$35,697.63	$19,656.89
4D	Claremont Condominiums	7.52	2.37	Commercial, Forest	2.84	Yes	Bioretention	0.65	9	3.00	3,037.1	11,389.0	65.1%	1.85	$74,028.83	$0.00	$74,028.83	$18,086.64	$9,847.33
4G	Hutchinson Street	11.29	3.06	Medium Density Residential, Commercial, Forest, High Density Residential	2.91	No	Gravel Wetland	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
5A	Pisani Field	19.61	8.58	Commercial, Medium Density Residential, Low Density Residential, Freeway	8.71	No	Infiltration Chamber	1.00	N/A	4.00	15,031.8	60,127.1	97.5%	8.50	$568,343.11	$0.00	$568,343.11	$30,272.73	$28,989.67
5B	Franklin Center Commons	2.30	1.79	Commercial	1.86	No	Infiltration Chamber	0.67	N/A	1.80	4,516.0	8,128.8	89.5%	1.67	$50,473.18	$0.00	$50,473.18	$13,699.87	$21,936.11
5C	East Street	31.73	12.91	Medium Density Residential, Commercial, Forest, Freeway, High Density Residential	11.15	No	Gravel Wetland	1.00	26	2.00	15,978.9	67,111.5	61.0%	6.80	$479,367.66	$0.00	$479,367.66	$31,894.44	$15,105.79
5D-1	Middle Cottage Street	21.86	4.74	Medium Density Residential, Forest, Freeway, Low Density Residential, Commercial	4.42	No	Gravel Wetland	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
5D-2	Lower Wachusetts Street	3.37	1.52	Medium Density Residential	1.14	No	Green Street	1.00	9	3.00	2,863.5	10,738.0	75.2%	0.86	$167,512.91	$0.00	$167,512.91	$88,400.07	$49,744.75
5E	Franklin Landing Housing Complex	4.94	2.94	High Density Residential, Forest, Freeway	2.98	Yes	Bioretention	0.65	9	3.00	3,502.0	13,132.6	65.1%	1.94	$136,578.83	$0.00	$136,578.83	$31,851.60	$27,664.96
5F	Mill Shops on Union Street	6.60	2.96	Industrial, Forest, Freeway	2.53	Yes	Bioretention	0.65	9	3.00	3,625.7	13,596.4	65.1%	1.65	$141,402.74	$0.00	$141,402.74	$38,876.34	$21,414.01
5G	Franklin Paint Company	3.40	2.66	Industrial, Forest, Freeway	2.13	Yes	Bioretention	0.65	9	3.00	3,097.2	11,614.5	65.1%	1.38	$120,791.25	$0.00	$120,791.25	$39,492.71	$35,563.61
5H	Lower Spruce Pond	44.93	4.99	Forest, Medium Density Residential, Industrial, Freeway, Commercial	5.27	No	None	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
5I-1	Franklin DPW Upper	1.23	0.54	Industrial	0.52	No	Infiltration Basin	1.00	36	N/A	529.0	1,587.0	98.8%	0.51	$7,922.37	$0.00	$7,922.37	$6,979.35	$6,421.47
5I-2	Franklin DPW Lower	2.50	0.07	Commercial, Industrial	0.36	No	Infiltration Basin	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
5J	Musto Carlo Paving Company	0.84	0.64	Industrial	0.54	No	Infiltration Basin	0.00	N/A	N/A	N/A	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total		**692.89**	**175.27**		**163.1**								**43.1%**	**70.23**	**$4,637,777.02**	**$283,611.70**	**$4,921,388.71**		

Modeling Results- Scenario 2

Site ID	Site Name	Total Area (ac)	Total Impervious Area (ac)	Land Use(s)	Existing Phosphorus Load (kg/yr)	RDA Site?	Assigned BMP Type	BMP Design Storm (inches)	Ponding Depth (inches)	Media Depth (feet)	BMP Area (sq. ft.)	BMP Treatment Volume (cu. ft.)	Phosphorus Reduction (%)	Phosphorus Load Removed (kg/yr)	Estimated BMP Cost	Estimated Land Cost	Total Cost	$/lb phosphorus removed	$/acres treated
1A-1	Union Place South	9.74	1.13	Forest, Low and High Density Residential	0.81	No	Infiltration Basin	0.26	24	N/A	662.7	1,325.3	64.0%	0.52	$5,623.13	$14,759.42	$20,382.55	$17,722.28	$2,093.10
1A-2	Union Place North	14.33	8.05	High Density Residential, Forest	8.74	No	Infiltration Chamber	0.20	N/A	3.5	3,388.4	11,859.4	57.9%	5.06	$68,976.12	$92,986.33	$161,962.45	$14,475.06	$11,303.70
1B	Beaulieu Business Park	2.09	1.47	Industrial, Forest	1.23	No	Infiltration Chamber	0.21	N/A	2.0	1,056.5	2,113.0	59.0%	0.73	$25,898.27	$0.00	$25,898.27	$16,135.28	$12,364.20
1C	Elemen-Tree House After School Care Program	1.41	0.40	Industrial, Forest	0.40	No	Infiltration Chamber	0.30	N/A	2.0	452.3	904.7	68.1%	0.27	$11,088.22	$0.00	$11,088.22	$18,652.30	$7,853.70
1D	I-495 East	19.24	7.22	Freeway, Forest	4.95	No	Infiltration Basin	0.71	24	N/A	9,110.4	18,220.7	90.5%	4.48	$77,306.30	$0.00	$77,306.30	$7,807.27	$4,019.04
2A	Upper Spruce Pond	46.04	1.29	Forest, Low Density Residential, Medium Density Residential	2.56	No	None	N/A	N/A	N/A	0.0	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2B	Fall Lane	17.27	4.02	Low Density Residential, Forest	2.32	No	Infiltration Basin	1.71	12	N/A	26,860.9	26,860.9	97.8%	2.27	$11,128.02	$0.00	$11,128.02	$2,220.59	$644.20
2C	Lockewood Drive South	24.36	3.42	Forest, Low Density Residential, Medium Density Residential, Commercial	2.57	No	Infiltration Basin	0.93	24	N/A	6,820.1	13,640.2	94.4%	2.42	$28,936.04	$0.00	$28,936.04	$5,400.70	$1,187.83
2D	Spruce Pond Condos	33.57	7.93	High Density Residential, Forest, Commercial	9.79	Yes	Green Street	0.65	9	3.0	10,669.2	40,009.4	65.1%	6.37	$624,145.93	$0.00	$624,145.93	$44,323.72	$18,591.10
2E-1	Boston Sports Club (parking lot)	1.40	0.96	High Density Residential	1.02	No	Bioretention	0.39	9	3.0	681.1	2,554.3	52.0%	0.53	$26,564.22	$0.00	$26,564.22	$22,553.21	$19,035.29
2E-2	Boston Sports Club (open area)	4.50	0.95	High Density Residential	1.39	No	Bioretention	0.60	9	3.0	1,204.2	4,515.9	63.4%	0.88	$29,353.58	$0.00	$29,353.58	$15,070.20	$6,524.91
2F-1	Upper Union Street	3.48	0.55	Forest, Commercial	0.60	No	Infiltration Basin	0.43	24	N/A	510.6	1,021.2	74.1%	0.44	$4,157.76	$11,381.53	$15,539.29	$15,918.59	$4,470.30
2F-2	King Street West	4.49	2.16	Medium Density Residential, Commercial, Forest, High Density Residential	2.08	No	Gravel Wetland	0.39	26	2.0	1,034.8	4,346.4	41.2%	0.86	$24,836.30	$17,252.75	$42,089.06	$22,206.24	$9,380.44
2F-3	King Street South Commercial Area	3.58	2.27	Commercial	2.46	Yes	Gravel Wetland	1.50	26	2.0	4,036.3	16,952.3	64.8%	1.59	$193,740.76	$0.00	$193,740.76	$55,054.14	$54,142.54
2G	Susan's Way	7.76	1.40	Medium Density Residential, Forest	1.43	No	Infiltration Basin	0.98	24	N/A	2,875.8	5,751.7	92.1%	1.32	$23,417.54	$0.00	$23,417.54	$8,040.43	$3,017.93
2H	Lockewood Drive North	12.79	1.37	Forest, Low Density Residential, Medium Density Residential, Agriculture	1.65	No	Green Street	0.15	9	3.0	534.3	2,003.5	27.3%	0.45	$23,441.39	$0.00	$23,441.39	$23,475.12	$1,833.03
2I	King Street East	8.79	2.91	Forest, Medium Density Residential, Low Density Residential	2.00	No	Infiltration Basin	0.75	12	N/A	7,397.5	7,397.5	91.3%	1.83	$33,181.59	$0.00	$33,181.59	$8,217.61	$3,776.52
3A	Middle Spruce Pond	69.67	6.46	Forest, Medium Density Residential, Low Density Residential, Commercial	7.33	No	None	N/A	N/A	N/A	0.0	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
3B	Odyssey Lane	11.22	2.34	Medium Density Residential, Forest	2.27	No	Infiltration Basin	1.82	12	N/A	15,673.5	15,673.5	99.0%	2.24	$7,030.40	$0.00	$7,030.40	$1,418.55	$626.48
3C	Loretta Road	4.14	0.84	Medium Density Residential, Forest	0.84	No	Gravel Wetland	0.54	26	2.0	630.9	2,649.7	48.3%	0.40	$18,926.59	$0.00	$18,926.59	$21,181.05	$4,573.80
3D	Chilmark Road	8.37	2.75	Medium Density Residential, Forest, Low Density Residential	2.12	No	Green Street	0.03	9	3.0	187.7	704.0	6.9%	0.15	$10,982.90	$0.00	$10,982.90	$34,063.34	$1,312.37
3E-1	Upper Union Street/Zachary Way	30.43	6.40	Low Density Residential, Forest, Medium Density Residential, Agriculture	4.86	No	Gravel Wetland	N/A	N/A	N/A	0.0	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
3E-2	Zachary Way	1.90	0.70	Low Density Residential	0.36	No	Infiltration Basin	0.20	24	N/A	192.7	385.4	72.3%	0.26	$3,172.48	$4,302.23	$7,474.71	$13,159.44	$3,941.06
3F	Saxon/Cottage/Washington Streets	40.95	10.90	Medium Density Residential, Forest, Low Density Residential	8.57	No	Gravel Wetland	N/A	N/A	N/A	0.0	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
3G-1	Cottage and Union Streets Industrial Area NE (no BMP proposed)	9.25	6.32	Industrial, Medium Density Residential, Commercial, Freeway	5.36	No	Green Street	N/A	N/A	N/A	0.0	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$42,235.79	$0.03
3G-2	Cottage and Union Streets Industrial Area SW (BMP proposed)	8.48	6.30	Commercial, Medium Density Residential, Industrial	5.69	No	Green Street	0.10	6	3.0	1,274.2	4,459.5	19.4%	1.10	$64,981.93	$0.00	$64,981.93	$26,657.10	$7,662.86
3I	A Street Extention	2.72	0.67	Forest, Medium Density Residential	0.39	No	Infiltration Basin	0.53	12	N/A	820.5	820.5	93.8%	0.37	$5,724.33	$0.00	$5,724.33	$7,055.50	$2,102.92
4A-1	SE Fletcher Field (Park Street FHA/Peck Street)	25.18	8.07	Medium Density Residential, High Density Residential, Forest, Low Density Residential	7.94	No	Infiltration Chamber	0.40	N/A	3.0	5,895.2	17,685.5	90.1%	7.15	$185,173.25	$0.00	$185,173.25	$11,723.71	$7,355.04
4A-2	Winter/Summer/King/Lower Peck St @ NE Fletcher Field	64.02	14.22	Medium Density Residential, Forest, Commercial, Low Density Residential	12.85	No	Gravel Wetland	0.50	26	2.0	9,760.5	40,994.1	46.5%	5.97	$292,814.77	$0.00	$292,814.77	$22,181.61	$4,573.80
4A-3	Fletcher Field Large Parking Lot	0.95	0.76	Low Density Residential	0.32	No	Bioretention	0.14	6	3.0	217.3	760.6	25.3%	0.08	$5,541.57	$0.00	$5,541.57	$30,939.28	$5,821.08
4B-1	Franklin Housing Authority Development on Wachusett Street	3.93	1.23	Medium and High Density Residential	1.14	No	Bioretention	0.40	9	3.0	974.0	3,652.4	52.8%	0.60	$28,488.69	$0.00	$28,488.69	$21,412.74	$7,251.92
4B-2	Fletcher Field Small Parking Lot and Lower Wachusett/Arlington Streets	5.82	1.93	Medium Density Residential, Forest, Low Density Residential	1.58	No	Bioretention	0.23	6	3.0	986.2	3,451.8	36.6%	0.58	$25,148.94	$0.00	$25,148.94	$19,707.71	$4,322.61
4B-3	NW Fletcher Field (Upper Wachusett Street)	24.93	6.43	Medium Density Residential, Low Density Residential, Commercial, Forest, High Density Residential	6.39	No	Gravel Wetland	0.45	26	2.0	3,800.5	15,962.0	43.8%	2.80	$114,014.32	$0.00	$114,014.32	$18,432.76	$4,573.80
4C-1	Parmenter Elementary School (building and lawn area)	2.09	1.14	Commercial, Low Density Residential	1.22	No	Bioretention	0.46	6	3.0	1,102.8	3,859.7	55.8%	0.68	$28,120.34	$0.00	$28,120.34	$18,661.26	$13,432.53
4C-2	Parmenter Elementary School (roadway)	1.89	0.53	Medium Density Residential	0.49	No	Infiltration Chamber	0.40	N/A	4.0	430.6	1,722.6	78.7%	0.39	$14,893.55	$0.00	$14,893.55	$17,331.58	$7,868.14
4D	Claremont Condominiums	7.52	2.37	Commercial, Forest	2.84	Yes	Bioretention	0.65	9	3.0	3,037.1	11,389.0	65.1%	1.85	$74,028.83	$0.00	$74,028.83	$18,086.64	$9,847.33
4G	Hutchinson Street	11.29	3.06	Medium Density Residential, Commercial, Forest, High Density Residential	2.91	No	Gravel Wetland	N/A	N/A	N/A	0.0	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
5A	Pisani Field	19.61	8.58	Commercial, Medium Density Residential, Low Density Residential, Freeway	8.71	No	Infiltration Chamber	0.40	N/A	4.0	5,967.7	23,870.9	84.1%	7.33	$225,636.49	$0.00	$225,636.49	$13,937.36	$11,509.12
5B	Franklin Center Commons	2.30	1.79	Commercial	1.86	No	Infiltration Chamber	0.60	N/A	1.8	4,035.5	7,263.9	87.8%	1.64	$45,103.31	$0.00	$45,103.31	$12,478.31	$19,602.31
5C	East Street	31.73	12.91	Medium Density Residential, Commercial, Forest, Freeway, High Density Residential	11.15	No	Gravel Wetland	0.39	26	2.0	6,198.8	26,034.8	40.7%	4.54	$185,962.53	$0.00	$185,962.53	$18,540.95	$5,860.03
5D-1	Middle Cottage Street	21.86	4.74	Medium Density Residential, Forest, Freeway, Low Density Residential, Commercial	4.42	No	Gravel Wetland	N/A	N/A	N/A	0.0	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
5D-2	Lower Wachusetts Street	3.37	1.52	Medium Density Residential	1.14	No	Green Street	0.10	9	3.0	293.5	1,100.7	20.2%	0.23	$17,170.44	$0.00	$17,170.44	$33,807.58	$5,098.94
5E	Franklin Landing Housing Complex	4.94	2.94	High Density Residential, Forest, Freeway	2.98	Yes	Bioretention	0.65	9	3.0	3,502.0	13,132.6	65.1%	1.94	$136,578.83	$0.00	$136,578.83	$31,851.60	$27,664.96
5F	Mill Shops on Union Street	6.60	2.96	Industrial, Forest, Freeway	2.53	Yes	Bioretention	0.65	9	3.0	3,625.7	13,596.4	65.1%	1.65	$141,402.74	$0.00	$141,402.74	$38,876.34	$21,414.01
5G	Franklin Paint Company	3.40	2.66	Industrial, Forest, Freeway	2.13	Yes	Bioretention	0.65	9	3.0	3,097.2	11,614.5	65.1%	1.38	$120,791.25	$0.00	$120,791.25	$39,492.71	$35,563.61
5H	Lower Spruce Pond	44.93	4.99	Forest, Medium Density Residential, Industrial, Freeway, Commercial	5.27	No	None	N/A	N/A	N/A	0.0	0.0	0.0%	0.00	$0.00	$0.00	$0.00	$0.00	$0.00
5I-1	Franklin DPW Upper	1.23	0.54	Industrial	0.52	No	Infiltration Basin	0.81	36	N/A	427.0	1,280.9	98.0%	0.51	$6,394.52	$0.00	$6,394.52	$5,680.44	$5,183.07
5I-2	Franklin DPW Lower	2.50	0.07	Commercial, Industrial	0.36	No	Infiltration Basin	0.96	36	N/A	172.6	517.8	98.6%	0.36	$2,584.74	$0.00	$2,584.74	$3,268.25	$1,032.84
5J	Musto Carlo Paving Company	0.84	0.64	Industrial	0.54	No	Infiltration Basin	1.67	24	N/A	1,373.1	2,746.3	100.0%	0.54	$1,507.19	$0.00	$1,507.19	$1,269.09	$1,787.69

Total		692.89	175.27		163.1								45.8%	74.75	$2,973,970.07	$140,682.27	$3,114,652.34		
Total Excluding Existing Pre-		692.89	175.27		163.1								44.0%	71.70					

APPENDIX B: TECHNICAL INFORMATION

Calculating Existing Phosphorus Loads for Modeling Analysis

New phosphorus unit loads were developed by TetraTech (2009) specifically for the 2005 land use. Although these new export coefficients were slightly different from the Upper/Middle Charles TMDL coefficients (CRWA, 2009), which were based on the 1999 land use data, they preserve the total calibrated stormwater TMDL load. Our project ignored small variations in phosphorus loading across soil types. The land-use based export coefficients, multiplied by the pervious and impervious areas within each drainage area, yielded the estimated total phosphorus load for the Spruce Pond sub-basin under existing conditions.

Treatment of Existing BMPs in Modeling Analysis

Drainage areas with existing BMPs were classified by the year in which they were constructed. BMPs constructed prior to 2000 were considered part of the TMDL "base conditions" and were given no phosphorus removal credit in the initial plan (Scenario 0). For the five BMPs constructed after 2000, the credit was estimated based on the existing BMP design. In modeling Scenario 0, existing BMPs were fixed, either at 0% removal, for structures built pre-2000, or at their estimated existing removal value, for structures built after 2000. In Scenario 2, the optimization scenario, existing BMPs were allowed to vary in the same manner as proposed BMPs. In fact, they also had no lower bound set on them so these systems were even allowed to get smaller, which is an unlikely real world scenario. Due to the fact that in Scenario 2 all BMPs, including those constructed pre-2000, were considered part of the stormwater treatment system CRWA had to calculate an estimated removal value for existing systems constructed pre-2000 which could then be subtracted out of the Scenario 2 results. The current real impact of these systems was estimated to be 1.9% phosphorus reduction across the subwatershed. Therefore, although Scenario 2 has a greater overall removal, it also has more units available to contribute to p removal.

BMP Sizing

The physical area of the BMPs was determined as the maximum of two area calculations (A1 and A2, see Table 3). The gravel wetland area was determined as the maximum of the area from a common sizing formula based on drainage area and the area required to store the entire design volume (drainage area x design depth). Similarly, the bioretention system area was determined as the maximum of the area from a common sizing formula based on Darcy's Law and the area required to store the entire design volume. For infiltration systems, area was determined using the Massachusetts Static Method (MA-DEP, 1999) (area required to store the design volume allowing for two hours of infiltration) and an area that allows a three-day drainage recovery time. Green streets were modeled as bioretention areas while rain gardens used a shallow infiltration basin design with a one-day recovery time. The maximum area determined the final physical treatment volume of the BMP.

Table 3. BMP Sizing Formulas

BMP	Drain Time (days)	Porosity (-)	Area (A1)	S	Area (A2)	S
Bioretention	2	0.4	WQD * DA / (Dw+Dm*n)	1	WQD * DA * [Dm/ { Ksat* (0.5*Dw+Dm) *T }]	3
Green Streets	2	0.4	WQD * DA / (Dw+Dm*n)	1	WQD * DA * [Dm/ { Ksat* (0.5*Dw+Dm) *T }]	3
Gravel Wetland	-	0.4	WQD * DA / (Dw+Dm*n)	1	0.0035 * DA	4
Infiltration Basin	3	-	WQD * DA / (Dw+Ksat*2/24)	2	WQD * DA / (T*Ksat)	5
Infiltration Chamber	3	-	WQD * DA / (Dm*n+Ksat*2/24)	2	WQD * DA / (T*Ksat)	5
Infiltration Trench	3	0.45	WQD * DA / (Dm*n+Ksat*2/24)	2	WQD * DA / (T*Ksat)	5
Rain Garden	1	-	WQD * DA / (Dw+Ksat*2/24)	2	WQD * DA / (T*Ksat)	5

Sources (S):
1 = storage formula
2 = storage formula with 2 hours of infiltration using simple dynamic method from MA-DEP(2008)
3 = bioretention formula using Darcy's law (need ref)
4 = area formula (VT-ANR, 2002)
5 = drainage time formula

Definitions:
A = BMP area (ft2) = maximum(A1, A2)
DA = drainage area (ft2)
Dw = water depth (ft)
Dm = media depth (ft)
Ksat = saturated hydraulic conductivity (infiltration=soil, biofiltration/green streets=media)
T = design drainage time (d)
WQD = design water quality depth (ft)

BMP Costing Information

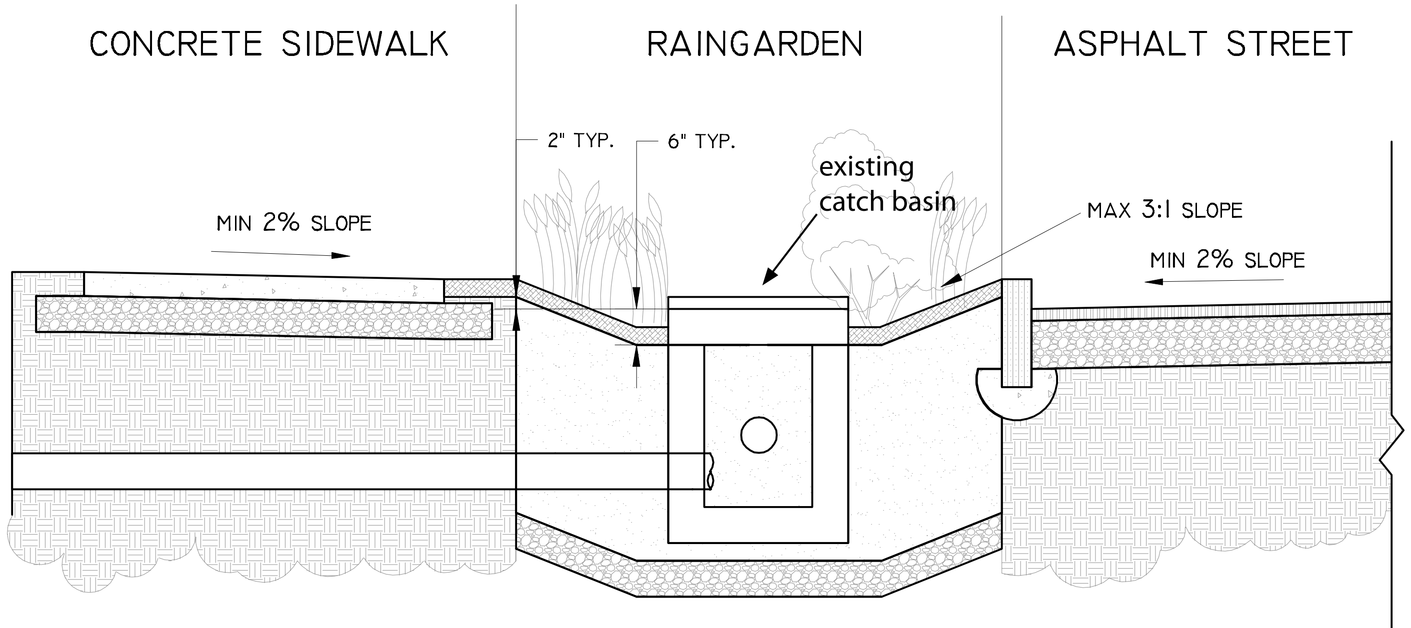
CRWA worked closely with our consultant Horsley Witten Group to determine current BMP costs (Claytor, 2010). Unit costs of new BMPs were estimated from literature sources as the cost per physical volume treated. Design costs (5-35%) were ignored as they are usually a fixed percentage of the total construction cost. Adjustment factors (0.1-2) were used to convert these costs from new site construction to retrofit site costs, with the assumption that retrofitting highly developed, dense properties may be more costly than placing BMPs on new or sparsely developed sites.

Retrofit costs may be higher (factors>1.0) if sites are more constrained for machinery and there are utilities (pipes, cables etc) present on or near the site. A simple retrofit BMP using an outlet modification had a very low factor (0.1). The construction cost for each BMP was determined from the BMP physical volume (ft3), unit cost ($/ft3), and the cost factor (0.1-2). Land cost for BMPs requiring a land purchase (Drainage areas 1A-1, 1A-2, 2F-1, 2F-2, and 3E-2) was determined from unit land costs ($/ft2) for current land sales in Franklin and the land areas for the BMP were estimated as 1.5 times the physical BMP areas. The total cost for retrofitting the Spruce Pond Brook subwatershed was the sum of the individual BMP costs for all BMPs chosen to meet the 42% target phosphorus load reduction.

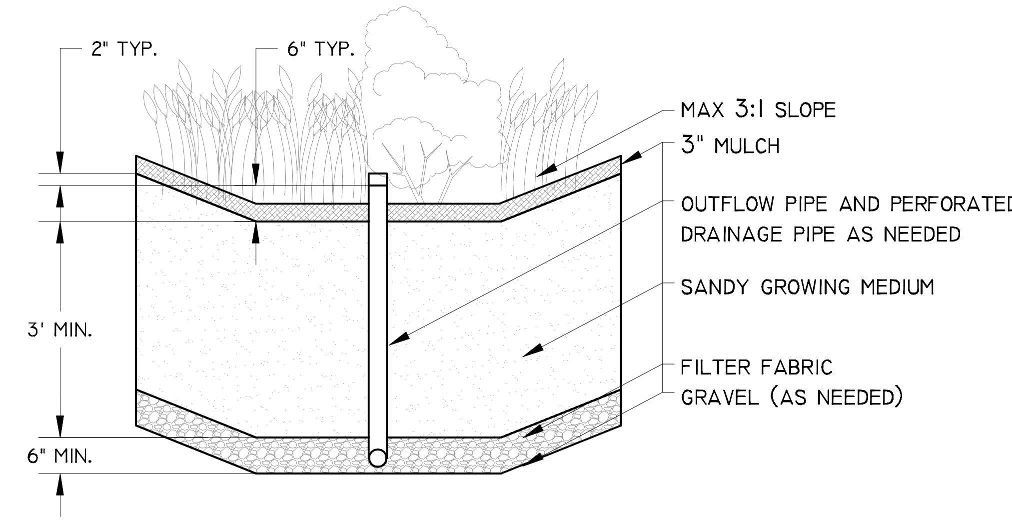
Table 4. BMP Unit Costs and Cost Factors

BMP	Cost ($/ft^3)
Dry Pond	2
Wet Pond	3
Gravel Wetland	8
Infiltration Basin	4
Infiltration Trench	8
Infiltration Chamber	12
Rain Garden	5
Bioretention	10
Green Street	15
Water Quality Swale	8

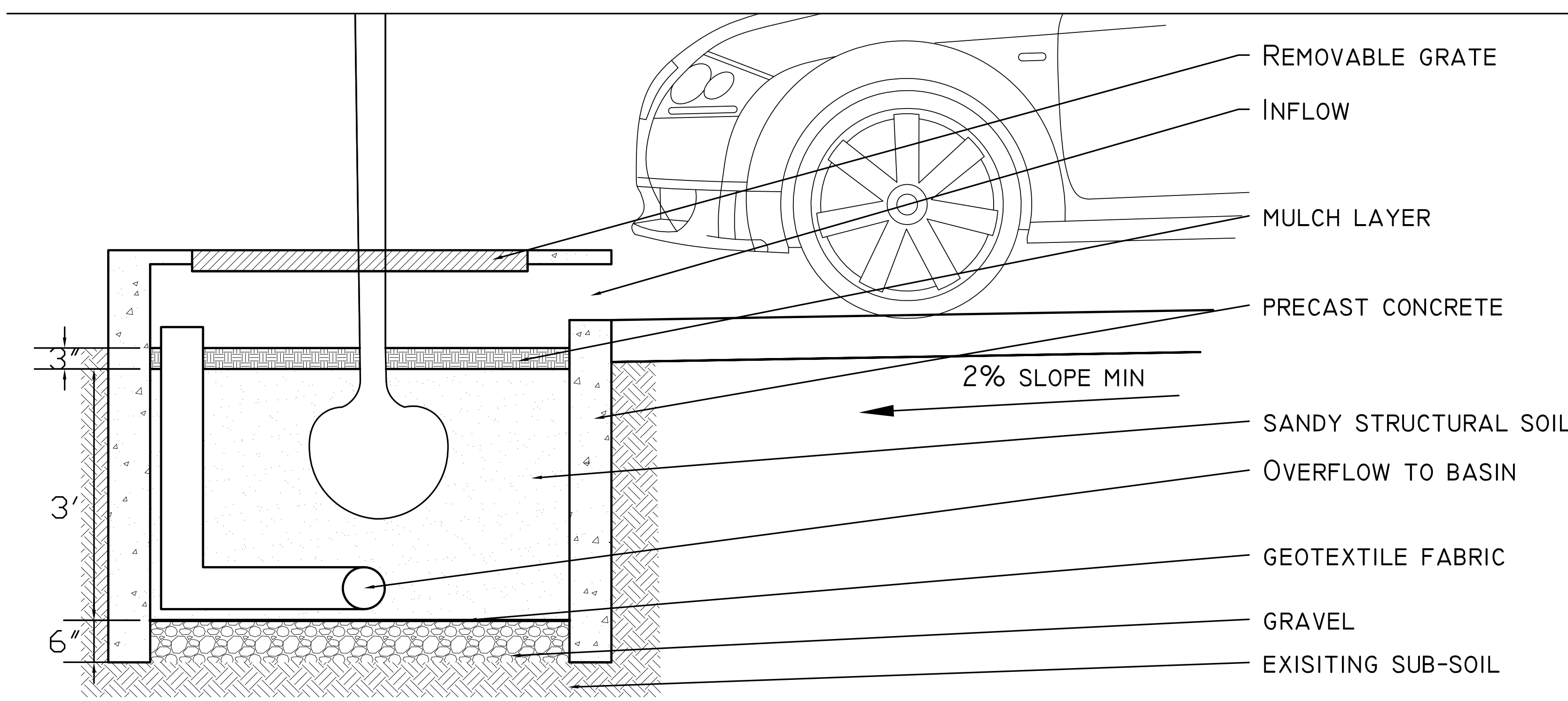
BMP Type	Cost Factor
Outlet modifications	0.1
New BMP in undeveloped area	1
New BMP in partially developed area	1.5
New BMP in developed area	2
Insitu BMP retrofit of dry systems	2
Insitu BMP retrofit of wet systems	3



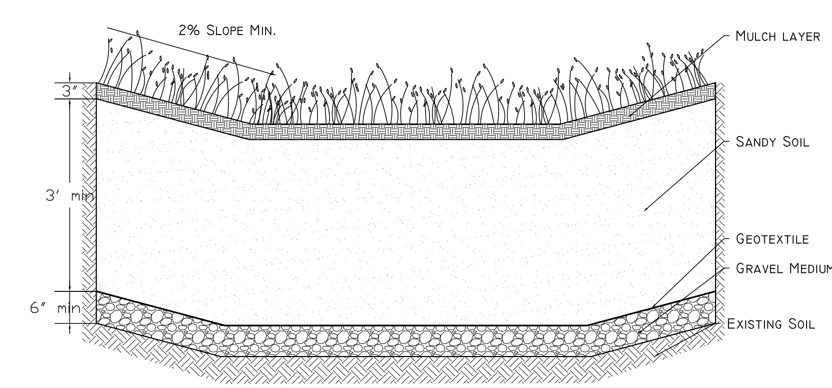
SCHEMATIC SECTION OF A BIORETENTION AREA WITH EXISTING CATCH BASIN
Typical of road-side retrofit



SCHEMATIC SECTION OF A BIORETENTION AREA
Typical of central cul-de-sac bioretention system

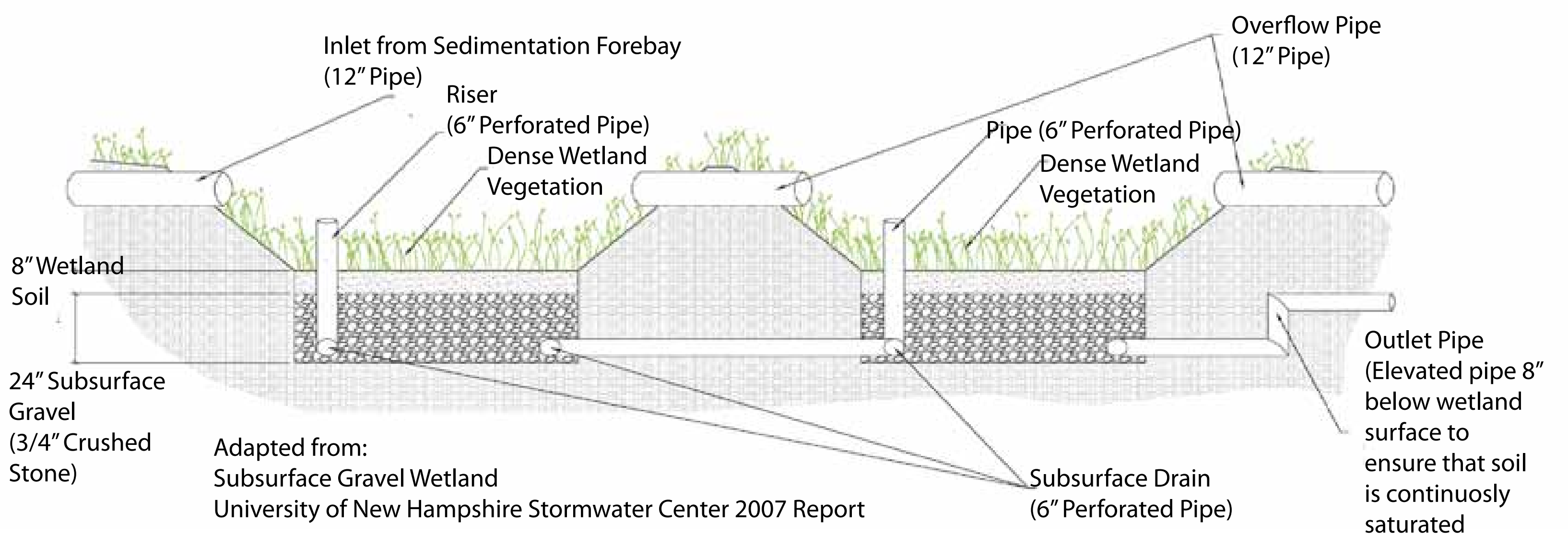


SCHEMATIC SECTION OF A TREE FILTER

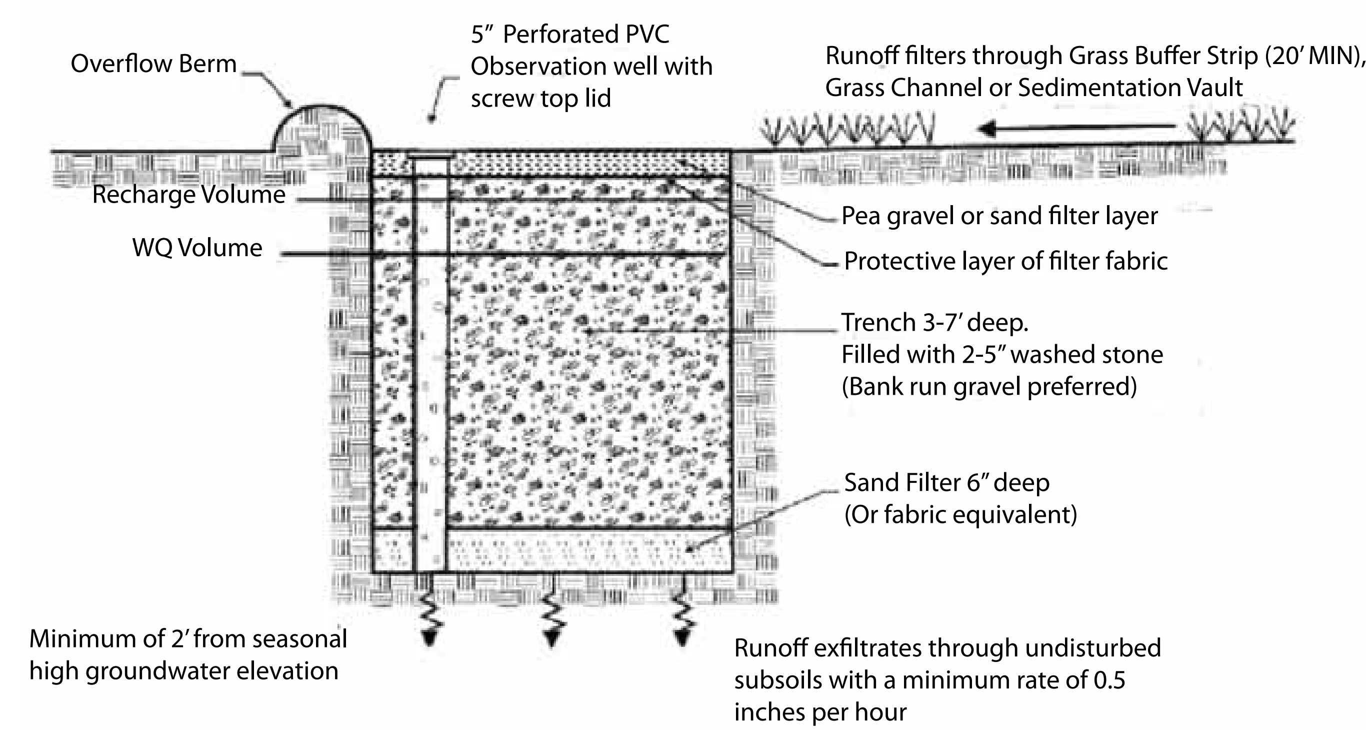


Minimum Depth is 6 inches

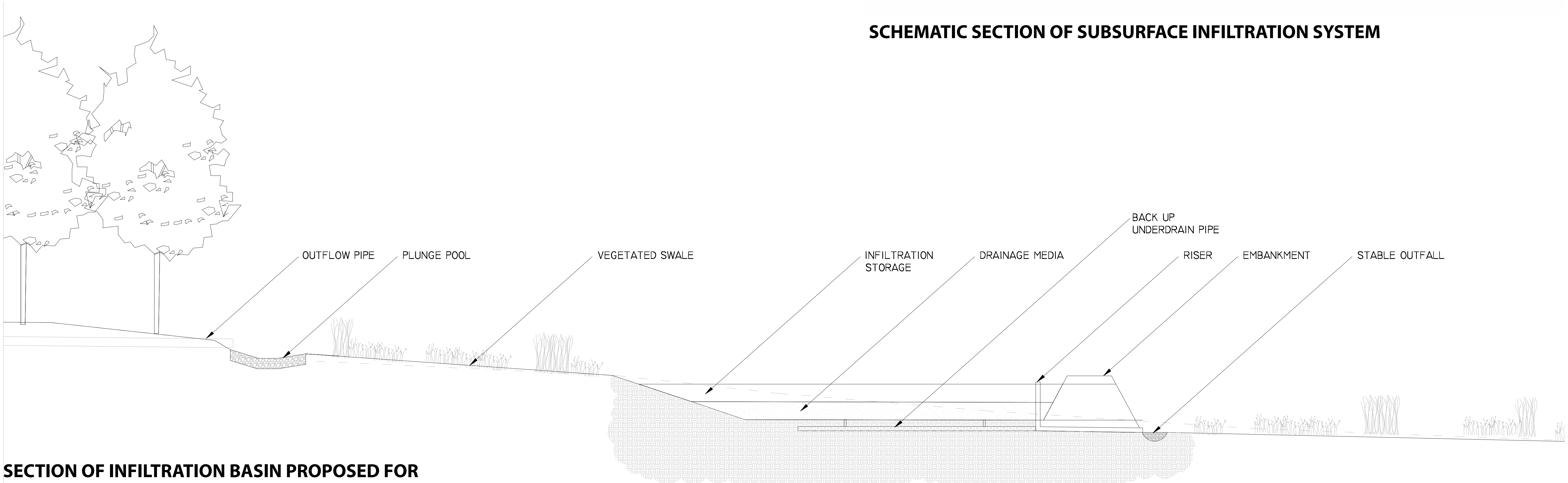
SCHEMATIC SECTION OF A VEGETATED SWALE



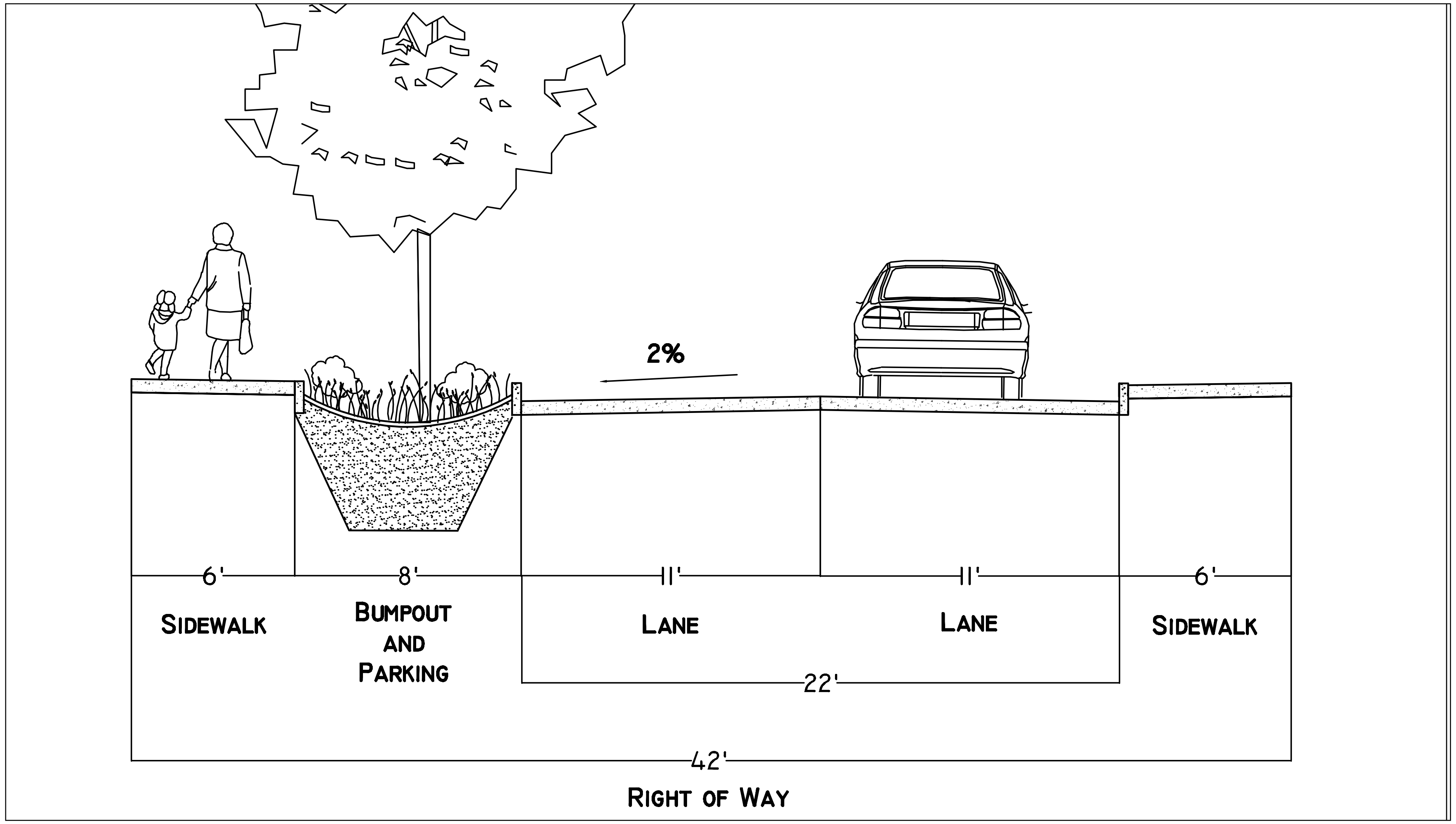
SCHEMATIC SECTION OF SUBSURFACE GRAVEL WETLAND



SCHEMATIC SECTION OF SUBSURFACE INFILTRATION SYSTEM



SECTION OF INFILTRATION BASIN PROPOSED FOR DRAINAGE AREA 2C - LOCKEWOOD DRIVE



WACHUSETT STREET - EXAMPLE BUMPOUT CONDITIONS: 42' RIGHT OF WAY
Franklin, MA