CCPR

CLIMATE CHANGE PREPAREDNESS & RESILIENCE

APPENDIX B:

# GREEN INFRASTRUCTURE ANALYSIS & URBAN HEAT ISLAND MODELING

City of Cambridge

11.15.2017

DRAFT

# Acknowledgements


## CITY OF CAMBRIDGE

Louis A. DePasquale, ***City Manager***

Lisa C. Peterson, ***Deputy City Manager***

## PROJECT STEERING COMMITTEE

John Bolduc, *Environmental Planner, Community Development Department, Project Manager*

Iram Farooq, *Assistant City Manager for Community Development*

Sam Lipson, *Environmental Health Director, Public Health Department*

Owen O'Riordan, *Commissioner of Public Works*

Susanne Rasmussen, *Environmental & Transportation Planning Director, Community Development Department*

Kari Sasportas, *Community Resilience & Preparedness Manager*

Kathy Watkins, *City Engineer, Department of Public Works*

## PRODUCED IN COLLABORATION WITH

**Kleinfelder**, *Lead Consultant*

**Chester Engineers** for green infrastructure conceptual design

**Stantec** for flood modeling of green infrastructure solutions

*WEBSITE:* http://www.cambridgema.gov/CDD/Projects/Climate/climatechangeresilianceandadaptation.aspx

# Table of Contents

## List of Tables



## List of Figures

# Attachments

# 1.0 Introduction

[THE PROBLEM] This study was conducted to address the City of Cambridge's questions about the extent to which the natural environment (such as trees) and engineered ecosystems (such as green infrastructure) can be effectively used to mitigate precipitation flooding and increased urban heat island[1] effects caused by climate change.

These concerns stem from projected changes in climate conditions, and the urban nature of the setting in which climate change impacts will be evident. The number of days over 90° Fahrenheit are projected to nearly triple by 2030 from present conditions of approximately 11 days a year to approximately 31 days a year[2]. Urban areas like Cambridge, particularly sections of the City that lack vegetation, will experience heat vulnerability exacerbated due to the Urban Heat Island (UHI) effect. The UHI effect is caused primarily by the conversion of permeable, moist areas (such as soil) to impervious dry areas, such as pavement and rooftops, which do not dissipate heat as effectively. Many residents in Cambridge are exposed to heat regularly through walking, biking, and public transit use.

Likewise, the Alewife area already experiences flooding problems caused by heavy rainfall during storms. The impervious surface coverage in Cambridge is a significant contributor to surface runoff that generates high peak flows to both the Brook and the conveyance pipes. The City has modeled flood risks from precipitation, storm surge and sea level rise. Flooding is likely to become more frequent, expansive, and deeper, and risks from flooding impacts are projected to nearly double between now and 2070 for a 100-year precipitation flood event. More detailed analysis of flooding specific impacts is available in CCVA[3]. Flooding by sea level rise and storm surge has not been factored in this study since flooding volumes as identified in CCVA are too large to be mitigated by green infrastructure.

[THE SPECIFIC QUESTIONS] To address these concerns and prepare a platform for future planning, the City is posing the following questions, which are addressed in the remainder of this memorandum:

- How can green infrastructure mitigate flood volume and improve water quality of stormwater?
- How can green infrastructure mitigate Urban Heat Island (UHI) effects?
- How can increased urban tree canopy and white roofs mitigate UHI?

[1] The term "heat island" describes built up areas that are hotter than nearby rural areas. The annual mean air temperature of a city with 1 million people or more can be 1.8–5.4°F (1–3°C) warmer than its surroundings. In the evening, the difference can be as high as 22°F (12°C). https://www.epa.gov/heat-islands

[2] The full City's Climate Change and Vulnerability Assessment (CCVA) Report Part 1 is available at http://www.cambridgema.gov/CDD/Projects/Climate/~/media/307B044E0EC5492BB92B2D8FA003ED25.ashx

[3] The full City's Climate Change and Vulnerability Assessment (CCVA) Report Part 2 is available at http://www.cambridgema.gov/CDD/Projects/Climate/~/media/F93208C3B12D4AACBD3E0F3A712F68C7.ashx

[APPROACH OVERVIEW / GOALS] To help answer these questions, this technical memorandum presents the methodology and findings related to green infrastructure analysis and urban heat island (UHI) modeling that was conducted for the Alewife area as part of the Climate Change Preparedness and Resiliency (CCPR) Plan. The goals of this analysis are primarily two-fold:

- Identify **Green Infrastructure** (also referred to as **Best Management Practices BMPs**) solutions that are most applicable for the Alewife area given the site-specific constraints and the variety of land use types in this area, and assess how these solutions may result in **flood mitigation, water quality improvements and urban heat island reduction**.

- Determine how **UHI effects** under existing and future climate change conditions can be **mitigated by increasing urban tree canopy cover and white roofs.**

[SUMMARY OF FINDINGS] This study suggests that both UHI effects and future flood risks can be mitigated in the Alewife area:

- **UHI Effects:** Increased tree canopy and other engineered green infrastructure solutions, such as bioretention basins, rain gardens, and green roofs have the potential to reduce the UHI effect in Cambridge.

- **Future Flooding:** Green infrastructure solutions, when appropriately designed and integrated as part of the natural ecosystem, can also help reduce flooding by reducing the peak flow via attenuation and detention of the stormwater runoff. Managing runoff generated from impervious surfaces with green infrastructure solutions is one of the effective measures to reduce flooding and improve water quality. For implementation, the City can consider integrating green infrastructure solutions into new development opportunities to meet the stormwater storage requirements, which are likely to become more stringent to cope with the rapid growth and development in the City.

# 2.0 Current and Projected Conditions

This section provides a brief summary of the baseline conditions in the City of Cambridge, as well as the projected trends in climate in the future, specifically related to temperature and precipitation. The projected climate change scenarios that the City adopted are based on "higher" and "lower" Greenhouse Gas (GHG) emission scenarios for the two planning horizons of 2030 and 2070[4].

## 2.1 Temperature

Over the coming century, mean annual and seasonal temperatures in Cambridge are expected to increase. Historically (1971-2000), annual temperature (night + day) averaged around 50ºF in Cambridge. Annual temperature is projected to be around 53ºF by 2030, and as much as around 56-59ºF by 2070 (Table 1). For extreme temperature indicators, days per year with maximum air temperature greater than 90ºF and 100ºF were used as temperature indicators for the City's Climate Change Vulnerability Assessment (CCVA). By 2030, it is likely that days above 90ºF per year will triple and, by 2070s, days above 90ºF per year will increase six fold, with 6-15 days per year above 100ºF. Historically, there have been less than 1 day per year above 100ºF in the Cambridge region. A critical measure for temperature is the heat index, which combines ambient air temperature and relative humidity to determine the "feels-like" or the human-perceived temperature. Heat index is a key indicator for reporting public health concerns since heat index exceeding 91ºF is considered to be in the "extreme caution" zone from prolonged exposure to heat or strenuous activity. Historically, average daily summer heat index in Cambridge hovered around 85ºF. By the 2030, summer heat index is projected to average around 95ºF, and by the 2070s, it is projected to exceed 100ºF for the lower scenario and 115ºF for the higher scenario.

**Table 1. Temperature Projections for City of Cambridge[4]**

| Temperature Changes | Baseline | 2030s (2015-2044) | | 2070s (2055-2084) | |
|---|---|---|---|---|---|
| | 1971-2000 | Lower | Higher | Lower | Higher |
| Annual Temperature (ºF) | 50 | 53.3 | 53.5 | 55.8 | 58.7 |
| Summer Temperature (ºF) | 70.6 | 74.5 | 74.8 | 77.4 | 80.6 |
| Winter Temperature (ºF) | 29.8 | 32.2 | 33 | 34.6 | 38 |
| **Days > 90ºF (days/year)** | 11 | 29 | 31 | 47 | 68 |
| **Days > 100ºF (days/year)** | <1 | 2 | 2 | 6 | 16 |
| **Heat Index (ºF)** | 85 | 94.75 | 96 | 101 | 115.5 |

[4] For a more detailed understanding of the climate change scenarios, explanation of baseline and projected future conditions, please refer to report CCVA Part 1 Technical Report on Climate Projections and Scenario available at http://www.cambridgema.gov/CDD/Projects/Climate/~/media/15687E2123FE4AD8A4DA5BB1B1A06D10.ashx

The 2030 and 2070 temperature scenarios were used in the assessment to evaluate the local impact of increased temperatures by identifying areas with urban heat island effect where heat absorbing surfaces and lack of shading exacerbate temperatures and are likely to result in an uneven heat burden across the City. The heat island mapping for Cambridge was conducted using information such as tree canopy cover, LiDAR[5] elevation data, and percent urban. The urban heat island maps developed for CCVA showed that that localized heat island impacts in the City are projected to increase in both extent and intensity by 2030 and 2070.

## 2.2 Precipitation Flooding

Annual precipitation in Cambridge is projected to remain fairly constant through 2030 and to increase by approximately 6 to 10 inches or 15-20% by 2070. (Table 2). In the future, the projected increase in annual, summer and winter precipitation is expected to continue, with greater changes by 2070s. The same holds true for the extreme precipitation events as reported for the projected 24-hour and 48-hour design storms[6]. For extreme precipitation projections, the City of Cambridge collaborated with other state and local agencies on development of design storm 'values' that take into consideration projected climate change for planning purposes. It can be observed from the results in Table 2 that the present (or baseline) 25-year[7] 24-hour storm, will likely be a 10-year storm[8] by 2070, and the present (or baseline) 100-year 24-hour storm will likely be a 25-year storm by 2070.

**Table 2. Precipitation Projections for City of Cambridge[9]**

| Precipitation Changes | Baseline | 2030s (2015-2044) | | 2070s (2055-2084) | |
|---|---|---|---|---|---|
| | 1971-2000 | Lower | Higher | Lower | Higher |
| Annual Precipitation (in.) | 45 | 48 | 48 | 51.5 | 54 |
| Summer Precipitation (in.) | 9.5 | 9.8 | 9.8 | 10.1 | 10.3 |
| Winter Precipitation (in.) | 11.4 | 12.6 | 12.7 | 14.1 | 15.4 |
| # days per year > 2 in. rain in 24 hrs. (days) | 2 | 3 | 3 | 3 | 3 |
| Max. 5-day precipitation per year (in.) | 6 | 6.5 | 6.6 | 7 | 7.2 |

[5] LIDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. https://oceanservice.noaa.gov/facts/lidar.html
[6] Design storm is a storm whose magnitude, rate, and intensity do not exceed the design load for a storm drainage system or flood protection project (https://encyclopedia2.thefreedictionary.com/design+storm)
[7] 25-year 24-hour storm is one which has a recurrence interval of 25-years, or a storm that has a 4% chance of occurring or exceeding in any given year
[8] 10-year 24-hour storm is one which has a recurrence interval of 10-years, or a storm that has a 10% chance of occurring or exceeding in any given year
[9] Full CCVA Part 1 Technical Report on Climate Projections and Scenario available at http://www.cambridgema.gov/CDD/Projects/Climate/~/media/15687E2123FE4AD8A4DA5BB1B1A06D10.ashx

| | | | |
|---|---|---|---|
| ***24-hr design storms*** | | | |
| **10yr** | 4.9 | 5.6 | **6.4** |
| 25 yr. | **6.2** | 7.3 | **8.2** |
| **100 yr.** | **8.9** | 10.2 | 11.7 |
| ***48-hr design storms*** | | | |
| 10yr | 5.5 | 6.4 | 7.2 |
| 25 yr. | 7 | 8.6 | 9.8 |
| 100 yr. | 10 | 13.2 | 15.7 |

Design storm projections were then input through the City's stormwater and combined sewer piped infrastructure system model to understand the impacts of both flooding extent and depth on specific assets and systems in the built and social environment. From the CCVA analysis it was determined that between present, 2030 and 2070, the area of the City projected to flood from the 100-year rainfall storm is likely to increase from 13% to 18% by 2030 and 23% by 2070. That is, the additional 2.5 inches of rainfall expected in a 2070 100-year 24- hour storm would flood an area almost twice the size of what would be flooded today.

The flooding projected to occur in northern Cambridge would result primarily from Alewife Brook overflowing its banks. The flooding projected for eastern Cambridge is a function of insufficient capacity in the area's stormwater and combined sewer systems and the inability of the piped infrastructure to convey the water away, resulting in water backing up and ponding around manholes and catch basins.

# 3.0 Green Infrastructure Analysis

This section describes the methodology and results for a planning level assessment of the potential implementation of green infrastructures solutions in the Alewife area, and their potential benefits with respect to flood reduction, water quality improvements and reduction of urban heat island impacts. The types of green infrastructure solutions included in this analysis are mostly infiltration based systems, such as bioretention basins, planter or tree boxes, water quality swales and porous/permeable pavements, as well as green roofs. The analysis described in this section presents guidelines for the types of future green infrastructure solutions that should be considered by the City as potentially effectively ways to mitigate climate impacts, but this analysis will not specify how, to what extent, or exactly where such initiatives should be applied.  In other words, this is not a predictive analysis to support design decisions, but a report to ascertain the potential value of green infrastructure, tree canopies, and white roofs.

## 3.1 General Description of Study Area

The green infrastructure analysis described in this section focuses on the Alewife neighborhood and is contained within the Alewife Brook sub-watershed of the City. The Alewife Brook is one of the main tributaries to the Mystic River. The Alewife Brook sub-watershed lies in the southwest portion of the overall Mystic River watershed. The majority of the 8.5 square mile Alewife Brook sub-watershed lies within three communities: Arlington (20%), Belmont (39%) and Cambridge (29%), with the balance of the area falling within portions of Somerville, Watertown, and Medford. The Alewife Brook flows northeasterly to the confluence with the Mystic River, which discharges into Boston Harbor.

In Cambridge, the area draining to the Alewife Brook is a mix of residential, commercial and industrial. Approximately 49% of the Cambridge portion of the Alewife Brook sub-watershed is impervious. There are 145 sub-catchments in Alewife Brook sub-watershed of Cambridge (referred to as the Alewife area, Figure 1) that drain to multiple outfall locations along the Alewife Brook. The size of these subcatchments[10] varies between 0.1 acres to 53 acres, the largest of which is the Golf Course area, with an overall average area of 6 acres.

One of the primary constraints in designing green infrastructure solutions in the Alewife area is that the proximity to the Cambridge Class A water supply reservoir at Fresh Pond precludes exfiltration[11]. Infiltrating types of green infrastructure solutions, also referred to as infiltrating BMPs[12], within the Alewife Brook sub-watershed with groundwater flow toward Fresh Pond will need to contain subdrains that remove majority of the infiltrated runoff to the storm drain system. The subcatchments in the Alewife area that are further to the north are likely to have groundwater flowing toward Little River and not Fresh Pond; therefore, exfiltration in this location would not impact the water supply. Proximity to the seasonal high water table (SHWT[13]) elevations must also be considered, which will limit the depth of the BMPs and types of BMPs that can be used at certain sites. Also, medium to thick clay layers are present in soils in this area and would have to be excavated if encountered.

[10] Subcatchment: An area of land where precipitation collects and drains off into a common outlet
[11] Exfiltration refers to a loss of water from a drainage system as the result of percolation or absorption into the surrounding soil.
[12] Infiltrating BMP: A structure designed to capture and detain stormwater runoff to reduce the discharge volume into existing drainage networks.
[13] The upper surface of where the ground is saturated with water. In Cambridge, this is highest in the early spring.

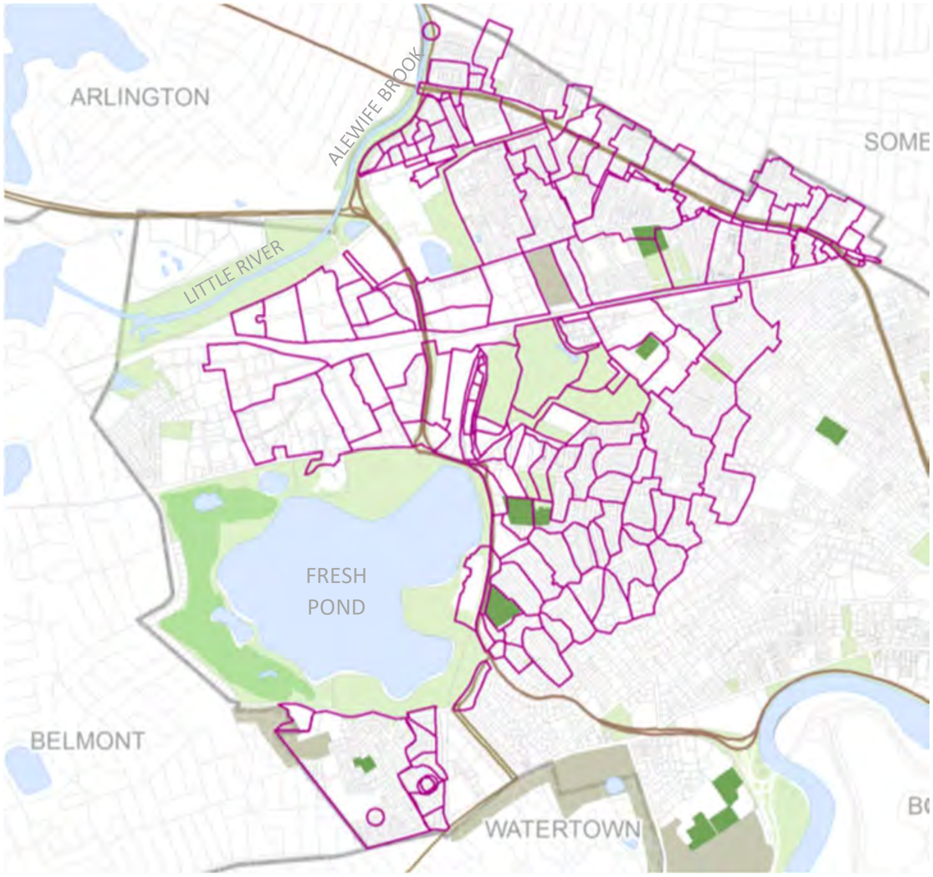



**Figure 1. Subcatchment Boundaries within the Alewife Area**

## 3.2 Parcel Identification and Green Infrastructure Performance Assumptions

This section describes the selection process for choosing typical parcels in the Alewife area to develop conceptual design for green infrastructure solutions, the basis of conceptual design and design options selected for each typical parcel, and how these conceptual design solutions for the typical parcels were scaled to the entire Alewife area.

### 3.2.1 Selection of Typical Parcels

The green infrastructure solutions were explored by considering typical parcels in the Alewife area. Typical parcels were selected per land use type using categories of medium- and high-density residential, commercial, public-right-of-way street, light industrial, and open space. When selecting the typical parcels, a distinction was made between parcels that are planned for new development and existing parcels that may undergo retrofits. The parcel selection process was designed in GIS based on factors including the average impervious area percentage, building area to lot size ratio, and total parcel size. Parcels chosen for the analysis were representative of the mean of these values within each land use segment. The ranking criteria are based on values calculated within Cambridge for the Alewife Brook sub-watershed, using the latest available data for impervious surface, land use type, and building footprint.

The different land use types and the corresponding parcels that were selected are shown in Figure 2 and listed below:

- Medium density residential (retrofit) – Parcel on Standish Street
- High density residential (new building) – Proposed development in the Quadrangle area
- Commercial (retrofit) – Existing hotel along Alewife Brook Parkway
- Light industrial (new building) – Proposed development in the Quadrangle area
- Public open space (retrofit) – Rafferty Park
- Public right-of-way (new) – Proposed new street in the Quadrangle area

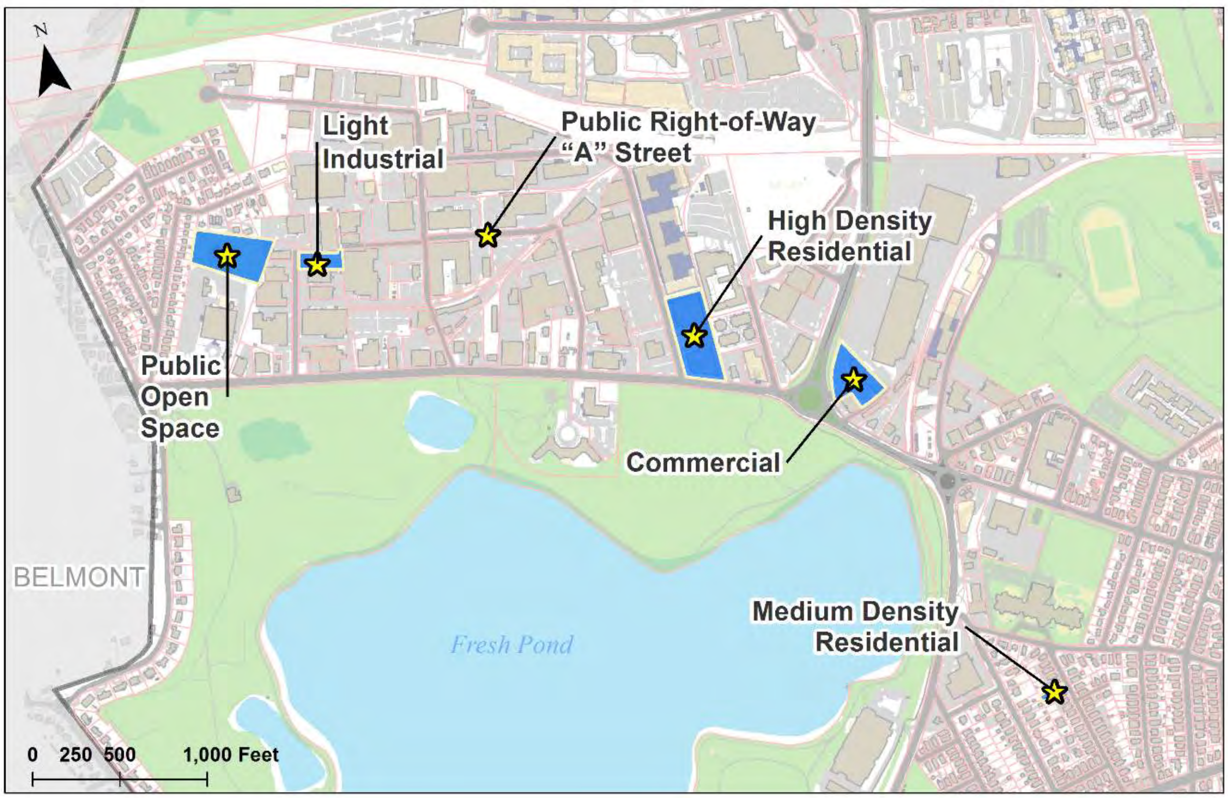



**Figure 2. Overview Map of Selected Typical Parcels**

### 3.2.2 Conceptual Design of Typical Parcels

Conceptual design of green infrastructure solutions were developed for each parcel type. The Massachusetts Stormwater Regulations require capture of the first ½-inch, the so-called first flush. However, the City in its environmental stewardship role and in its commitment to improving water quality of its receiving waters, recommends a more stringent 1.5-inch capture requirement.

Consequently, the concept designs are meant to capture the first 1.5 inch rain aligned with City's recommendations. For each typical parcel, green infrastructure solutions were identified considering site-specific parameters, such as soil conductivity, depth to groundwater table and percent imperviousness. Some of the key factors in selecting the types of green infrastructure solutions for the respective land use types were driven by building typology, land use and other site constraints. For example, flat roofs of commercial buildings are better suited for green roofs while pitched roofs in typical existing medium density residential parcels are not. Large subsurface infiltration chambers are designed for larger paved areas, such as parking lots and hence more appropriate for commercial parcels. Porous pavement is not used for light industrial since it can be expected that heavier cargo traffic can damage this surface.

When developing the conceptual designs, a distinction was made between new development and retrofits. The new development sites and new streets were selected based on the proposed development scenario for the Alewife area after coordination with Envision – the City's Master Plan. It is important to note that green infrastructure opportunities for new development were maximized in the current study beyond what was being proposed in Envision to evaluate the benefits of a more aggressive level of implementation. For example, for high-density residential, no underground parking was assumed in the backyard space.

Details of design for each site, including design parameters, assumptions and suitable options identified are outlined in Attachment 1 titled "Green Infrastructure Concept Overview for Typical Parcels" by Chester Engineers. The green infrastructure solutions that were considered as most suitable in the Alewife area are presented in Table 3.

**Table 3: Types of Green Infrastructure Solution Types Identified for Typical Parcels in the Alewife Area by Land Use Type**

| GI solution types | Bioretention Basin | Porous Pavement | Green Roof | Subsurface Infiltration Chamber |
|---|---|---|---|---|
| Medium-density Residential | ✓ | ✓ | | |
| High-density Residential | ✓ | | ✓ | ✓ |
| Commercial | | | ✓ | ✓ |
| Public Open Space | ✓ | | | |
| Public ROW | ✓ | ✓ | | |
| Light Industrial | ✓ | | ✓ | |

### 3.2.3 Scaling Conceptual Design to Maximum Extent Practicable (MEP)

The conceptual design of green infrastructure solutions were scaled from the parcel scale to the subcatchment scale in the Alewife area based on land use types. For each subcatchment, a total acreage of each land use type was calculated in GIS. Existing land use classification categories were reclassified to fit into the 6 types of land use criteria used in this study. Figure 3 provides an overview of the land use types within the Alewife basin area used for this study.

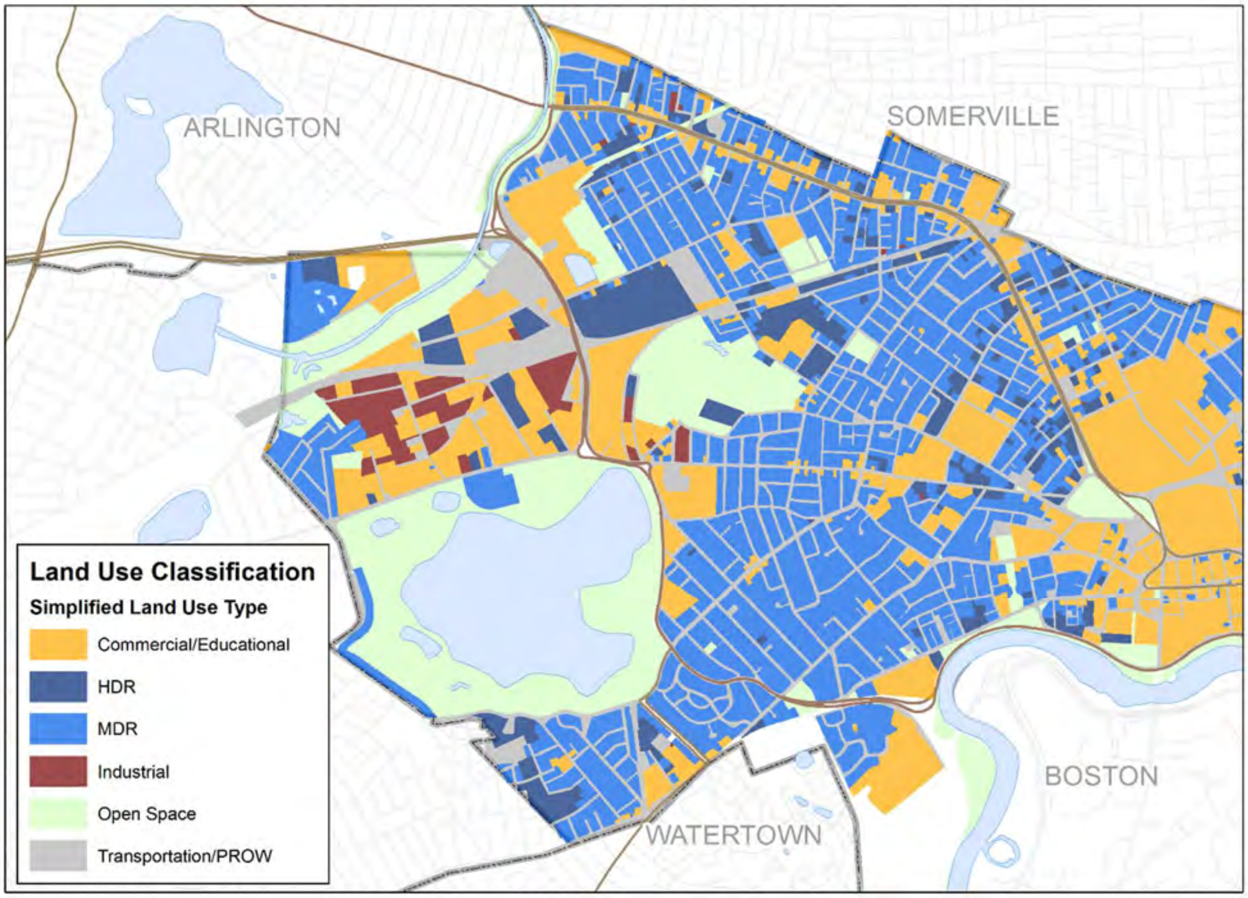



**Figure 3. Land Use Classification of Alewife Area**

When aggregating the conceptal designs from the parcel scale to the subcatchment scale, the level of implementation, referred to as the “Maximum Extent Practicable (MEP)”, was assumed for each landuse type. The percentage of land area that has been assumed to implement green infrastructure solutions per landuse type at the MEP scale is listed in Table 4. The MEP percentages selected for this analysis were based on discussions and cosensus wth the City regarding what might be acceptable and optimistic implementaion levels that can be requested of the differnet land use types as part of new development and retrofit if existing parcels.

**Table 4. Assumed Maximum Extend Practicable (MEP) Level of GI Implementation for Different Land Use Types**

| Land Use Type | Use Code | Percentage of land area assumed to implement green infrastructure (at MEP scale) |
|---|---|---|
| Medium Density Residential (retrofit) | MDR | 50% |
| Commercial (retrofit) | COM | 100% |
| Public Open Space (new) | OS | 100% |

| | | |
|---|---|---|
| Public ROW (retrofit and new) | PROW | 50% |
| High Density Residential (new) | HDR | 75% |
| Light Industrial (new) | LI | 100% |

To determine the numbers/sizes of GI solutions that needed to be implemented at MEP level, ratios of triburary areas for each green infrastructure types have been calculated and are listed in the Table 5 below. The ratios represents a generalization of the size of green infrastructure in relatios to its tributary area based on presumed site chacteristics. For example, a bioretention basin with 1 acre footprint is designed to treat runoff generated from 9.2 acres of impervious area. The detailed calculation sheets for determining the ratios are included in Attachment 2. The tributary area captured for each square unit of green infrastructure type was determined on using the 1.5 inch water quality volume capture requirement recommended by the City.

**Table 5. Tributray Areas Captured by 1 Square Unit of each Green Infrastructure Type**

| Green Infrastructure (GI) Types (BMPs) | Tributary area being captured by 1 square unit of the GI (square units) |
|---|---|
| Bioretention basin | 9.2 |
| Porous pavement | 3.7 |
| Green roof | 1.0 |
| Sub-surface infiltration chamber | 24.7 |

## 3.3 Evaluation of Flood Reduction Benefits

The potential flood reduction benefit of implementation of green infrastructure at the MEP scale was evaluated in the Alewife watershed area using the subcatchments boundaries as shown in Figure 1. The main objective of the analysis is to determine the effectiveness of the implementation GI solutions in reducing street and property flooding during extreme storm events.

### 3.3.1 Methodology

The City's InfoWorks ICM v7.5 H&H model was used for this evaluation. The modeling framework for GI is based on ICM's Sustainable Urban Drainage System (SUDS) control objects (SUDS is United Kingdom's terminology for Low Impact Development (LID) technologies). The design storm selected to evaluate the effectiveness of GI implementation is the 10-year, 24-hour design storm considering the 2070 time horizon. The details of the modeling methodology and results are presented in the Attachment 3 titled "Green Infrastructure (GI) Flooding Analysis in the Alewife Watershed Area" by Stantec (2017).

### 3.3.2 Results

The flood reduction benefits were evaluated in terms of flood depth, peak flow and flood volume. Figure 4 shows simulated flood inundation (peak flood depth) maps under the 2070 10yr. 24 hr. storm scenario with current infrastructure conditions (4a) and with implementation of GI solutions at MEP level (4b). Figure 4b shows areas where substantial flood reduction was achieved, particularly in the areas indicated by the (red dashed) boxes. For instance, the region bounded by Smith Place, Alewife Brook Parkway, Concord Ave. (box 1), and the railroad exhibits substantial flood reduction. On the other hand, flood reduction is less pronounced in some other areas, particularly in the close proximity of the Alewife brook, as flooding in such areas are dominated by river-bank overtopping. Other areas displaying substantial flood reduction are those in the vicinity of Dudley St., Cogswell Ave. and Mass. Ave. (box 2).

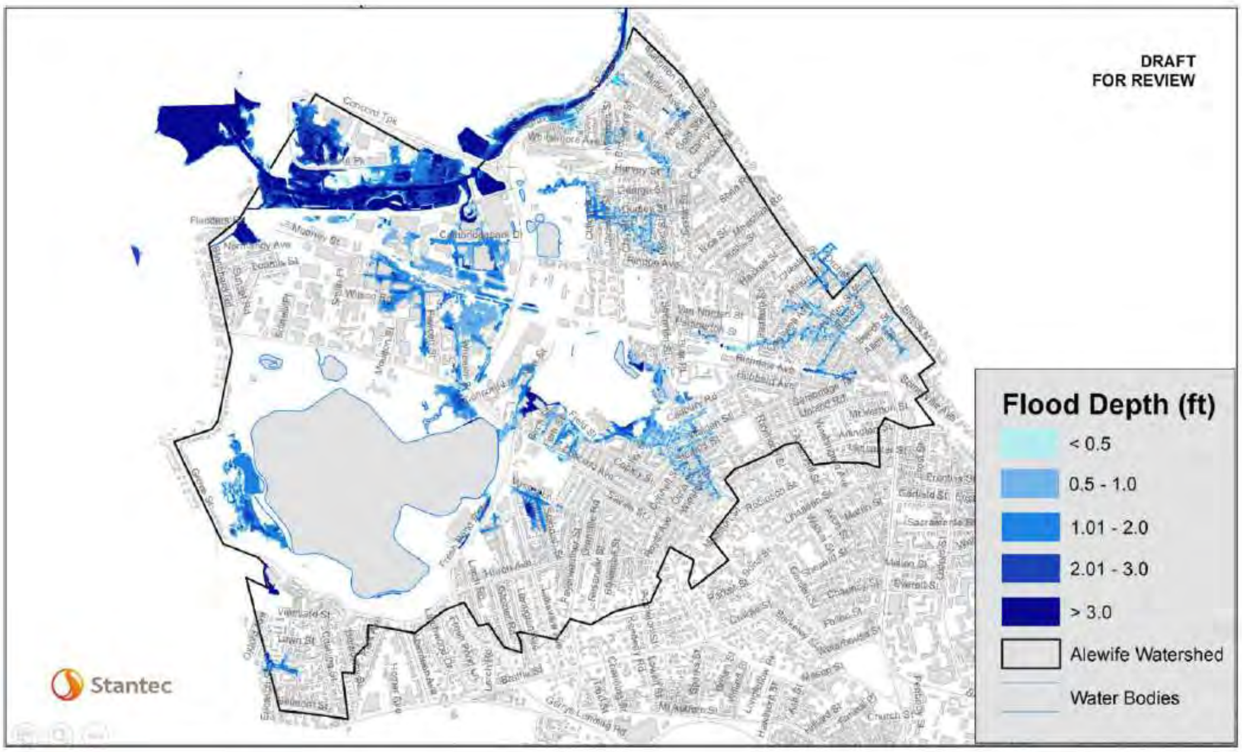



**Figure 4a. Flood Depth with Current Infrastructure Conditions, 10-year 24hr Storm, 2070 using 3 Pumps at the Amelia Earhart Dam, Cradock Locks Removed (InfoWorks ICM Integrated Model)**

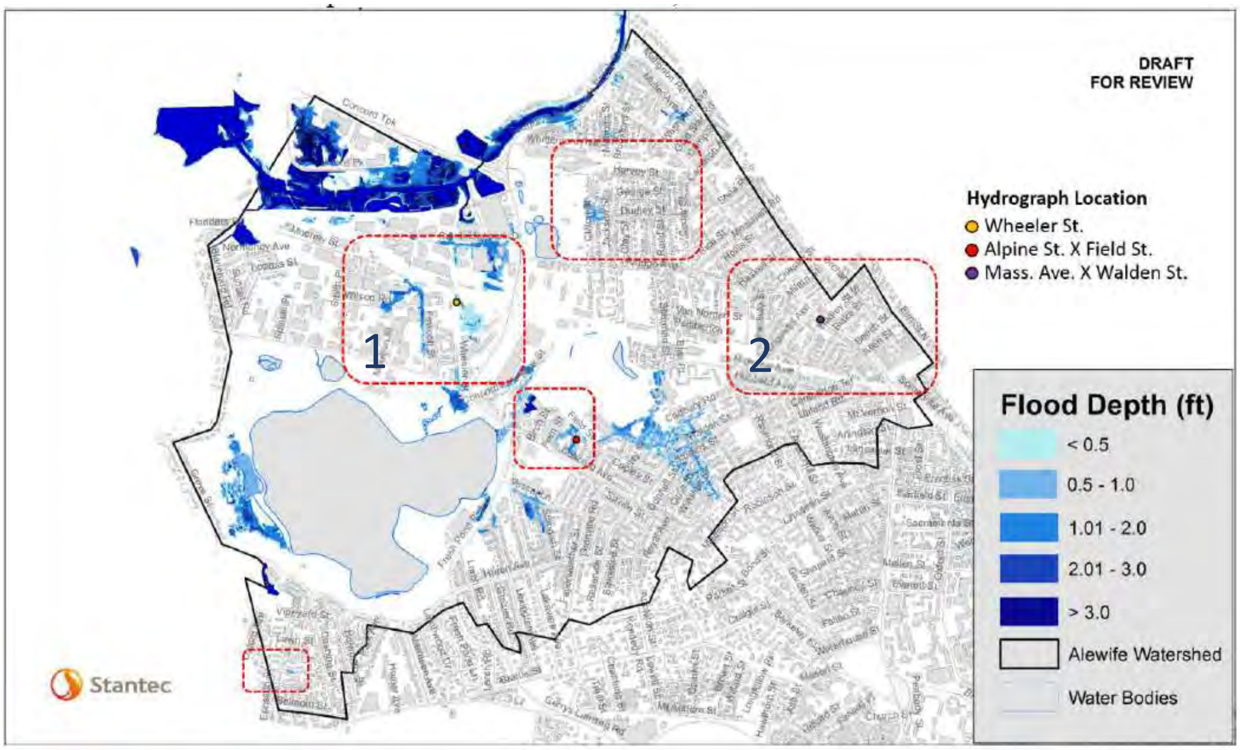



**Figure 4b. Flood Depth with Green Infrastructure at MEP, 10-year 24hr Storm, 2070 using 3 Pumps at the Amelia Earhart Dam, Cradock Locks Removed (InfoWorks ICM Integrated Model)**

3.3.3 Conclusions The potential effectiveness of the implementation of green infrastructure BPMs is not only reflected by the extent of the flooded area but also by the reduction in both peak flowrate and total runoff volume to the combined sewer and storm drain systems. Based on the flood modeling results, flood volume for the 10-year 24-hour storm in the Alewife area is projected to increase from approximately 13 MG (present/baseline climate with existing infrastructure) to 33 MG (2070 climate scenario with existing infrastructure), which translates to an increase of flooding volume of about 160% (Table 6). On the other hand, implementation of the GI solutions at MEP levels within the Alewife area can result in flood volume of approximately 21 MG for the 10-year storm by 2070, which is essentially a 37% reduction (or 12 MG less) in flood volume compared to the 33 MG. The peak flow in the conveyance system of the Alewife area is projected to reduce 23% to 32% at different location; while volume reduction could fall within the range 11% to 40% if green infrastructure is implemented at the projected MEP[14].

[14] For more detailed explanation of the peak flow reduction percentages, please refer to Attachment 3 titled "Green Infrastructure (GI) Flooding Analysis in the Alewife Watershed Area" by Stantec (2017)

**Table 6. Flood Volume Reduction Under Present, 2070, And 2070 With GI Scenarios**

| Scenario | Volume (MG) | % Difference compared to present climate with existing infrastructure | % Difference compared to 2070 climate with existing infrastructure |
|---|---|---|---|
| Present/ baseline climate, Existing Infrastructure | 12.7 | - | - |
| 2070 climate scenario (10yr. 24 hr. storm), Existing Infrastructure | 33.1 | 160.1 | - |
| 2070 climate scenario (10yr. 24 hr. storm), Green Infrastructure at MEP | 20.8 | 63.5 | 37.1 |

As demonstrated by the analysis, the large scale implementation of green infrastructure BMPs can reduce flooding during large storm, and delay the onset of peak flooding while lowering peak flooding volume

### 3.3.4 Limitations and Next Steps

- Model inputs for GI footprint are based on MEP levels of implementation, which is considered aggressive. The exact implemenetation levels and types of GI BMP installed will determine the resulting flood reduction benefit.
- This analysis evaluated only the 10-year 24-hour storm for future climate conditions. It may be useful to examine a spectrum of plausible future storms to more clearly ascertain the range of conditions over which green infrastructure can be valuable.

## 3.4 Evaluation of Water Quality Benefits

The water quality benefits of green infrastructure were assessed with respect to total phosphorous reduction in the stormwater runoff that eventually reaches the receiving water body. Phosphorus from urban runoff contributes to nutrient loading in a water body. Excess phosphorus loading can lead to harmful algal blooms and eutrophication of freshwater ecosystems. The Alewife Brook has been identified as nutrient impaired water body, according to the Massachusetts 2014 Integrated List of Waters. A Total Maximum Daily Load (TMDL)[15] for total phosphorous has yet to be developed by Massachusetts Department of Environmental Protection (MADEP). The purpose of this evaluation is to assess total potential phosphorus reduction under large implementation scale of green infrastructures.

### 3.4.1 Methodology

The water quality benefits of green infrastructure were estimated based on a methodology as shown in the flow chart in Figure 5. A spreadsheet model was developed to assess the potential Total Phosphorus (TP) reduction from implementation of the same green infrastructure solutions that were evaluated for flood reduction benefits. Parameters such as percent of directly connected

[15] TMDL: The maximum amount of a pollutant that a body of water can receive while still meeting water quality standards.

impervious area (DCIA) as part of the tributary area draining to a green infrastructure solution, hydrologic soil group (HSG) of the subcatchments in the Alewife area were used to evaluate flood reduction and stormwater quality benefits.

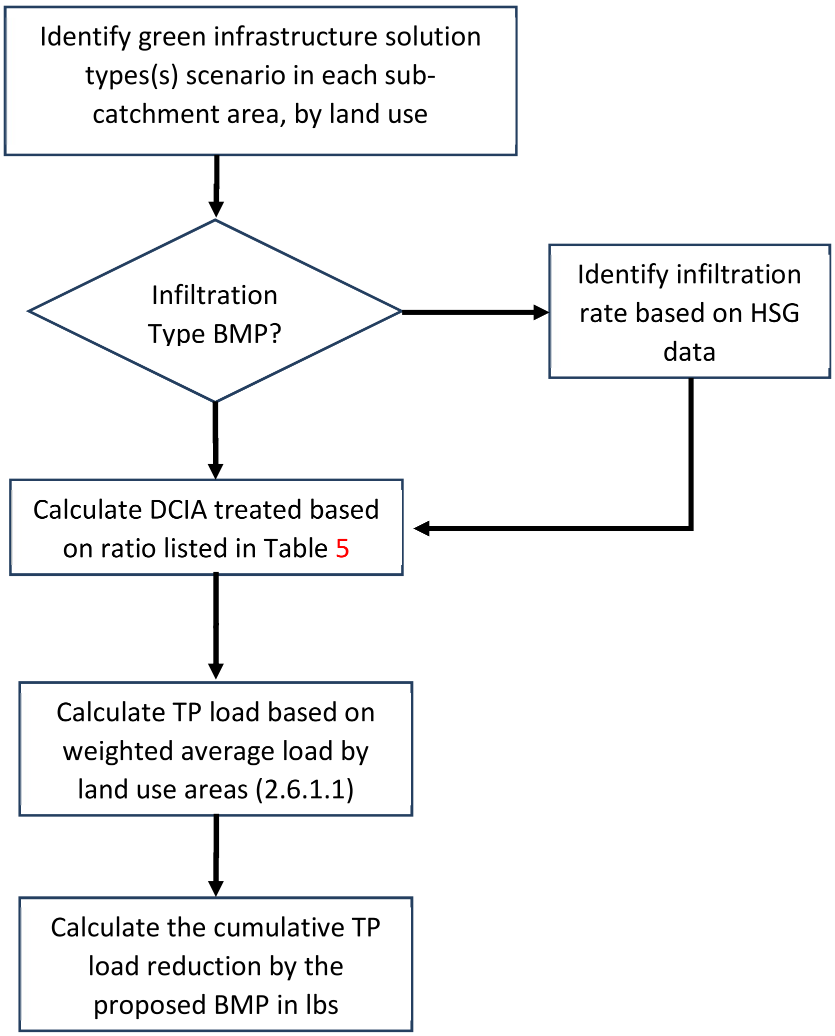



**Figure 5: Flow Chart of Method to Determine Total Phosphorus Load Reduction Based on known BMP Implementation Level**

### *3.4.1.1 Calculation of Phosphorus Loading*

Phosphorus Load Export Rates (PLER) for each land use type was based on using the rates as defined in the "Charles River Basin Nutrient (Phosphorus) TMDLs, Phosphorus Load Export Rates and BMP Performance– Fact Sheet Massachusetts Small MS4[16]. These PLER values are listed in Table 7. Given that the impervious land use area components of each subcatchment are known, these were multiplied by the PLER rates to determine the annual phosphorous load for each land use type for each subcatchment in the Alewife area. The total pounds of phosphorous

[16] https://www3.epa.gov/region1/npdes/stormwater/ma/2014FactSheet-Attachment1.pdf

loading per year per land use type by aggregating all subcatchments in the Alewife area are also listed in Table 7. Based on this calculation the annual total phosphorus load for all subcatchments in the Alewife area is approximately 1,017 lbs.

**Table 7: Summary of Impervious Area, Phosphorus Load Export Rates and Total Annual Phosphorous Loading from Alewife Area by Land Use Type**

| Land Use Type | Land use area (ac) | Impervious area | % Imperviousness | TP Export Rate (lb/ac/year) | TP annual load (lb/year) |
|---|---|---|---|---|---|
| Commercial | 153.4 | 115.1 | 75% | 1.78 | 205 |
| HDR | 99.8 | 68.8 | 69% | 2.32 | 160 |
| Industrial | 23.0 | 18.7 | 81% | 1.78 | 33 |
| Open Space | 71.1 | 26.8 | 38% | 1.52 | 41 |
| MDR | 351.3 | 227.0 | 65% | 1.96 | 445 |
| PROW | 139.0 | 99.0 | 71% | 1.34 | 133 |
| **Total** | **837.6** | **555.4** | **66% (Average)** | | **1,017** |

#### *3.4.1.2 Calculation of Estimated Phosphorus Removal using Green Infrastructure*

Phosphorus removal using green infrastructure at the MEP scale in the Alewife area is calculated by using the removal rates given by EPA's Best Management Performance (BMP) curves (Table 8). These removal rates were multiplied by the percentage of Directly Connected Impervious Area (DCIA) treated by each strategy on a per-catchment basis. For this study, all impervious area within the subcatchment is assumed to be DCIA. The USEPA method[17] was used to determine the total phosphorus load reduction for structural BMPs included in the optimal scenario.

These performance curves sourced from the BMP guidance document are based on the "Simple Dynamic" method (MassDEP Structural BMP Specifications), which assumed that the treatment volume was discharged into the infiltration basin in two hours and exfiltrated during in a two-hour period. The total removal was also measured in lbs/year and is represented as a percentage of the total phosphorus produced within that catchment.

**Table 8. Total Phosphorus Removal Rates for Different Green Infrastructure Solutions Used in the Alewife Area**

| GI Solution Types | TP Removal Rate (lb/ac/year) |
|---|---|
| Bio-retention | 0.76 |
| Porous Pavement | 0.65 |
| Green Roof | 0.76 |
| Subsurface Infiltration Chamber | (0.0 – .98)<br>*Based on hydrologic soil group |

[17] Method #2, USEPA, 2014, Appendix F, Attachment 3, Page 12

To calculate the relative benefit of Subsurface infiltration chambers as a BMP strategy, a hydrologic soil group classification was assigned to each subcatchment in GIS based on the prevailing soil type within that location.

Soil data was sourced from the USDA NRCS Web Soil Survey (Figure 6). A significant portion of the Alewife watershed (and the City of Cambridge as a whole) is classified as “unknown” due to the presence of urban fill. For these unknown soils, an infiltration rate of 50% was assumed. The infiltration total phosphorous removal rates for each know soil group are listed in Table 8.

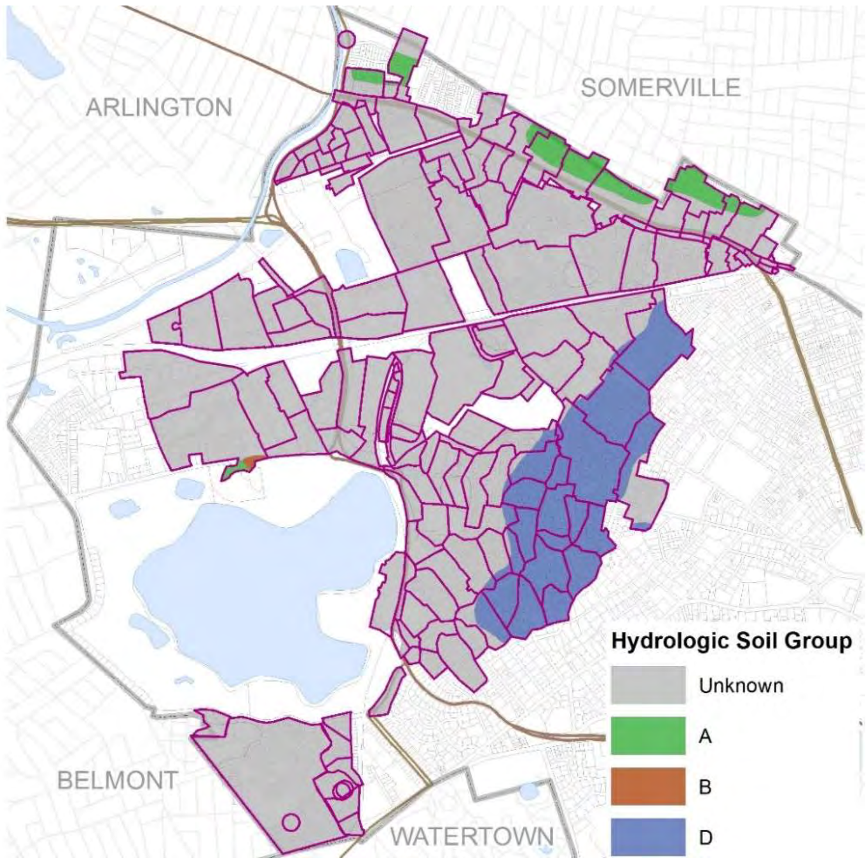



**Figure 6. Hydrologic Soil Group (HSG) Classification in the Alewife Area**

**Table 9. HSG Classification with Infiltration Rates**

| Soil Type | Infiltration TP Removal Rate |
|---|---|
| A | 98% |
| D | 0% |
| Unknown | 50% |

Figure 7 shows a sample output of the calculations performed for the subcatchments in the Alewife area with a breakdown of the percent impervious area in each drainage catchment being captured by each green infrastructure BMPs, the sum of the total phosphorus removed, and the percent phosphorous removed for each drainage catchment area.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Removal rates from BMP Performance Curves: | 0.76 | 0.65 | 0.76 | (Based on HSG infiltration rate) | Citywide Average: | 41% |
| subcatchment | DCIA (ac) | % DCIA Treated by Bio-retention | % DCIA Treated by Porous Pavement | % DCIA Treated by Green Roof | % DCIA Treated by Sub-surface infiltration chamber | Total TP Removal (lbs) | Percent Removed |
| 700 Huron Ave | 1.14 | 2% | 0% | 95% | 2% | 0.8576 | 33% |
| 87 New Street | 0.36 | 5% | 0% | 94% | 1% | 0.2713 | 36% |
| C2401B-1010 | 8.54 | 4% | 14% | 80% | 2% | 6.3270 | 36% |
| C2401B-1024 | 7.36 | 13% | 16% | 69% | 2% | 5.4261 | 38% |
| C2401B-1030A | 7.62 | 17% | 32% | 50% | 1% | 5.5072 | 39% |
| C2401B-1042 | 9.05 | 1% | 7% | 91% | 1% | 6.7883 | 43% |
| C2401B-1094_2 | 1.73 | 16% | 19% | 65% | 1% | 1.2760 | 49% |
| C2401B-1172 | 10.61 | 36% | 53% | 11% | 0% | 7.4271 | 39% |
| C2401B-1175 | 1.05 | 45% | 4% | 49% | 1% | 0.7908 | 43% |
| C2401B-1236 | 6.28 | 5% | 5% | 88% | 2% | 4.7022 | 35% |
| C2401B-1355 | 0.72 | 23% | 49% | 28% | 0% | 0.5117 | 43% |
| C2401B-1402 | 3.43 | 32% | 49% | 18% | 0% | 2.4156 | 39% |

**Figure 7. Sample of Total Phosphorous Removal Calculations by Subcatchment Area**

### 3.4.2 Results and Conclusions

At the maximum extent practicable level of implementation for each green infrastructure BMPs, an estimated 40% removal was achieved using the current model for total phosphorous removal at the subcatchment scale within the Alewife area. This represents an approximate total of 400 lbs. of phosphorus removal compared to an estimated total annual load of 1017 lbs/year of phosphorus load. Figures 8 and 9 show the percentage relative contribution of phosphorous removal per green infrastructure type and the annual total phosphorous removed per green infrastructure type, respectively in the Alewife area.

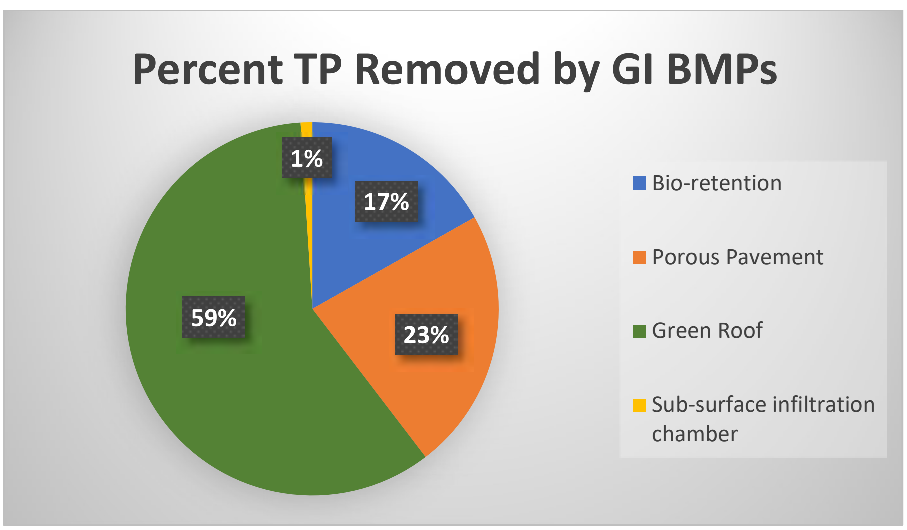



**Figure 8. Percentage Relative Contribution of Phosphorous Removal Per Green Infrastructure Solution Type**

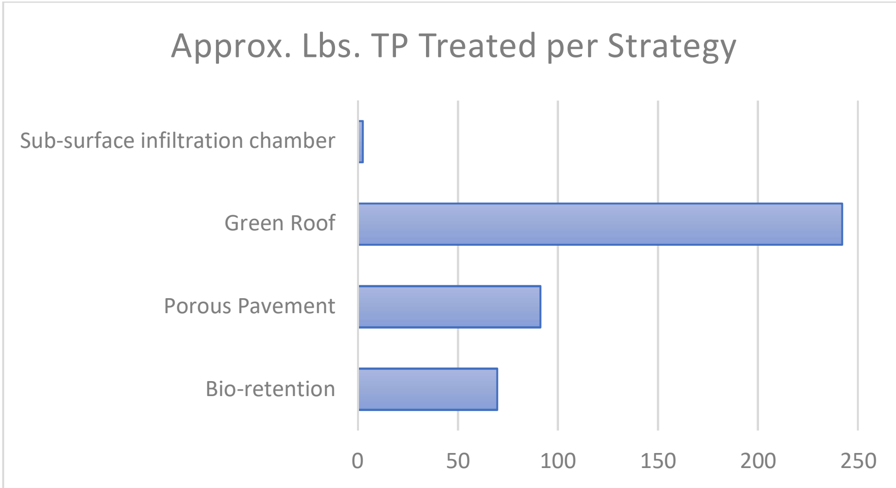



**Figure 9. Annual Phosphorous Loads Removed Per Green Infrastructure Solution Type**

At aggressive levels of implementation, the green infrastructure solutions assessed above may reduce phosphorus loading to surrounding water bodies on the order of 40% of the total estimated phosphorus loading, based on land use.

### 3.4.3 Limitations and Next Steps

- Increased accuracy and availability of soils data for the Alewife watershed area would improve the calculations related to infiltration treatment, as the areas classified as "unknown" (720 acres out of 890 total acres) leave a large degree of uncertainty as to their specific drainage and Infiltration capacity.
- Land use classes were summarized at a catchment scale and assumptions are based on EPA guidance for pollutant loading. Actual conditions may vary from parcel to parcel.
- Phosphorus loading was calculated based on assigned land use type from city assessor data (2017), while actual site-specific conditions may vary.
- MEP percentages that are used may be considered aggressive
- Conceptual designs are based on typical parcels, which may or may not reflect the site conditions across all sites of the same use type within the Alewife area. T
- Some infiltrating phosphorus will remain in groundwater. While phosphorous loads in first flush may be reduced, phosphorous loads in base flow could increase over time and should be further analyzed.

## 3.5 Evaluation of Urban Heat Island Mitigation

This section describes the cooling impacts of green infrastructure BMPs on urban heat island effect in the Alewife area.

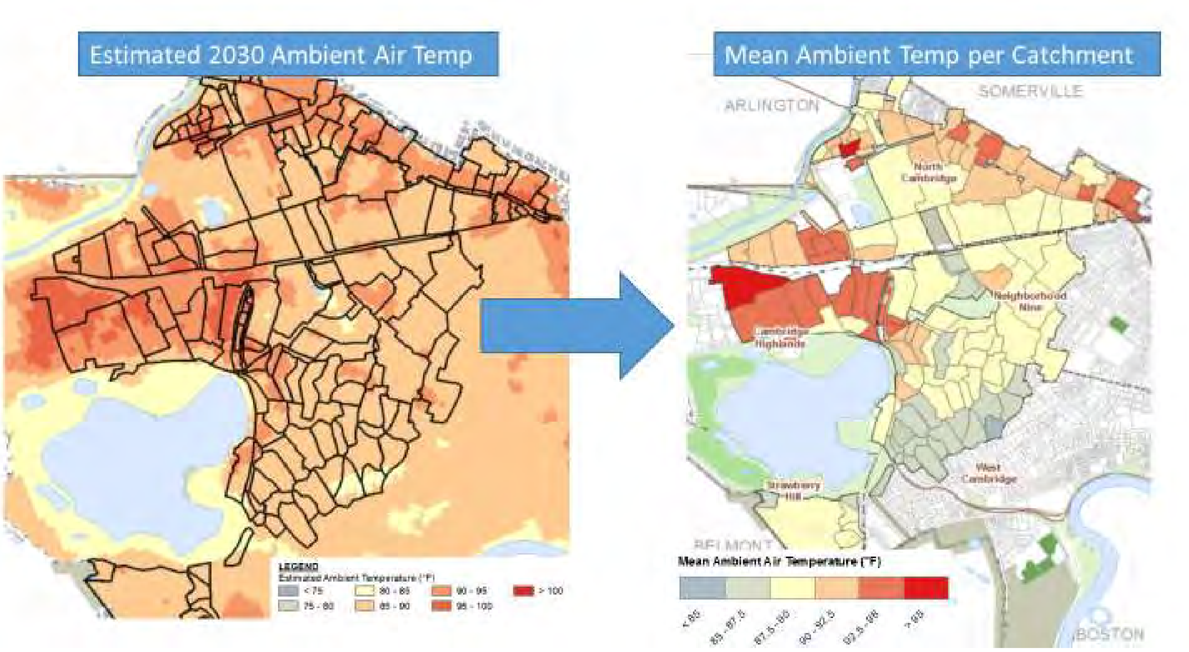
The cooling impact of green infrastructure was examined by comparing the existing impervious surface area, to a proposed future scenario as a result of green infrastructure implementation at MEP level for each subcatchment area. While green roofs, bioretention and to a lesser extent, porous pavement have shown to reduce the effects of UHI, subsurface infiltration chambers are not effective at temperature reduction. These estimates were performed using same subcatchment areas and MEP level as used in the flood reduction and water quality benefit analyses.

When solar radiation in the form of sunlight hits a surface, some percentage of this energy is absorbed, while some is reflected diffusely. The physical properties including surface characteristics and color are largely responsible for the differences in this reflectance amount, which is referred to as surface albedo. One potential benefit of green infrastructure implementation is the modification of the absorptive and reflective properties of a surface, which in effect causes it to behave less like an impervious surface and more like a pervious surface, such as planted terrain with respect to both heat absorption and emissivity.

### 3.5.1 Methodology

A spatial relationship between impervious surface percentage and ambient air temperature within the City of Cambridge was used as the numerical basis for this analysis. The calculations for the cooling impact of the selected green infrastructure BMPs were summarized on a per sub-catchment scale, to be consistent in using the same spatial scale for analyzing flood reduction and water quality benefits.

Using the projected 2030 ambient air temperature raster dataset based on the CCVA analysis (Figure 10a), temperature values were summarized per subcatchment using zonal statistics in GIS, to calculate a mean ambient air temperature value for each subcatchment (Figure 10b). A relationship was established between 2030 ambient air temperature and percent imperviousness under existing conditions before proposed implementation of green infrastructure. The data exhibit a clear upward tendency, such that as impervious area increases in percentage, so does the ambient temperature. A statistically averaged slope derived from these data was used to estimate the potential reduction of ambient temperature with corresponding reduction in imperviousness (Figure 11). The resulting relationship demonstrates that for every 10% decrease in impervious surface, approximately 1°F of cooling can be achieved.




(a) (b)

**Figure 10. 2030 ambient air temperature (a) as determined in the CCVA study, and (b) summarized at the subcatchment scale under existing conditions with no green infrastructure**

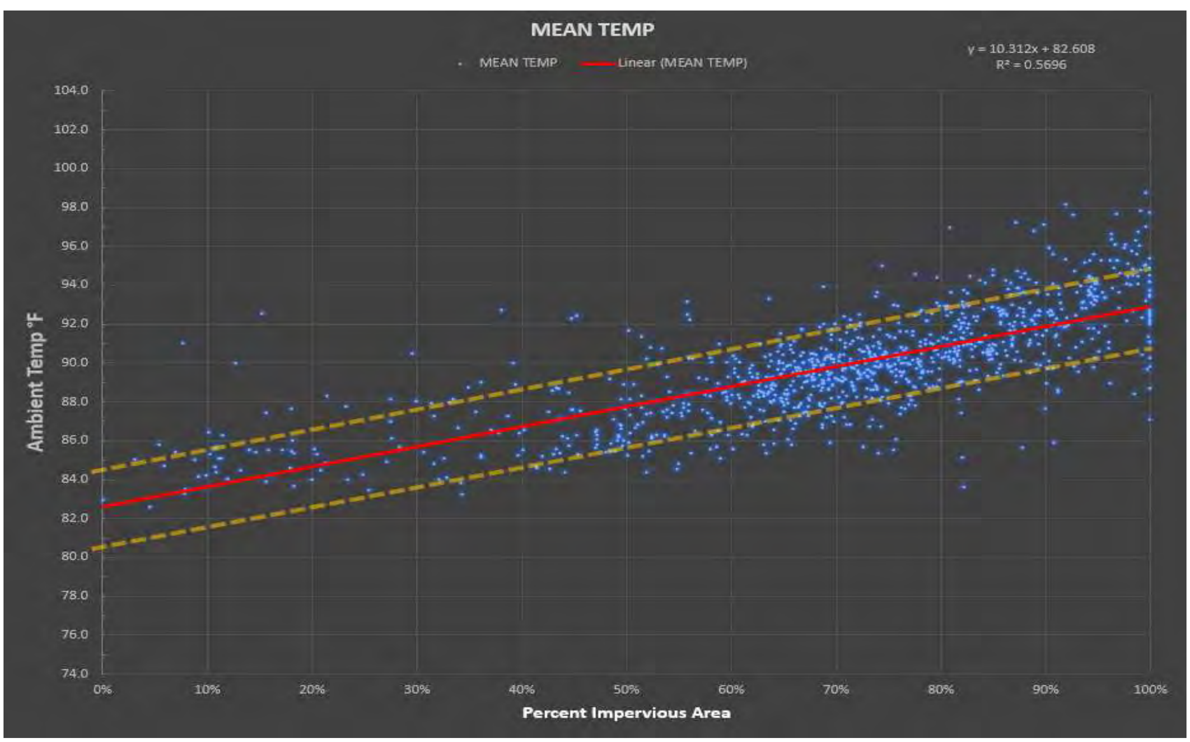



**Figure 11: Relationship between ambient air temperature and percent imperviousness under existing conditions**

The relationship between ambient air temperature and percent imperviousness was then applied to calculate the proposed mean ambient air temperature for each catchment under proposed green infrastructure implementation since green infrastructure decreases the effective percent imperviousness for each catchment. Figure 12a shows the existing percent imperviousness and Figure 12b shows the proposed percent imperviousness after implementation of green infrastructure summarized at the subcatchment scale. Figure 13a shows the mean 2030 ambient air temperature for each subcatchment under existing conditions and Figure 13b shows the reduced 2030 mean ambient air temperature for each subcatchment after implementation of green infrastructure.

### 3.5.2 Results and Conclusions

For catchments in the Alewife area, the results suggest a potential average temperature decrease of 1.7 °F across all catchments, with a range of decrease in temperature varying from 0.1 ºF to 6 °F. Catchments with the largest green infrastructure BMPs cooling potential (4 – 6 °F) were found in the Quadrangle and Fresh Pond Mall Areas, which also corresponds BMPs providing for the largest reduction in impervious surface due to the presence of large parking lot and roof footprints.

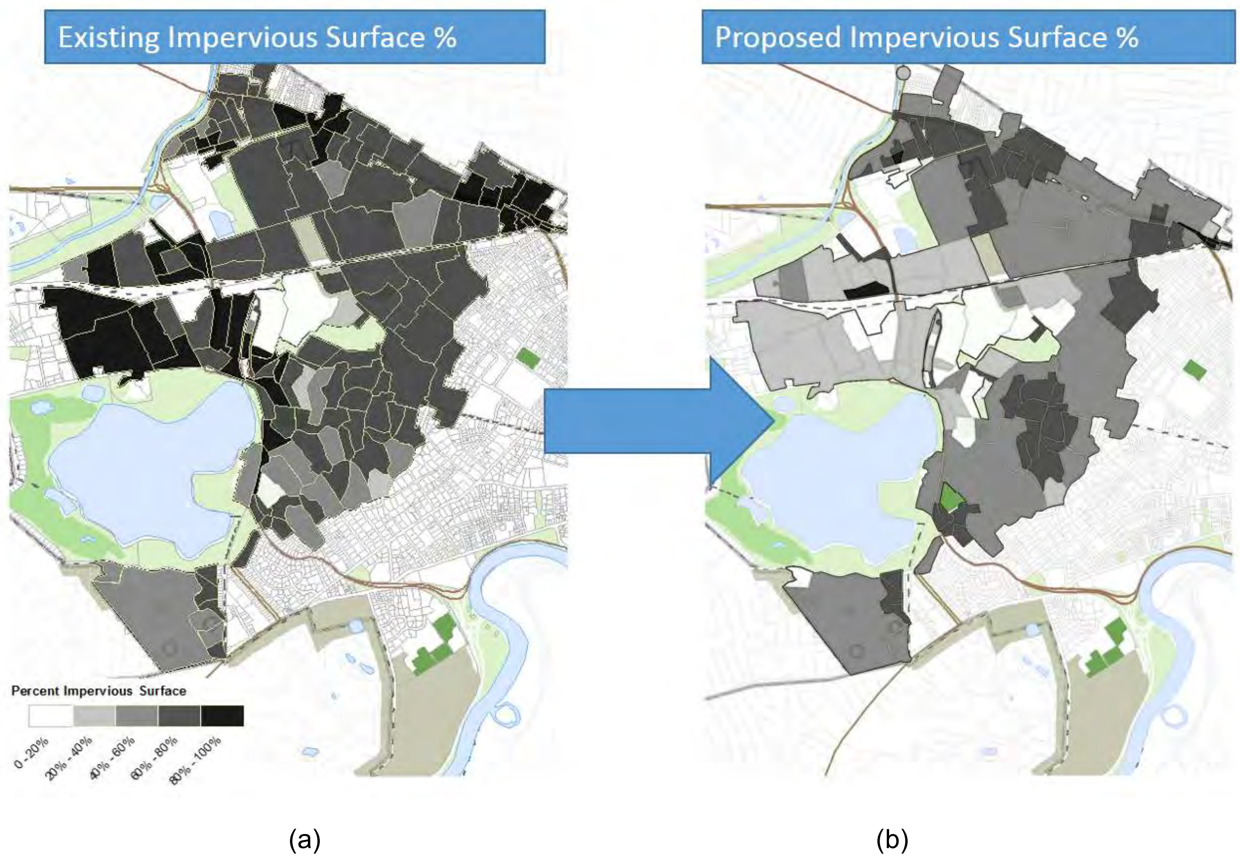
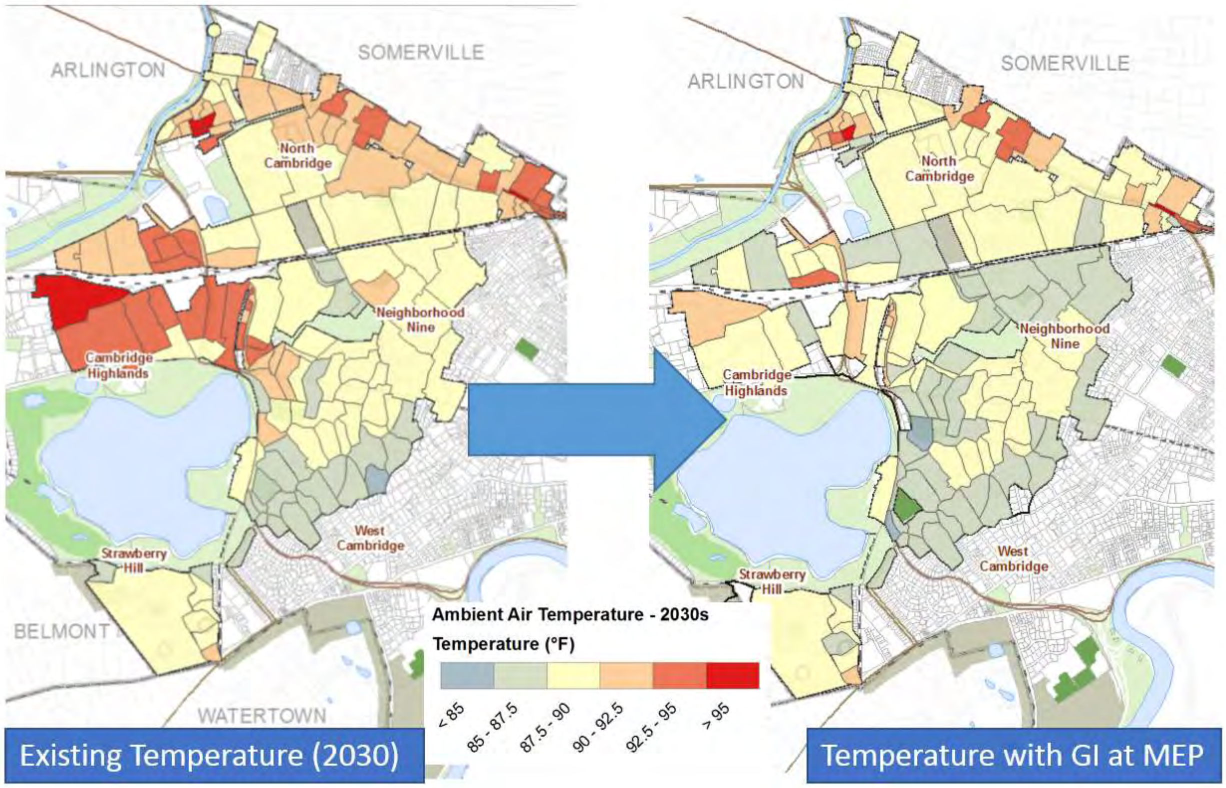



**Figure 12. Percent imperviousness summarized at the subcatchment scale under (a) existing conditions with no green infrastructure, and (b) proposed conditions with green infrastructure**




(a) (b)

**Figure 13. 2030 mean ambient air temperature summarized at the subcatchment scale under (a) existing conditions with no green infrastructure, and (b) proposed conditions with green infrastructure**

### 3.5.3 Limitations and next steps

- Structural limitations will impact the ability for green infrastructure to be implemented on a site-specific basis. Additionally, the presence of existing rooftop mechanicals or photovoltaic panels would limit the available square footage for green infrastructure implementation.
- Model inputs for temperature are derived from existing Landsat data converted to ambient air temperatures.[1] Access to accurate ground-based or in-situ temperature measurements would be necessary to calibrate and validate this model to real-world conditions.
- For a more accurate representation of the cooling impact of green infrastructure, SRI values for the specific surface being modified or installed would be needed to calculate the difference in reflectance and absorption of solar energy.
- Impervious surface data are based on a best-available data as received from the City of Cambridge GIS data portal, and may be subject to change or updates as site conditions evolve. Data used for the analysis represents conditions at one snapshot in time and thus approximates the current and frequently changing conditions.

# 4.0 Urban Tree Canopy and White Roof Analysis

This section describes the potential cooling impacts of increased tree canopy and white roofs on urban heat island effects in the City, with focus on Alewife area.

## 4.1 Methodology

The methodology used to analyze the cooling impacts of both tree canopy and white roofs is described in this section.

### 4.1.1 Cooling Impact of Urban Tree Canopy

The cooling impact of tree canopy has been shown to provide reduction of the urban heat island effect for as much as 9°F above the surrounding areas[18]. The 2012 UVM LiDAR model of tree canopy coverage for the City of Cambridge (Figure 14) provided the basis for the baseline cooling across the city, as a function of degrees (°F) of cooling per tree canopy percentage as documented in the CCVA Appendix D- Urban Heat Island Protocol for Mapping Temperature Projections[19].

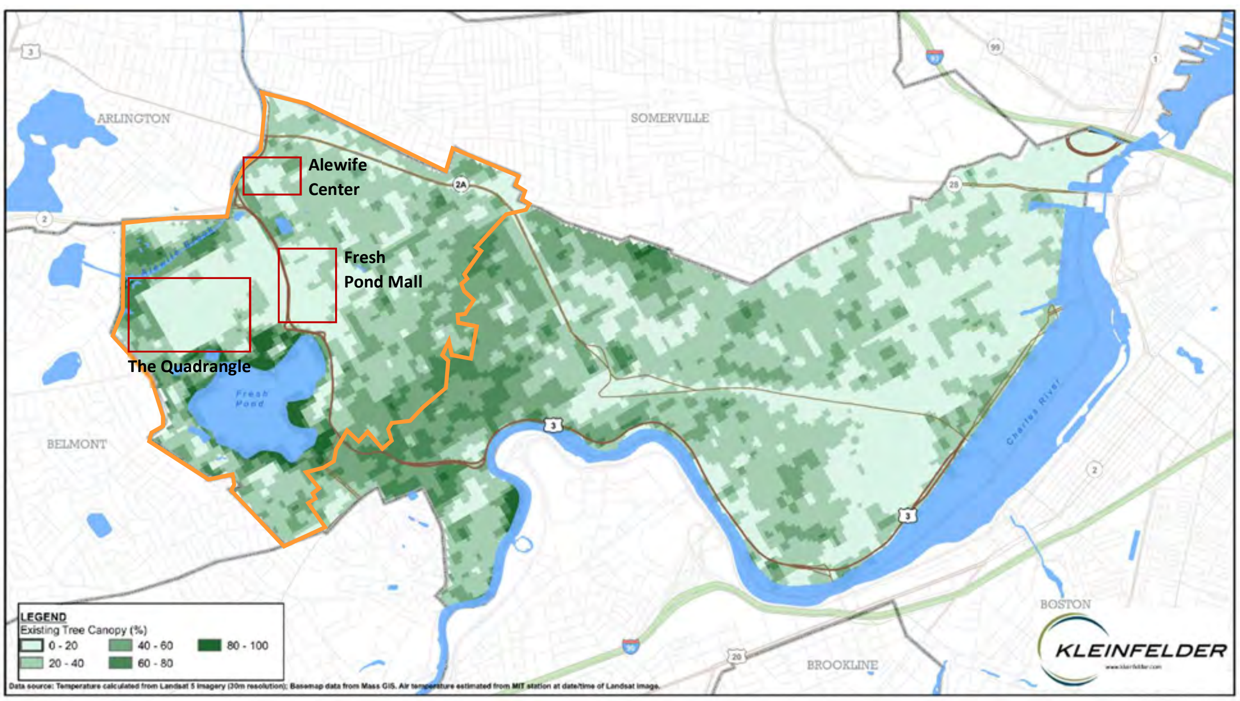



**Figure 14. Tree Canopy Cover Existing Conditions**

The initial analysis correlated tree canopy coverage to cooling impact (in terms of ambient air temperature) across the City of Cambridge, using a linear regression based on satellite derived

[18] Trees and vegetation lower surface and air temperatures by providing shade and through evapotranspiration. Shaded surfaces, for example, may be 20–45°F (11–25°C) cooler than the peak temperatures of unshaded materials. Evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures by 2–9°F (1–5°C). https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands

[19] http://www.cambridgema.gov/CDD/Projects/Climate/~/media/007A3255079540399C25A78038B961A9.ashx

temperature and LiDAR tree canopy coverage. This relationship was found to be approximately 0.12 degrees Fahrenheit of cooling per 1 percent increase of tree canopy. Therefore, an area with a tree canopy coverage of approximately 45 percent would expect to experience 5.2 °F of cooling relative to the prevailing ambient air temperature. A city-wide map was produced which defined the estimated existing cooling impact of tree canopy based on the data from the 2012 UVM tree canopy study (Figure 14).

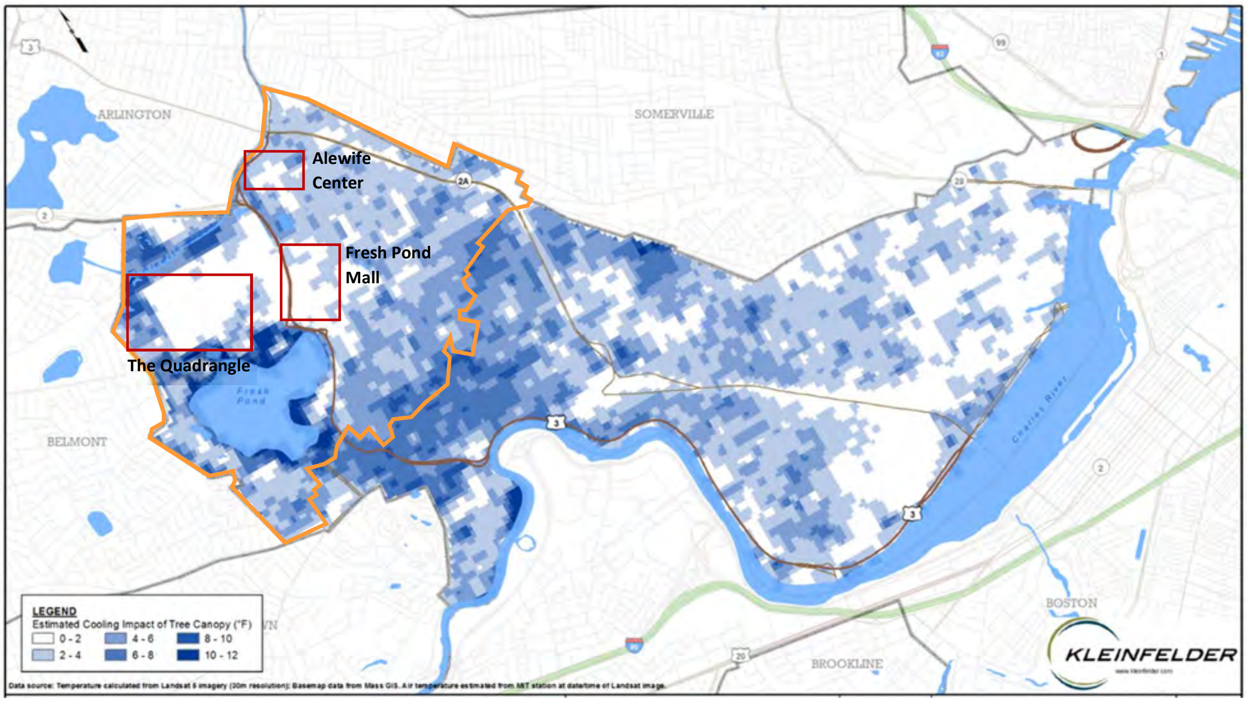



**Figure 15. Existing Cooling Impact of Tree Canopy**

The areas at greatest risk for human health impacts from heat in 2030 and 2070 are highly spatially correlated to the areas currently lacking in tree canopy coverage. The most prominent of these zones in the Alewife area include the Quadrangle area, the Fresh Pond Mall area, and Alewife Center. (Figure 15).

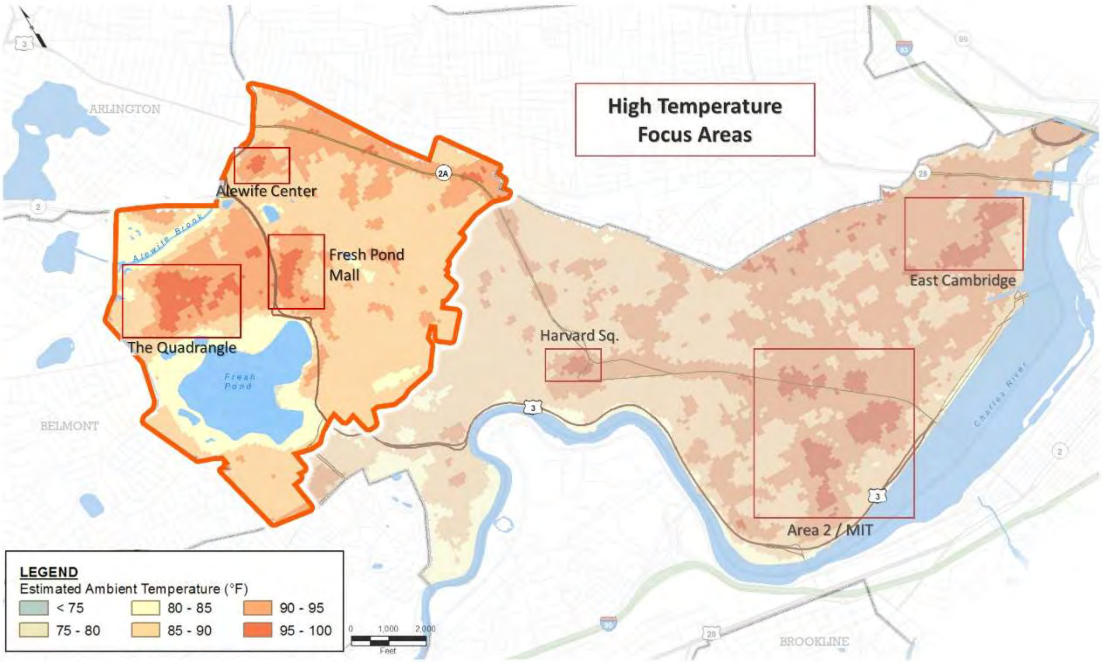



**Figure 16: 2030 Ambient Air Temperature with existing tree canopy. "Danger' Areas are defined by the National Weather Service Heat Index Chart and are a function of air temperature and relative humidity.**

Figure 16 represents ambient temperature variability by 2030s on a day when average "feels-like" temperature is 96°F (ambient temperature of 90°F) with relative humidity of 50-55%, with localized heat islands at or above 100°F

Using a combination of this existing data and proposed tree implementation amounts, it is possible to project the cooling impact from several potential scenarios. These projections were based on the 2030 Ambient Air Temperature maps produced by Kleinfelder as part of CCVA Part 1.

A model was developed in GIS to interpret the difference in ambient air temperature between existing conditions and several iterations of proposed tree implantation, represented as an increase of tree canopy by a defined percentage. A flow chart of the modeling approach is presented in Figure 17.

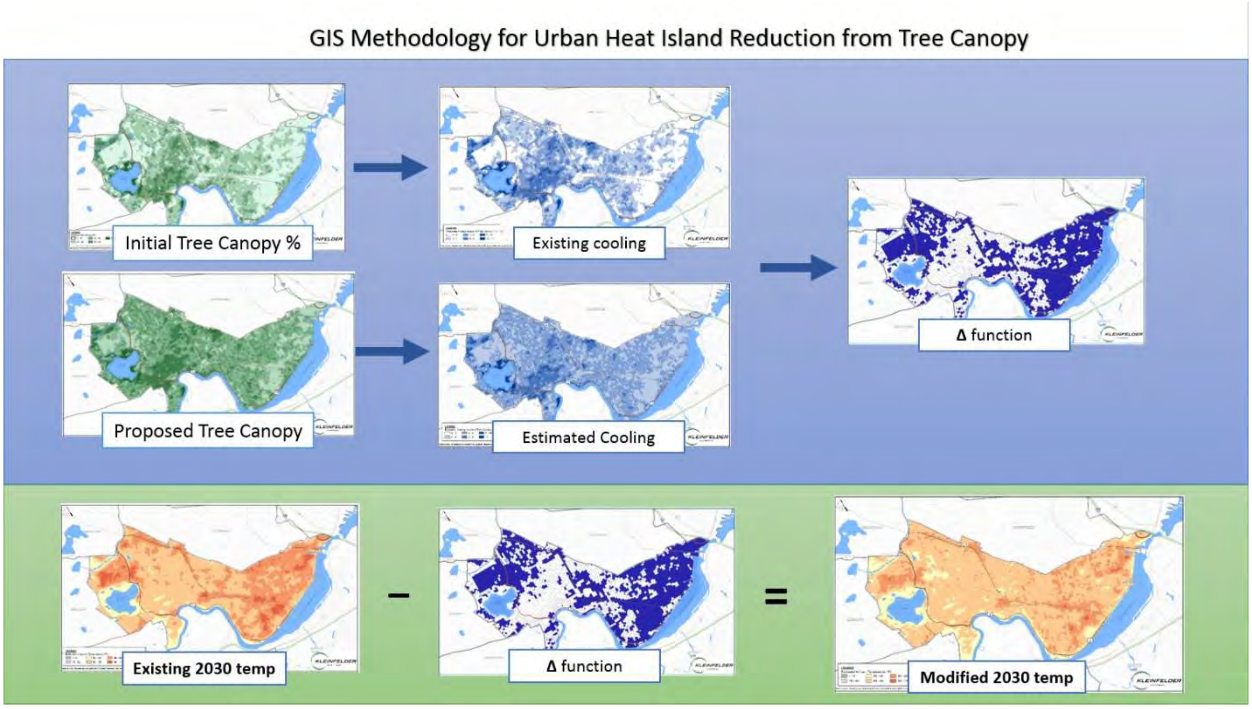



**Figure 17. Modeling Process for Tree Canopy Increase**

The UHI model takes two inputs and produces an updated 2030 temperature map to assess the impact of an enhanced tree canopy. The model inputs for estimating the tree impact are defined as the following:

**Tree Canopy Increase:** An additive increase of tree canopy percentage. For example, in this model a 20% tree canopy increase would bring an area with existing 10% canopy to 30%, or an area with 30% existing canopy to 50%

**Tree Canopy Threshold:** A percentage of existing canopy, below which would be targeted for planting at the defined level of implementation. For example, if the threshold was set to 30%, and the increase set to 20%, an area that currently has 15% canopy would be increased to 35% under this proposed scenario. An area that currently has 40% canopy would remain unchanged, as this is above the defined cutoff threshold.

Calculations were performed at the grid cell level of the existing heat and tree canopy data layers, which have a resolution of approximately 7 meters by 7 meters.

### 4.1.2 Cooling Impact of White Roofs

A white roof or cool roof is one that has been designed to reflect more sunlight and absorb less heat than a standard roof. Cool roofs can be made of a highly reflective type of paint, a sheet covering, or highly reflective tiles or shingles. Nearly any type of building can benefit from a cool roof[20]. The Solar Reflectance Index (SRI) value represents both the reflective and absorptive properties of the roof material. The higher the SRI value, the cooler the roof will be when exposed

[20] https://energy.gov/energysaver/energy-efficient-home-design/cool-roofs

to sunlight. Cool roofs typically have a SRI value of close to 90% when un-weathered, compared to a black roof which will typically have a SRI value of below 20%.

A cool roof may have a surface temperature as much as 50°F cooler than a conventional black roof. This results in a lower ambient air temperature in the vicinity of the buildings as this energy is reflected rather than being absorbed and later emitted as surface radiation (heat). White roofs have the benefit of reducing summertime energy usage, by decreasing air conditioning needs. This lowers peak energy demand and leads to lower surrounding ambient air temperatures.

The cooling impact of cool/white roofs was analyzed for buildings within the Alewife study area assuming that 50% of all existing buildings in the Alewife area across all land use types will be painted white. The total roof areas were calculated for each subcatchment using the City of Cambridge building footprint layer in GIS. The roof areas were represented as a percentage of total area for each subcatchment and a formula based on the total area to be modified (at a 50% implementation) was applied to predict the potential change in ambient temperature, should cool roofs be implemented.

## 4.2 Results

Modeling potential tree planting strategies using this tool, a significant reduction in Urban Heat Island effect was found to be possible at certain levels of implementation. Depending on the goal (such as, reduce or eliminate the extent of the heat-index *danger* areas of 2030), a strategy can be identified to optimize the tree canopy increase needed and where it would be implemented spatially.

Overall, with an aggressive level of implementation (>30% canopy increase) the models suggest that increased tree canopy coverage in the currently most vulnerable areas would have a significant impact in reducing the effects of urban heat island, lowering the ambient air temperature and heat index to below the NOAA defined danger threshold in most neighborhoods in the 2030 scenario. Figure 18 shows the reduced ambient air temperature in 2030 if tree canopy coverage is increased by 40% in areas that have less than 15% tree canopy coverage.

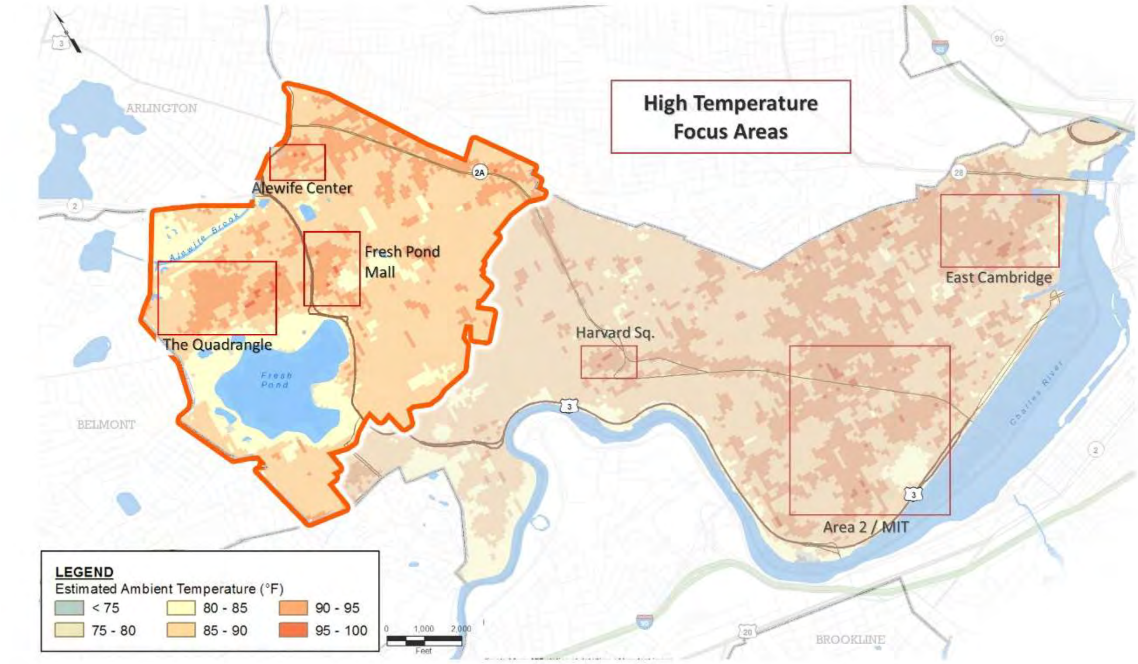



**Figure 18. 2030 Ambient Air Temperature Projections Using a 40% Tree Canopy Increase in Areas with Less Than or Equal to 15% Existing Tree Canopy**

### 4.2.1 Results on Tree Density Recommendations

Building upon the findings from predicting future cooling, this study sought to identify a proposed density of street tree implementation via a *tree count*, to provide direction to city officials, landowners, and developers as to what density of tree planting will achieve the desired effects in terms of cooling impacts.

There are a number of compounding variables which reduce the certainty of data correlation between existing tree count data and existing canopy raster / temperature data, so a more intensive strategy was used to assess street tree density and relate these counts to the existing ambient air temperatures.

Fifty streets in the Alewife area were analyzed for tree count and cooling impact using existing data combined with Google Street View Imagery. Trees were counted and tabulated along with the mean ambient air temperature on a given street segment, sampling multiple locations along the selected street. A linear relationship was found between street tree counts and tree canopy cooling, in areas with established street trees. For street trees, approx. 1°F of cooling is achieved per tree per 100 ft. (+/- 2 °F), up to a maximum observed impact of 6.5 °F within the Alewife study area. It should be noted that the overall temperature variation between individual may be greater than 6.5 °F, and in some areas as is high as 15 °F, however this is attributed to a combination of other factors beyond canopy coverage alone, such as density of buildings, green space, and urban morphology.

In addition to the impacts of shade cooling, a review of existing literature suggested that the effects of evapotranspiration in urban trees may provide up to 1°F of additional cooling benefit under idealized conditions. Tree/pant species type, tree density, atmospheric mixing ratio, soil moisture availability, and wind conditions are all variables which impact the local cooling potential of evapotranspiration, therefore the effect will not be experienced uniformly across the urban climate.

Figure 19 presents a visual comparison of the cooling effect that street trees can produce by looking at specific streets in the Alewife area and comparing their projected 2030 ambient air temperature, as well as the cooling effect of tree canopy on these streets. Figure 17 presents a rendering of the proposed tree spacing for a street in the Kendall Square area, such that 5 full size trees every 150 feet can result in a 3.5°F cooling.

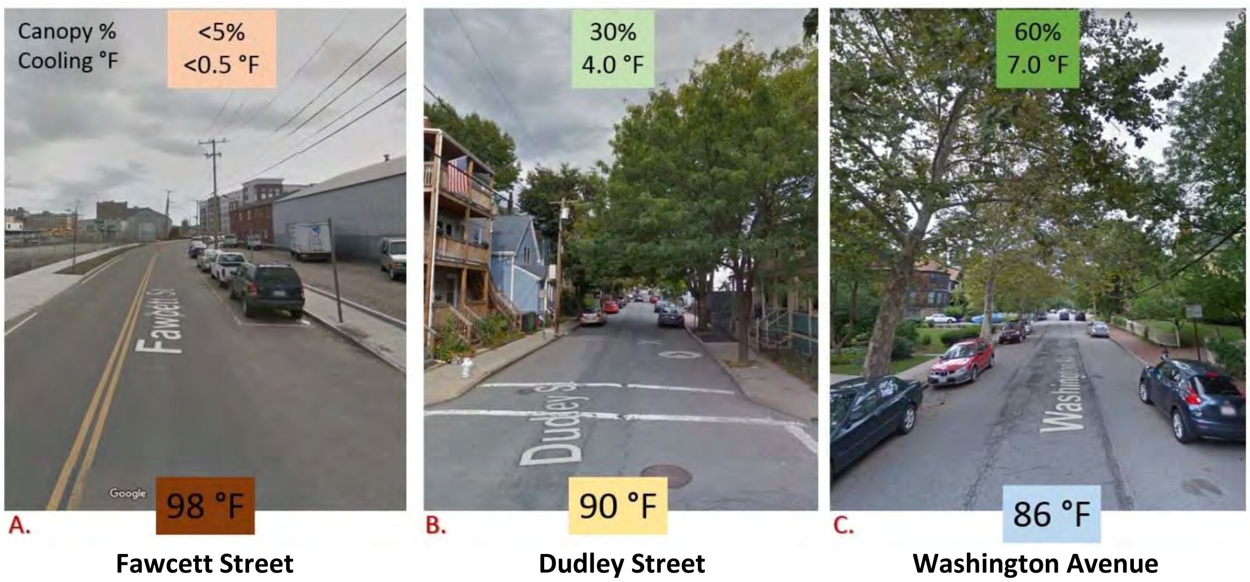



**Figure 19. Street Canopy % and Related Ambient Temperature Comparison in the Alewife Area**

- **Street A:** In this example, we have a street located in a light industrial area with a high percentage of impervious surfaces and low tree canopy coverage (<5%). Daytime ambient temperatures are projected to be 98 °F in the 2030 scenario (90°F)
- **Street B:** In this medium density residential street in North Cambridge, mature trees are spaced with an approximate density of 5 trees / 250 feet. In this case, this represents a canopy coverage of approximately 30%
- **Street C:** This street in Neighborhood Nine has mature trees with large canopy coverage on both sides of the street, including the presence of privately owned trees. In addition to amble trees, above average green space in the form of lawns, landscaping, and gardens results in lower than average impervious surface percentages within this streetscape. This street has approximately 60% tree canopy coverage.

Using results of the predictive model, a graphic rendering of Kendall Street as an example of possible improvements for Alewife is shown in Figure 20. Modeling results indicate that 5 trees over 150 feet (which relates to one tree every 30 feet) can achieve a cooling potential of 3.5°F. It is important to note that this estimated cooling effects of trees will be effective only after the trees reach mature canopy size, which may vary from one tree species to another.

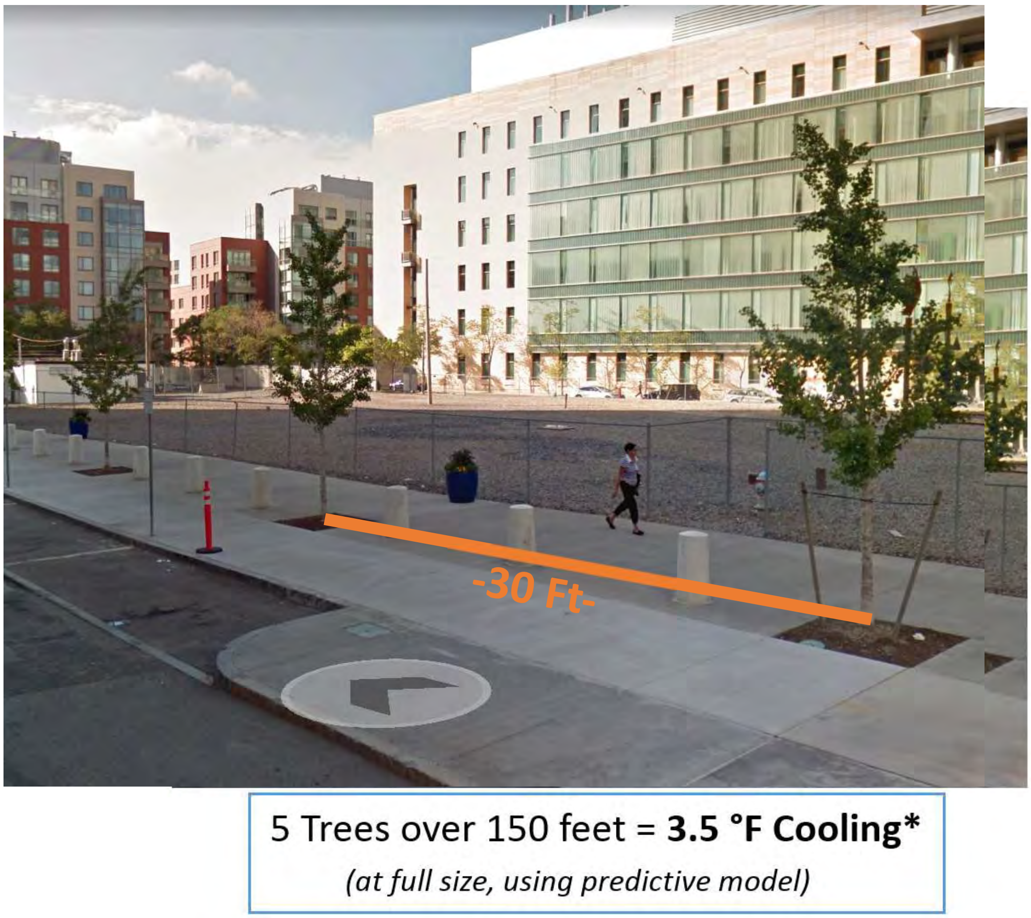
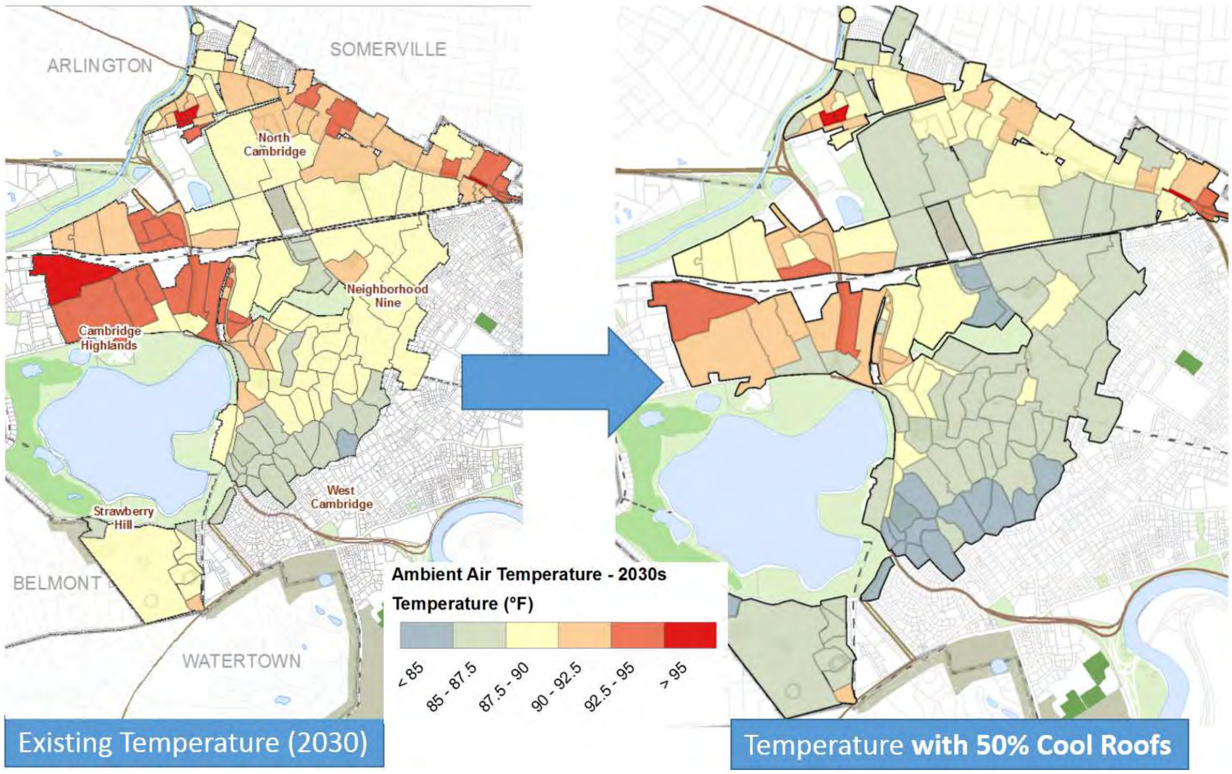



**Figure 20. New Tree Plantings on Kendall St Examined for Cooling Benefit Using the Predictive Model.**

### 4.2.2 Results on White Roofs

Figure 21a shows the mean 2030 ambient air temperature for each subcatchment under existing conditions and Figure 21b shows the reduced 2030 mean ambient air temperature for each subcatchment after 50% implementation of white roofs. The cooling impact of white roofs was found to be approximately 2.4 °F on average within the Alewife area at the projected 50% level of implementation. This is in part due to a high density of large roof surfaces, notably in the Quadrangle area where commercial and light industrial land use types dominate. Within these specific catchment areas, benefits as great as 4.5°F of cooling were noted.




**(a)** **(b)**

**Figure 21: 2030 Mean Ambient Air Temperature Summarized at the Subcatchment Scale under (a) Existing Conditions, and (b) Proposed Conditions with 50% Implementation of White Roofs**

## 4.3 Conclusions

An idealized scenario for mitigating UHI would involve a combination of an enhanced tree canopy and white/cool roofs, implementing the strategy that provides the greatest spectrum of benefits, considering site-specific parameters, cost limitations, and planned future development

## 4.4 Limitations and Next Steps

### 4.4.1 Tree Canopy

- The 2012 Tree canopy data is summarized at a 250-foot wide resolution which is limiting at the desired street by street scale of analysis.
- Variables such as age/size/species of tree, diameter of canopy affect the relative cooling benefit of any given tree, therefore unlike this analysis, not all trees have an identical cooling benefit.
- Literature suggests certain species are four times more effective at shading. Cambridge tree database has more than 32 different species listed
- Need for in-situ measurement of temperature data.

- Varying urban morphology and road widths/use types.
- Optimum tree spacing and increased survivability of street trees.
- Increased street trees within the public right-of-way may come at the expensive of limiting the areas available for street parking, bike infrastructure, and ADA compliant sidewalks.

### 4.4.2 White Roofs

- The Alewife area contains a variety of roofing types, shapes, and designs. Sloped roofs and flat roofs have different thermodynamic properties in addition to feasibility for hosting green infrastructure, which would impact the calculated results.
- Buildings in the Alewife area have considerably different heights and therefore the effects of cooling may not all affect ground ambient air temperatures. For example, if a white roof is installed on an 8-storey structure, the potential benefits cooling benefits are likely not being felt at ground level. They will however, still contribute to lowering the energy use of the facility.
- Cool roofs require maintenance to remain effective. This may include regular cleaning, since as the roof naturally darkens from exposure to dirt particles, the reflective capacity decreases significantly.

# 5.0 Key Findings

The green infrastructure analysis and impacts of tree canopy increase and white roofs on urban heat island effects was to address the City's questions on the impact of green infrastructure solutions on flooding and UHI, as well as to determine how effective approaches, such as increased tree canopy and white roofs are in terms of mitigating UHI by enhancing the urban tree canopy and implementing white roof. The key findings form the analysis are summarized below.

## 5.1 Flooding Mitigation & Water Quality Benefits of Green Infrastructure

Flooding volumes are anticipated to increase by approximately 160% for the 10-year 24 hour storm between present day and 2070 scenarios (13 million gallons to 33 million gallons). The implementation of Green Infrastructure can reduce the risk of flooding through increasing pervious surfaces capable of infiltration to groundwater, slowing the rate of discharge to existing stormwater infrastructure, and capture of precipitation into green roof and bioretention systems.

At the aggressive levels of implementation suggested in this memo, Green Infrastructure may reduce this 2070 flood risk to 21MG, a 37% reduction over forecasted peak flooding. In addition to a minimized volume, peak flowrates to combined sewer and stormwater systems are reduced

The study found that at MEP implantation, up to a 40% total phosphorus removal could be achieved within the Alewife watershed through the use of treatment type BMPs. This represents an approximate reduction of 400lbs per year, from a total estimated load of 1020lbs per year within the Alewife watershed.

## 5.2 Green Infrastructure, Tree Canopy and White Roofs Impacts on Mitigating UHI

An idealized scenario for mitigating UHI impact would involve a combination of green infrastructure and white/cool roofs, implementing strategies that provide the greatest spectrum of benefits, considering site-specific parameters. Within the Alewife watershed area, a maximum cooling benefit of 2.3 °F may be possible at a 50% level of implementation from white roofs alone. Figure 22 shows the comparison of the average 2030 ambient air temperature in the Alewife area under existing conditions with no green infrastructure or white roofs and the reduced ambient air temperature with green infrastructure and white roofs. It is expected that green infrastructure implementation at MEP scale can reduce the 2030 ambient air temperature from 90°F to 88.4°F, whereas if 50% of the roofs in the Alewife area are painted white, the 2030 ambient air temperature is expected to similarly reduce from 90°F to 87.7°F

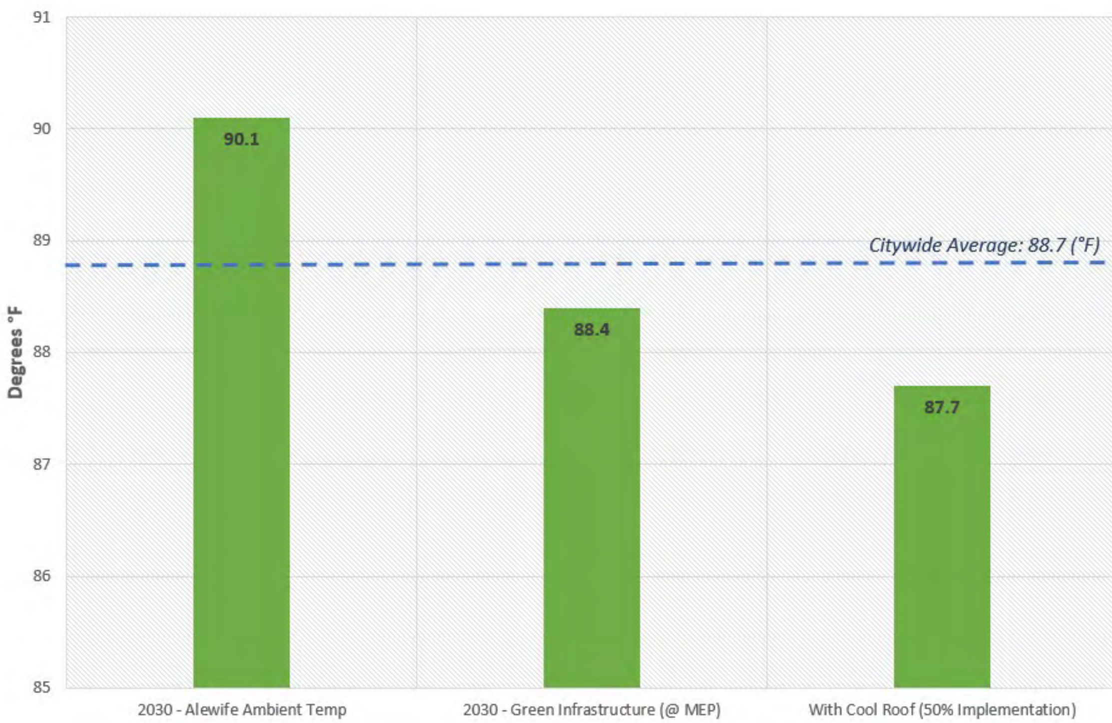



**Figure 22. Comparison of Cooling Strategies for Green Infrastructure BMPs and White/ cool roofs for mitigating projected 2030 ambient air temperature**

Enhancing the tree canopy would also significantly contributing in mitigating UHI. Targeted approaches modeled an aggressive tree canopy increase in areas which currently have less than or equal to 15% canopy coverage. A 40% increase in these scenarios would represent an approximate 4.8 degree reduction in ambient air temperature over existing conditions, which would reduce the spatial extent of projected heat island health danger zones.

Additionally, street scale recommendations were developed, providing an estimated cooling benefit from tree density along a given streetscape. This relationship was found to be approximately 1°F of cooling is per tree per 100 ft. (+/- 2 °F), up to a maximum observed impact of 6.5 °F within the Alewife study area.

For example, a street segment with a length of 400 feet which included 16 trees could expect a potential cooling benefit of 4°F averaged across the length of the street.

Combined with green infrastructure, tree planting is shown to be an effective strategy for reducing urban heat islands by lowering temperature, in addition to improving air quality in urban areas, leading to more sustainable, prepared and resilient communities.

Attachment 1

# Green Infrastructure Concept Overview for Typical Parcels

## Alewife Watershed Area, Cambridge, MA

City of Cambridge
**Climate Change Preparedness & Resiliency (CCPR) Plan**

Prepared by Chester Engineering

May 2017

For

Kleinfelder

# Green Infrastructure Concept Overview for Typical Parcels within Alewife Watershed Area of Cambridge, MA

## Introduction and Purpose

The purpose of this memorandum is to summarize the approach used in the selection and treatment potential of Green Infrastructure (GI) Best Management Practices (BMP's) in the Alewife watershed area in Cambridge, MA. First, typical parcels were selected per land use type using categories of medium- and high-density residential, commercial, public-right-of-way street, light industrial, and open space). Then, conceptual GI design strategies were developed per land use type for each of these typical parcels. Using these conceptual designs, Kleinfelder will then develop hydrologic inputs for each catchment area in the Alewife watershed area, which will then be modeled computationally by MWH to determine the benefits in terms of flooding peak flow and volume reduction as a result of various levels of implementation of these GI strategies. The water quality benefits in terms of phosphorous load reduction to the Alewife Brook will be quantified as a result of implementation of these green infrastructure strategies.

The six typical parcels for the Alewife area were selected based on feedback from the City.

Typical parcels to be investigated for GI opportunities:

1. Medium Density Residential (Retro-fit)
2. Commercial (Retro-fit)
3. Public Open Space (Retro-fit)
4. Public Right-of-Way "A" Street (New)
5. High Density Residential (New)
6. Light Industrial (New)

## Background and GI Stormwater BMP Selection

Types of Green infrastructure (GI) include infiltration based systems such as bioretention basins, planter or tree boxes, water quality swales, and porous/permeable pavements. Other types of GI include green roofs, rainwater harvesting, downspout disconnection, and tree planting.

Infiltration-based BMP's are pervious stormwater treatment devices that promote temporary storage and pollution mitigation through physical, chemical and biological interaction between the infiltrating runoff and the rock/soil medium through which it passes. Depending on site circumstances and design objectives, these devices may or may not be designed to promote groundwater recharge thru exfiltration into adjacent soils.

Proximity to the Cambridge Class A water supply reservoir at Fresh Pond, precludes exfiltration. Cambridge DPW utilizes a mixture of calcium chloride-based products as its primary deicing agent on streets. Minimizing chloride contamination in the reservoir by migrating groundwater is a priority. For these reasons, infiltrating BMPs within the Alewife Brook catchment with groundwater flow toward Fresh Pond will need to contain subdrains that remove the majority of the infiltrated runoff to the storm drain system. Alewife Brook catchment areas further to the north likely have groundwater flowing toward Little River and not Fresh Pond; therefore exfiltration would not impact the water supply. Proximity to the seasonal high water table (SHWT) elevations must also be considered, which will limit the depth of the BMPs and types of BMPs that can be used at certain sites. Also, medium to thick clay layers are present in soils in this area and would have to be excavated if encountered.

## BMP Capture Volume

Massachusetts Stormwater Regulations require treatment of the first ½ inch, the so-called first flush; however, the City of Cambridge favors the more stringent 1-inch and most recently the 1.5-inch requirement.

## Summary of GI Strategies per Typical Parcel

### 1. Medium Density Residential (Retro-fit)

72 Standish Street was selected as an existing medium density residential parcel to assess for retro-fit green infrastructure opportunities.

**Figure 1: Medium Density Residential Parcel**

Single Lot Assumptions:

- 40' x 150' = 6,000 sf typical lot size
- Percent Impervious = 60% (30% Building, 30% Pavement)
- Impervious Area = 3,600 sf
- Depth to Water Table < 5 ft.

Water Quality Volume (WQV):

- Water Quality Depth x Impervious Area
- 1.5-inch WQV = (1.5 inch/12) x (3,600 sf) = 450 cf
- 1.0-inch WQV =(1.0 inch/12) x (3,600 sf)= 300 cf

Green Infrastructure Strategies Considered:

- Rain Barrel
- Dry Well
- **Above-ground Planter**
- **Bioretention Basin**
- **Porous Paving - Driveway** and/or Walkways
- Subsurface Infiltration Chambers
- Subsurface Rain Cistern

The GI strategies selected for the medium-density residential parcel are highlighted in bold above.

Bioretention Basins (Biobasins) are the preferred stormwater BMP since they are recognized by EPA and MA DEP for their effectiveness at phosphorous removal (30-90% according to the MA Stormwater Handbook) as well as nitrogen, organics, bacteria, metals and hydrocarbon removal (See Figure 2 and Figure 3). The benefits of the above-ground planters will be similar to those of the biobasin.

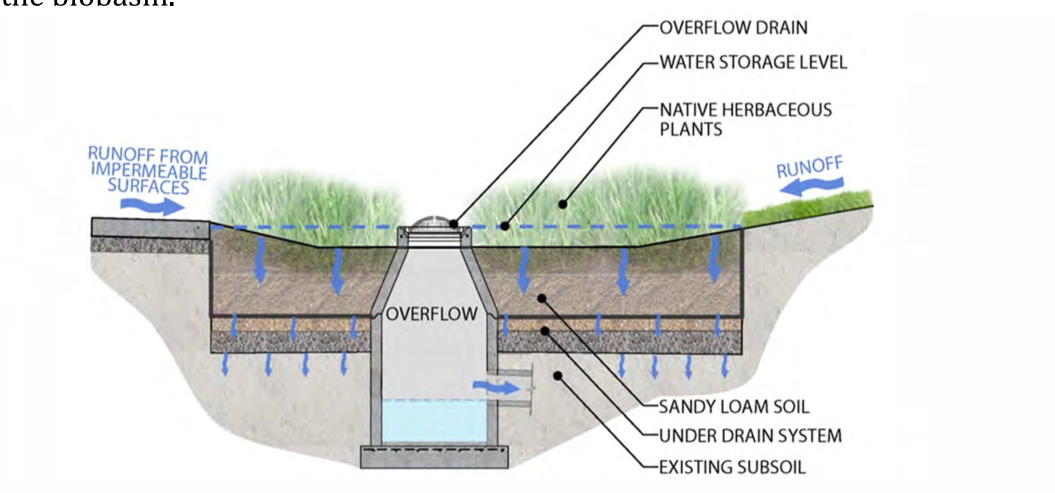



**Figure 2: Bioretention Basin Typical Section**

**Figure 3: Bioretention Basin**

Porous asphalt pavement can be installed in driveways with a slope less than or equal to 4%. Groundwater conditions will limit the depth of the typical porous pavement BMP to 36 inches. A porous asphalt section similar to what was installed in the parking lanes of streets in Cambridge as part of the CAM 004 Project can be used (see Figure 4). In the typical section four inches of porous asphalt at the surface permits water to infiltrate, transmitting runoff to the next level quickly. From that point it infiltrates through two distinct types of material beginning with a stone choker course, a stone-filled reservoir course, a filter course, and a stone-filled base course with the subdrain.

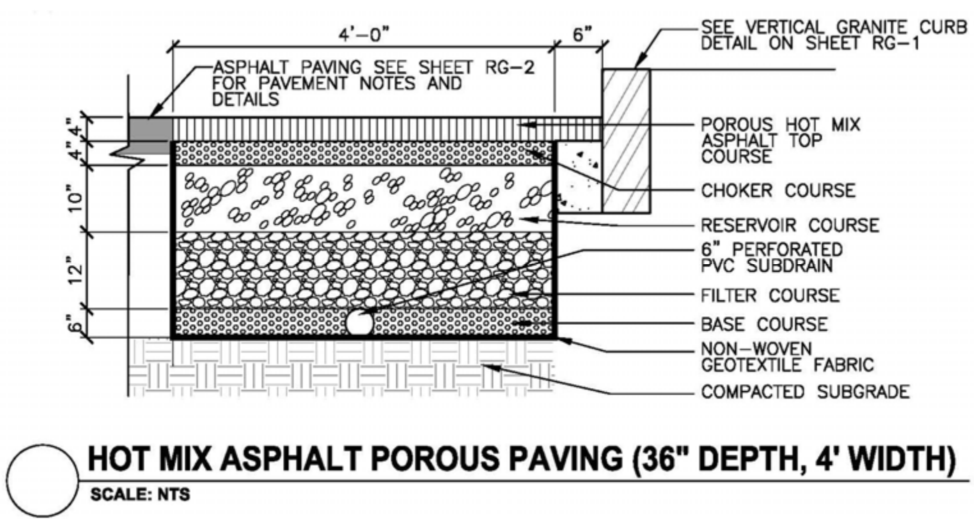



**Figure 4: Porous Pavement Detail**

Rain barrel and rain cisterns were not chosen since the storage they provide will reduce stormwater runoff as long as they are emptied between storms, but they offer no pollutant removal benefits.

Dry well and subsurface infiltration chambers were not chosen due to the depth to SHWT and the additional footprint that they would require within the parcel.


**Figure 5: GI Concept for Medium Density Residential Parcel**

Volume Stored and Treated:

- Above-Ground Planter
  Area = 12 ft. x 3 ft. =36 sf
  Assume planting soil depth = 2 ft.
  Assume soil has 20% voids
  Storage Volume = 36 sf x 2 ft. x 0.20 = 14 cf

- Porous Asphalt Driveway
  Area = 8 ft. x 70 ft. = 560 sf
  Assume reservoir stone depth = 9 inches
  Assume stone has 40% voids
  Storage volume = 560 sf x (9 in./12) x 0.40 = 168 cf

- Bioretention Basin
  Area = 25 ft. x 12 ft. = 300 sf

Assume 0.5 ft. of ponding depth
Assume 2 ft. of soil storage with 20% voids
Storage volume = (300 sf x 0.5 ft.)+(300 sf x 2 ft. x 0.20) = 270 cf

- Total Water Quality Storage Volume = 14 cf + 168 cf + 270 cf = 452 cf
- ~ 1.5-inch Water Quality Depth

## 2. Commercial (Retro-fit)

220 Alewife Brook Parkway, Hotel Tria, was selected as an existing commercial parcel to assess for retro-fit green infrastructure opportunities.

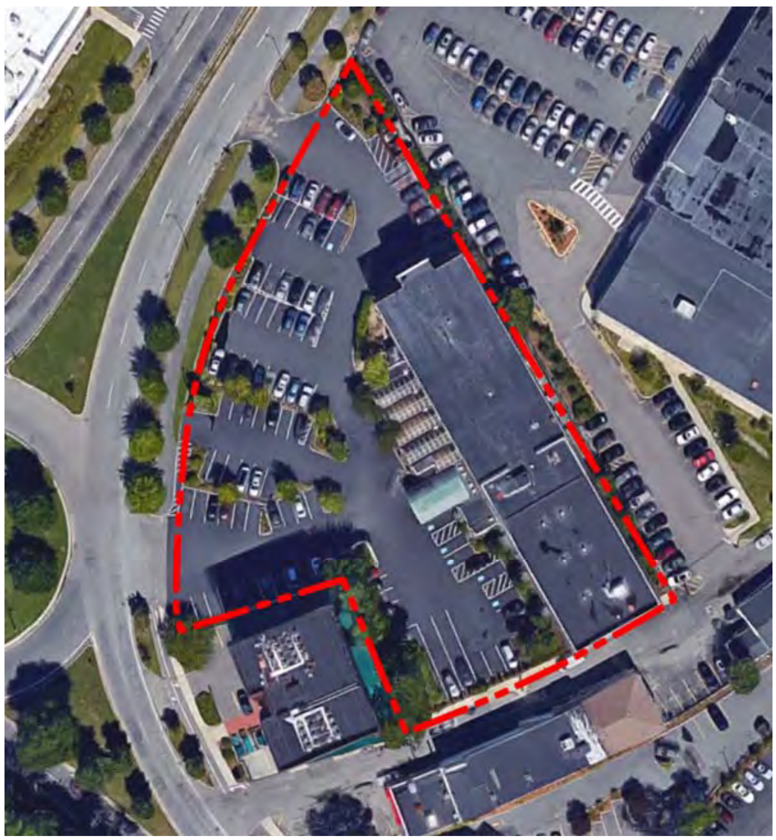


**Figure 6: Commercial Parcel**

Commercial Lot Assumptions:

- Lot size = 58,906 sf
- Percent Impervious = 95% (30% Building, 65% Pavement)
- Impervious Area = 55,960 sf
- Depth to Water Table < 4 ft.

Water Quality Volume (WQV):

- Water Quality Depth x Impervious Area
- 1.5-inch WQV = (1.5 inch/12) x (55,960 sf) = 6,995 cf
- 1.0-inch WQV =(1.0 inch/12) x (55,960 sf)= 4,663 cf

Green Infrastructure Strategies Considered:

- Bioretention Basin
- Water Quality Swale
- **Porous Paving**
- Subsurface Infiltration Chambers
- Blue Roof
- **Green Roof**

The GI strategies selected for the commercial parcel are highlighted in bold above.

Bioretention basins, water quality swales, and subsurface infiltration chambers were not selected as viable GI strategies due to the depth to SHWT and the additional footprint that they would require within the parcel. Since this is a retrofit site, impact to the existing parking and operations of the commercial site must be considered when considering the GI strategies.

Porous asphalt pavement can be installed parking stalls with a slope less than or equal to 4%. The parking stalls are selected to be porous since they will receive less traffic volume and are lower speed areas (see Figure 7). Porous asphalt is not ideal for high traffic and high speed areas because it has lower load-bearing capacity than conventional pavement. Groundwater conditions will limit the depth of the typical porous pavement BMP to 36 inches. A porous asphalt section similar to what was installed in the parking lanes of streets in Cambridge as part of the CAM 004 Project is recommended to be used here and includes a subdrain (see Figure 4).

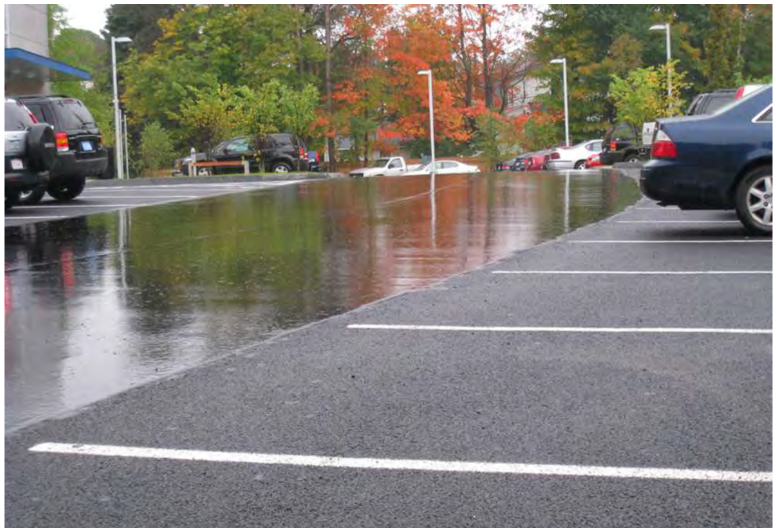


**Figure 7: Porous Asphalt Parking Stalls**

Green roofs can be installed on existing buildings after a professional structural engineer assesses the necessary load reserves and ensures the roof structure meets state and local codes. Green roofs are ideal for structures with a wide roof area that is flat or with slopes less than 15%. An extensive green roof requiring less than 6-inches of soil medium, supports mostly herbaceous plants, has no public access, and requires low maintenance is recommended (see Figure 8 and 9). A green roof will reduce total runoff volume through rainwater storage and evapotranspiration; reduce peak discharge rates; reduce heating and cooling costs through roof insulation; extend roof life; and reduce “heat island” effect.

**Figure 8: Extensive Green Roof**

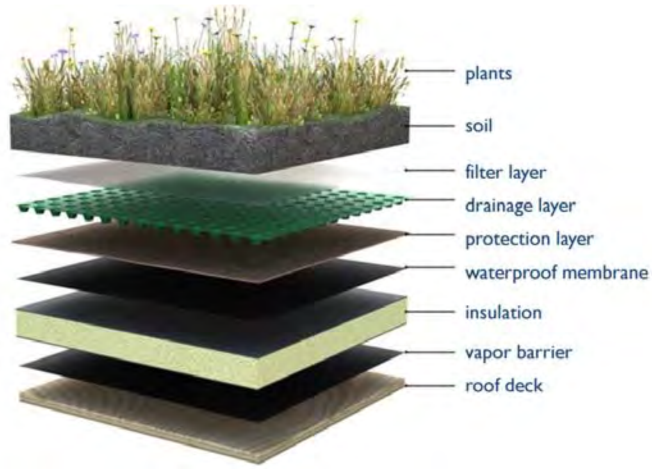



**Figure 9: Typical Extensive Green Roof Section**


**Figure 10: GI Concept for Commercial Parcel**

Volume Stored and Treated:

- Porous Asphalt Parking Stalls
  Area = 12,000 sf
  Assume reservoir stone depth = 9 inches
  Assume stone has 40% voids
  Storage volume = 12,000 sf x (9 in./12) x 0.40 = 3,600 cf

- Green Roof
  Area = (120 ft. x 50 ft.) + (40 ft. x 50 ft.) = 8,000 sf
  Assume 1.6 inch retention in 4-inch extensive green roof system
  Storage volume = 8,000 sf x (1.6 in./12) = 1,067 cf

- Total Water Quality Storage Volume = 3,600 cf + 1,067 cf = 4,667 cf
- ~ 1.0-inch Water Quality Depth

### 3. Public Open Space (Retro-fit)

Rafferty Park at 795 Concord Avenue was selected as an existing public open space parcel to assess for retro-fit green infrastructure opportunities. Even though this parcel is meant to be representative of a typical public open space parcel, the park appears to be unique in that it abuts no City streets and its location is over 15 feet above the elevation of the streets in the vicinity. This precludes the possibility of gravity transfer, via a right-of-way, of runoff for water quality treatment or flood storage. There is, however, a large parking area located on the southern boundary, which drains onto the access path of the park and across the playing field. A portion of this runoff that can be treated with on-site bioretention with minimal disruption to athletic field activities. The runoff from the on-site paved surfaces can also be captured.

**Figure 11: Public Open Space Parcel**

Public Open Space Lot Assumptions:

- Lot size = 99,999 sf
- Percent Impervious = 9%
- On-site Impervious Area = 9,000 sf
- Assume Off-site Impervious Area=4,500 sf
- Depth to Water Table > 14 ft.
- Runoff from surrounding infrastructure is typical for open space areas
- Treatment impacts to recreation space must be minimal
- Subsoil drains at 2 in/hr minimum to exclude subdrains

Water Quality Volume (WQV) including off-site runoff:

- Water Quality Depth x Impervious Area
- 1.5-inch WQV = (1.5 inch/12) x (13,500 sf+) = 1,688 cf
- 1.0-inch WQV =(1.0 inch/12) x (13,500 sf+)= 1,125 cf

Green Infrastructure Strategies Considered:

- **Bioretention Basin**
- **Water Quality Swale**
- Porous Paving
- Subsurface Infiltration Chambers

The GI strategies selected for the public open space parcel are highlighted in bold above.

Pretreatment for the contaminated runoff will consist of a shallow grass swale, 10 feet wide and 6 inches deep leading into a 12 inch deep grass covered depression with a bioretention basin soil profile (See Figure 2). The swale should present no obstacle to pedestrians crossing it to gain access to the athletic field, and the basin should appear obvious only when charged with runoff.

The bioretention basin itself will function as a level spreader for rainfall events that exceed basin capacity. With subsoil draining at 2 in/hr, standing water in the basin should disappear in 6 hours. If the existing soil does not drain at 2 in/hr, elevation change on-site would permit a subdrain system.


**Figure 12: GI Concept for Public Open Space Parcel**

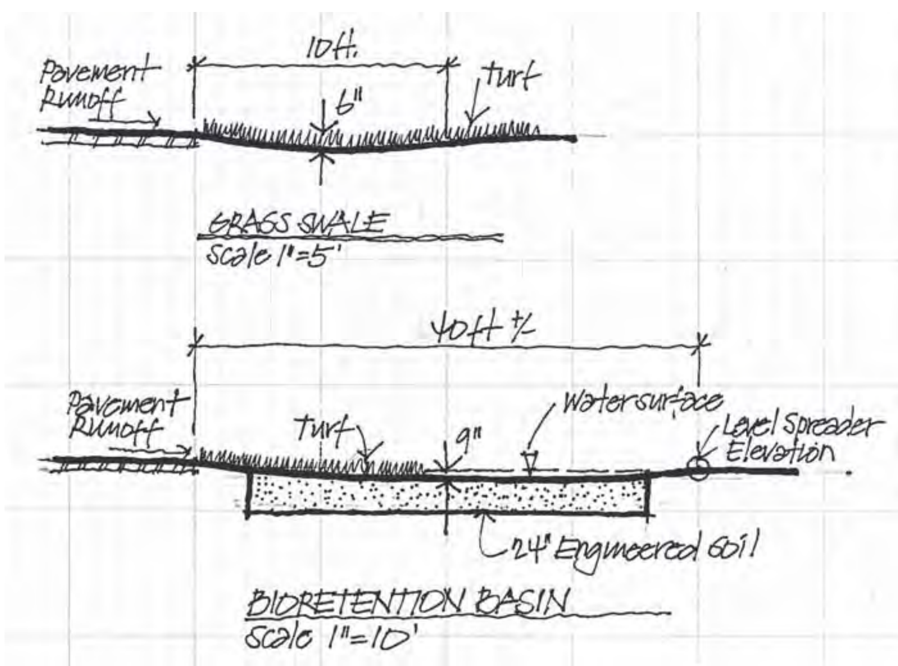



**Figure 13: Sections for Public Open Space Parcel**

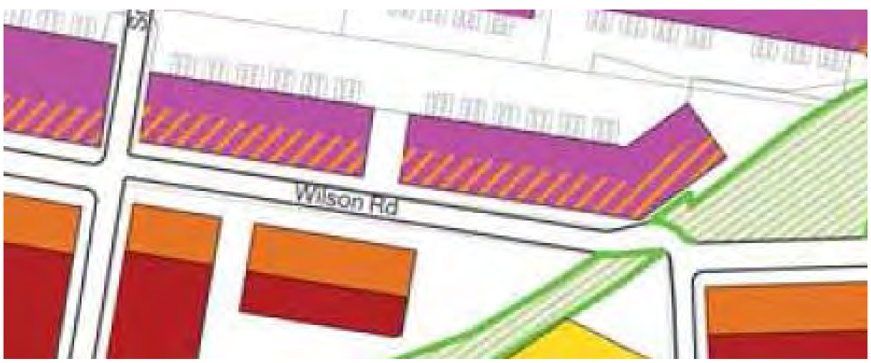
Volume Stored and Treated:

- Bioretention Basin
  Area = 1,500 sf
  Assume 0.75 ft. of ponding depth
  Assume 2 ft. of soil storage with 20% voids
  Storage volume = (1,500 sf x 0.75 ft.)+(1,500 sf x 2 ft. x 0.20) = 1,725 cf

- Total Water Quality Storage Volume = 1,725 cf
- ~ 1.5-inch Water Quality Depth

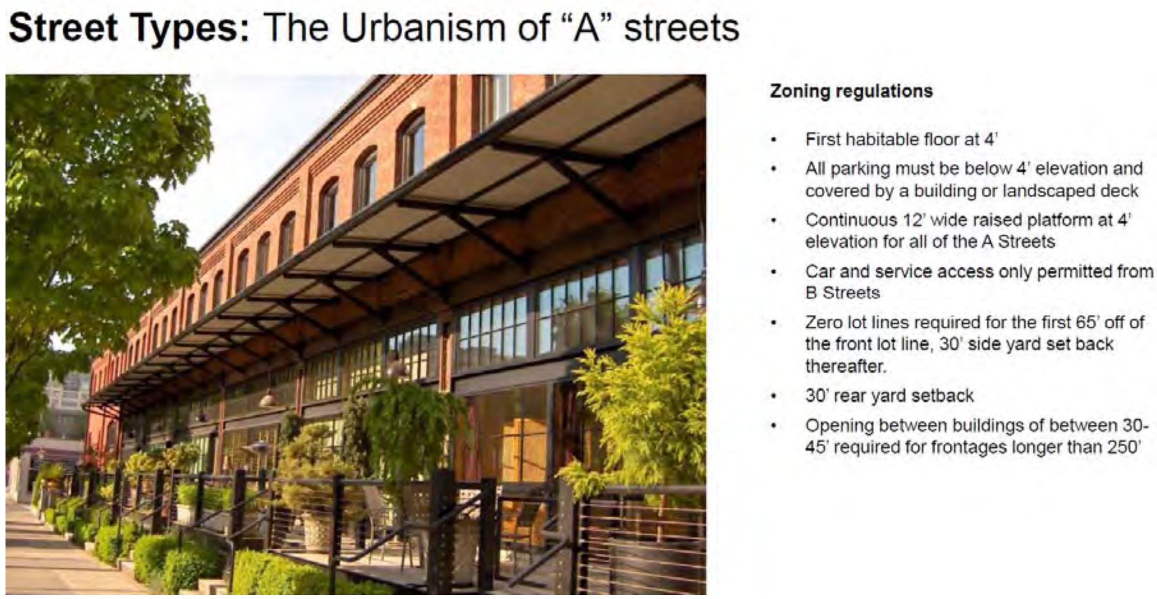
### 4. Public Right-of-Way "A" Street (New)

Wilson Road is an existing public right of way (ROW) parcel that per Envision Cambridge (Envision) will be reconfigured and reconstructed as a Type "A" Street. Refer to Figure 15 below which includes the zoning regulations associated with "A" Streets. The cross-section of the Type "A" Street provided by the Envision team on May 10, 2017 is also below, see Figure 16.



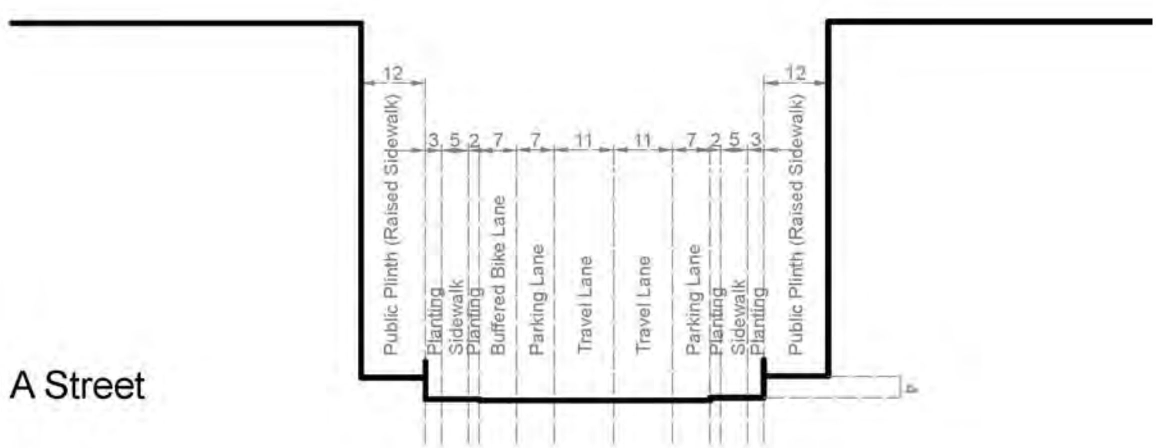

Source: Envision Cambridge

**Figure 14: Wilson Road – Public ROW Parcel**




Source: Envision Cambridge

**Figure 15: "A" Street**




Source: Envision Cambridge

**Figure 16: "A" Street Section**

Direction given by Kleinfelder was to assess Wilson Road for green infrastructure opportunities making alternative layout suggestions as necessary to optimize the green infrastructure capabilities of the street.

Alternative layout suggestions as part of the GI concept for this parcel include combining the 3 ft. and 2 ft. planting strips to make one 5 ft. planting and amenity area on each side of the street and moving it to the back of curb. This will allow for better tree planting and GI opportunities and provide tree canopy over the sidewalk and street. The 12-foot wide, 4-foot elevated public plinths on each side could be constructed with wooden deck planking to allow for infiltration through the deck to the subgrade below.

Public ROW Parcel Assumptions:

- Length = 700 ft.
- Width=63 ft. (not including public plinth, raised sidewalk)
- Lot size = 44,100 sf
- Percent Impervious = 88% 39280
- Depth to Water Table Varies ~ 3 - 5 ft.

Water Quality Volume (WQV):

- Water Quality Depth x Impervious Area
- 1.5-inch WQV = (1.5 inch/12) x (38,800 sf) = 4,850 cf

Green Infrastructure Strategies Considered:

- **Curb Extension Bioretention Basin**
- Stormwater Planter
- **Porous Paving – Porous Asphalt and Permeable Pavers**
- Subsurface Infiltration Trenches
- Dry Wells
- **Street Trees**

The GI strategies selected for the public ROW parcel are highlighted in bold above.

Curb Extension Bioretention basins, street trees, and porous pavement were selected as GI strategies (see Figure 17 and 18). Approximately two-thirds of the street will have a 2ft. separation from the seasonal high water table (SHWT) allowing for exfiltration as along as the infiltration rate for the soils in this area are acceptable. In areas where the depth to groundwater will prohibit exfiltration, a subdrain can be used.

On the north side of Wilson Rd. porous asphalt can be installed in the bike and parking lane and will manage direct rainfall and runoff from the adjacent 11-foot travel lane. A 5-foot planting strip with street trees between the 5-foot sidewalk and the bike lane will provide tree canopy and will manage runoff from the adjacent sidewalk. The depth to ground water varies along the length of the street. The depth of the typical porous pavement BMP will be 36 inches, (see Figure 4).

On the south side of Wilson Road, three, 40-foot long by 12-foot wide curb extension bioretention basins will manage runoff from the adjacent 11-foot travel lane, parking lane, and sidewalk. In the 5-foot strip between the parking lane and sidewalk, permeable pavers and street tree plantings will manage runoff from the adjacent sidewalk. The tree planting pit s will be limited to 3-foot width to allow for a 2-foot wide step-out zone for the parking lane. Cut through areas from the step-out zone to the sidewalk will be provided.

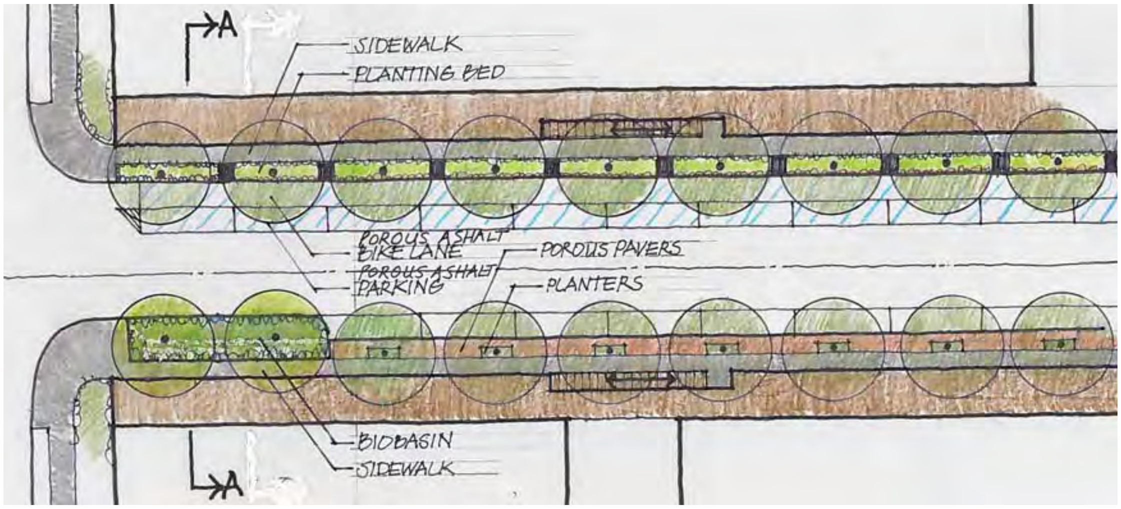



**Figure 17: GI Concept for Public ROW Parcel**

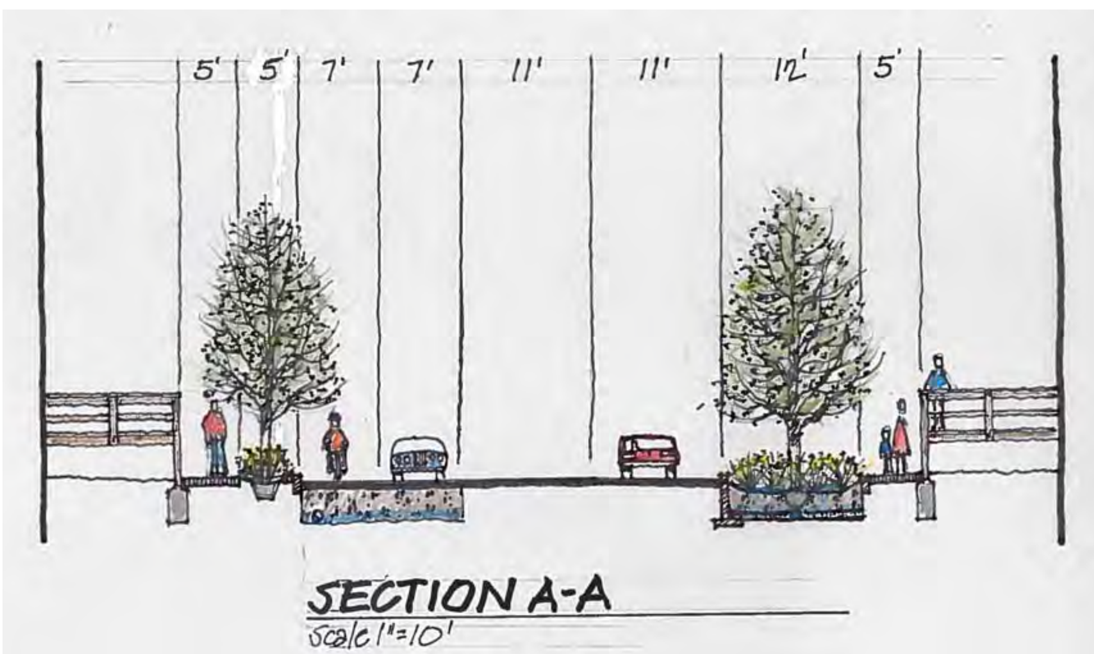
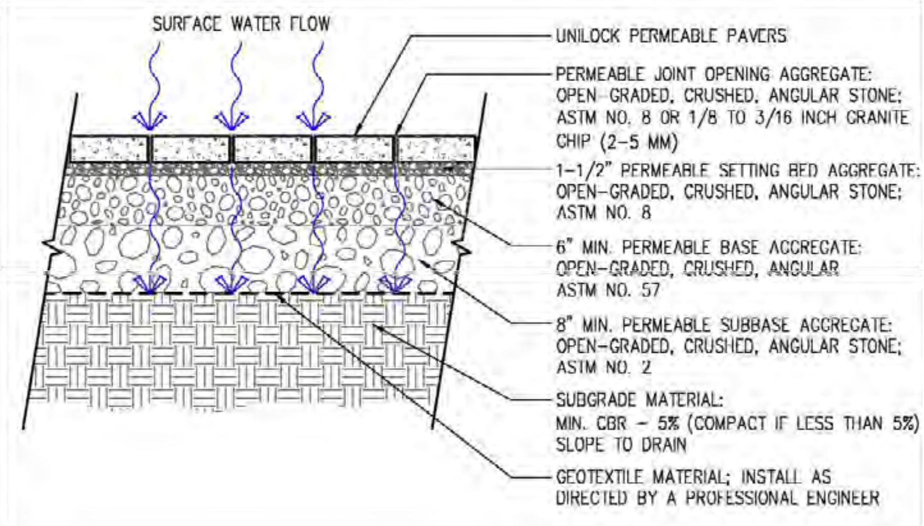



**Figure 18: Section A-A for GI Concept for Public ROW Parcel**




Source: Unilock

**Figure 19: Permeable Paver Section for Exfiltration**

Volume Stored and Treated:

- Porous Asphalt Parking and Bike Lane
  Area = (7 ft + 7 ft.) x (700 ft.) = 9,800 sf
  Assume reservoir stone depth = 9 inches
  Assume stone has 40% voids
  Storage volume = 9,800 sf x (9 in./12) x 0.40 = 2,940 cf

- Bioretention Basin
  Assume 3, 40-foot long by 12-foot wide with 10 ft. usuable
  Area = 3(37 ft. x 9 ft.) = 999 sf
  Assume 1 ft. of ponding depth
  Assume 2 ft. of soil storage with 20% voids
  Storage volume = (999 sf x 1.0 ft.)+(999 sf x 2 ft. x 0.20) = 1,399 cf

- Permeable Pavers
  Area = (580 ft. x 1.5 ft.) + (580 ft. x 3 ft.x0.33) = 1,450 sf
  Assume reservoir stone depth = 14 inches
  Assume stone has 40% voids
  Storage volume = 1,450 sf x (14 in./12) x 0.40 = 677 cf

- Total Water Quality Storage Volume = 2,940 cf + 1,399 cf +677 cf
  = 5,016 cf
- > 1.5-inch Water Quality Depth

## 5. Light Industrial (New)

The area bounded by Fawcett Street, Smith Place, Adley Road, and Spinelli Place was selected as the Light Industrial Parcel to be assessed for GI opportunities. As part of Envision Cambridge (Envision) this is planned for four mixed-use industrial buildings. Fawcett Street and Adley Road will be Type "A" Streets with a proposed pedestrian walkway from Fawcett Street to Adley Road between the buildings. Spinelli Place and Smith Place will be Type "B" Streets and serve for vehicular access to the buildings. Refer to Figure 20 below and Figure 21, a rendering provided by the Envision team from an April 27, 2017 Alewife Working Group presentation.


**Figure 20: Light Industrial Parcel**

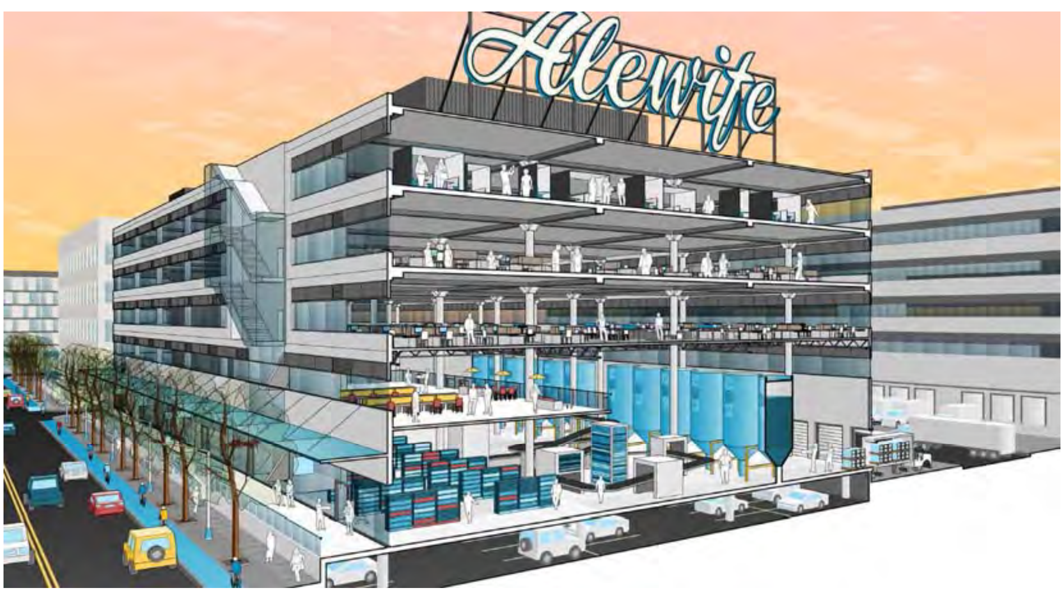



**Figure 21: Light Industrial Rendering**

Direction given by Kleinfelder was to assess the Light Industrial parcel for green infrastructure opportunities by maximizing pervious surface while allowing vehicular traffic movement, planning for green/blue roofs, and making alternative layout suggestions as necessary to optimize the green infrastructure capabilities.

Light Industrial Parcel Assumptions:

- Projects will cover an entire block
- First floor will be 4 feet above existing ground
- Deliveries will be concentrated in the interior of the block
- Parking will be beneath the buildings, approximately 4 feet below existing ground and will be limited to the footprint of the buildings above.
- Approximate Lot size = 274,200 sf
- Percent Impervious = 88% (52% Buildings, 36% Pavement)
- Depth to Water Table Varies ~ 5 ft.

Water Quality Volume (WQV):

- Water Quality Depth x Impervious Area
- 1.5-inch WQV = (1.5 inch/12) x (241,296 sf) = 30,162 cf

Green Infrastructure Strategies Considered:

- **Bioretention Basin**
- Porous Paving
- Subsurface Infiltration Chambers
- Blue Roof
- **Green Roof**

The GI strategies selected for the Light Industrial parcel are highlighted in bold above.

Subsurface infiltration chambers were not selected as viable GI strategy due to the depth to SHWT. Porous asphalt is not ideal for high traffic and heavy trucks because it has lower load-bearing capacity than conventional pavement. Green roofs were selected instead of blue roofs since the buildings are for industrial use and would not have as much need for reusing non-potable water for toilet flushing or for landscape watering. Blue roofs would be better suited for commercial office buildings or high density residential buildings.

Bioretention basins and green roofs were selected as GI strategies (see Figure 22). There may be a 2ft. separation from the seasonal high water table (SHWT) allowing for exfiltration as along as the infiltration rate for the soils in this area are acceptable. In areas where the depth to groundwater will prohibit exfiltration, a subdrain can be used.

Green roofs are proposed for the new buildings. Approximately 67% of the building is assumed to be green roof and the remaining 33% of the roof will be occupied by mechanical equipment and access paths. An extensive green roof requiring less than 6-inches of soil medium, supports mostly herbaceous plants, has no public access, and requires low maintenance is recommended (see Figure 8 and 9). Although, raised beds for an urban farm are also a potential option that could be considered.

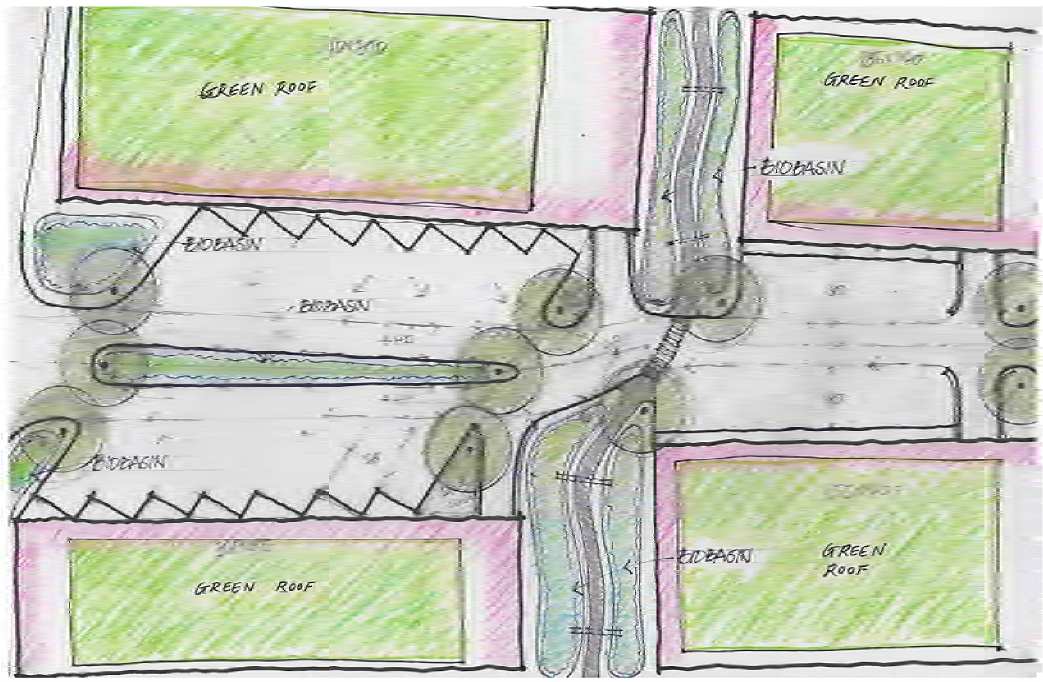



**Figure 22: GI Concept for Light Industrial Parcel**

Volume Stored and Treated:

- Bioretention Basin
  Total Area = 20,000 sf
  Assume 0.75 ft. of ponding depth
  Assume 1.5 ft. of soil storage with 20% voids
  Storage volume = (17,000 sf x 0.75 ft.)+(17,000 sf x 1.5 ft. x 0.20)
  = 17,850 cf

- Green Roof
  Area = 0.67((140 ft. x 370 ft.) + (185 ft. x 140 ft.)+(320 ft. x 95 ft.)+(255 ft. x 140 ft.)) = 0.67(143,800 sf) = 96,346 sf
  Assume 1.6 inch retention in 4-inch extensive green roof system
  Storage volume = 96,346 sf x (1.6 in./12) = 12,846 cf

- Total Water Quality Storage Volume = 17,850 cf + 12,846 cf = 30,696 cf
- > 1.5-inch Water Quality Depth

### 6. High Density Residential (New)

The area bounded by Fawcett Street to the west, Concord Street to the south, a new Type "A" Street to the north, and Wheeler Street and existing buildings to the east was selected as the High Density Residential (HDR) Parcel to be assessed for GI opportunities. As part of Envision this is planned to have two buildings with 72 and 61 residential units each. Refer to Figure 23 below provided by the Envision team from an April 27, 2017 Alewife Working Group presentation and Figure 24 provided by the team on May 11, 2017.

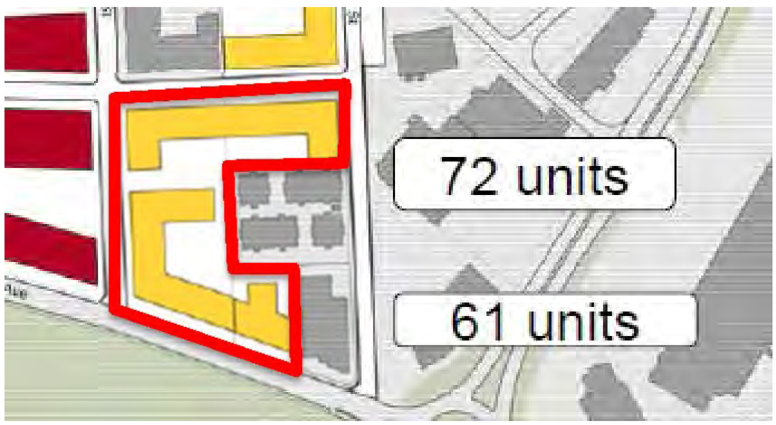



**Figure 23: High Density Residential (HDR) Parcel**

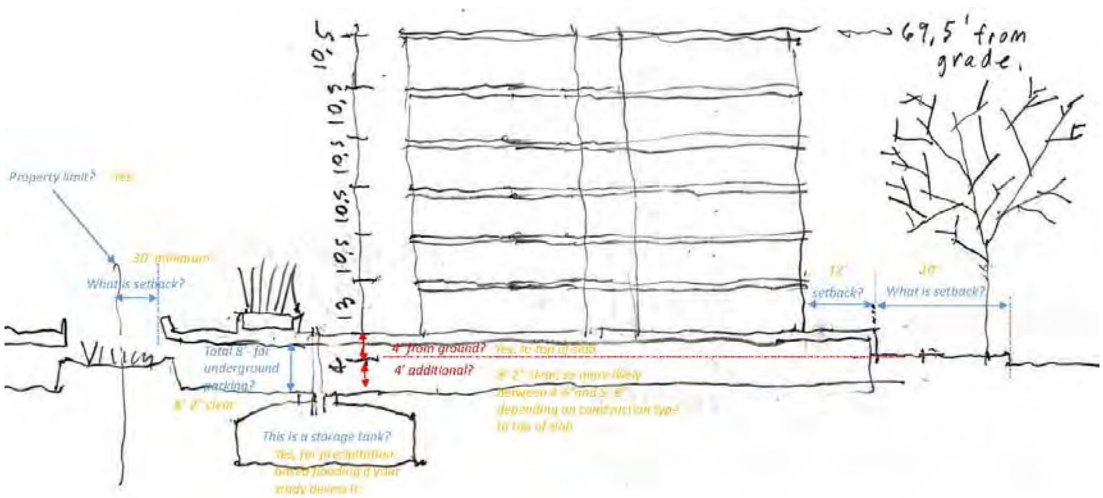



**Figure 24: High Density Residential (HDR) Section**

Direction given by Kleinfelder was to assess the HDR parcel for green infrastructure opportunities by maximizing space for GI assuming no underground parking in the backyard space. Also, taking into account that the building is raised by 4 ft. allowing for green infrastructure opportunities for the open space and an increased depth to groundwater table.

HDR Parcel Assumptions:

- First floor will be 4 feet above existing ground
- Parking will be beneath the buildings, approximately 4.5-5.67 feet below existing ground and will be limited to the footprint of the buildings above.
- Depth to water table <4 ft (ex. grade) and ~7-8 ft. (proposed grade)
- Approximate Lot size = 142,500 sf
- Percent Impervious = 70% (55% Buildings, 15% Pavement)

Water Quality Volume (WQV):

- Water Quality Depth x Impervious Area
- 1.5-inch WQV = (1.5 inch/12) x (99,750 sf) = 12,469 cf

Green Infrastructure Strategies Considered:

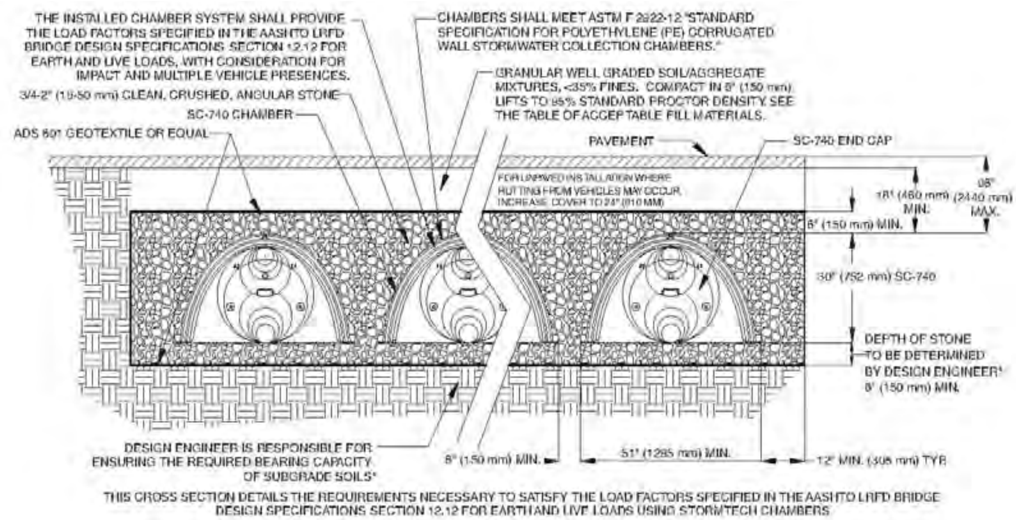
- **Bioretention Basin**
- Porous Paving
- **Subsurface Infiltration Chambers**
- Blue Roof
- **Green Roof**

The GI strategies selected for the HDR parcel are highlighted in bold above.

Porous pavement was not considered since the amount of pavement is minimal and would not account for a large water quality volume thereby having a smaller impact. Green roofs were selected instead of blue roofs, but the HDR parcel would be a good opportunity for reusing non-potable water for toilet flushing or for landscape irrigation and should be considered as an alternative to a green roof.

Bioretention basin, green roofs, and subsurface infiltration system were selected as GI strategies (see Figure 25). Subsurface infiltration system was selected to maximize the amenity and lawn space available to residents. See Figure 26 for a typical section for an arched chamber system that could be used. There will be a 2ft. separation from the seasonal high water table (SHWT) allowing for exfiltration as along as the infiltration rate for the soils in this area are acceptable.

Proximity to the Cambridge Class A water supply reservoir at Fresh Pond, precludes exfiltration since Cambridge DPW utilizes a mixture of calcium chloride-based products as its primary deicing agent on streets. Minimizing chloride contamination in the reservoir by migrating groundwater is a priority. However in this particular situation, the building roofs and amenity space will not be a source for calcium chloride and infiltrating BMPs can be used.



Source: Stormtech

**Figure 25: Subsurface Infiltration System**

Green roofs are proposed for the new buildings. Approximately 67% of the building is assumed to be green roof and the remaining 33% of the roof will be occupied by mechanical equipment and access paths. An extensive green roof requiring less than 6-inches of soil medium, supports mostly herbaceous plants, has no public access, and requires low maintenance is recommended (see Figure 8 and 9).

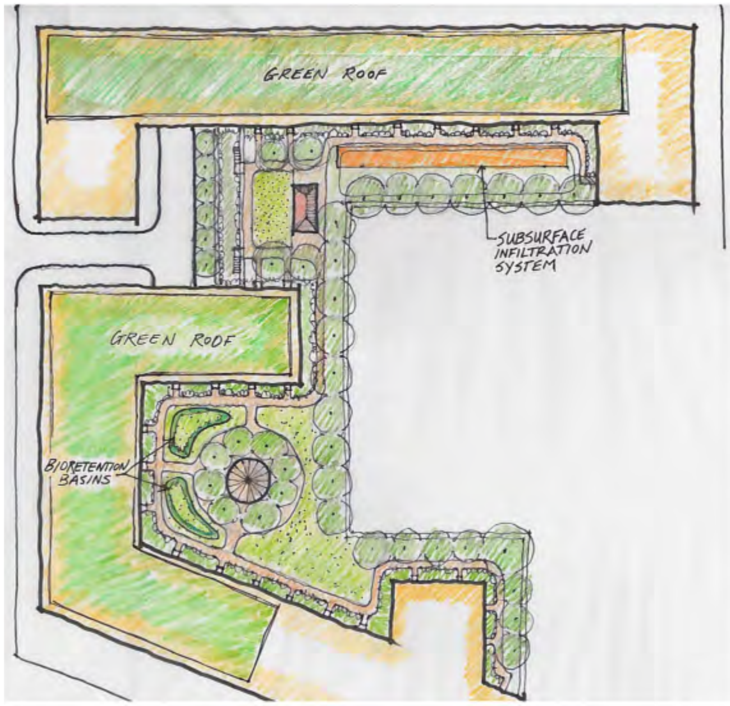



**Figure 25: GI Concept for HDR Parcel**

Volume Stored and Treated:

- Subsurface Infiltration Chambers
  Total Area = 2,006 sf
  Assume arched chamber system with 3 rows of 16 chambers
  6" stone foundation and 6" stone above chambers
  Storage per chamber = 74.90 cf
  Storage volume = 4,132 cf

- Bioretention Basin
  Total Area = 820 sf +550 sf = 1,370 sf
  Assume 0.75 ft. of ponding depth
  Assume 2 ft. of soil storage with 20% voids
  Storage volume = (1,370 sf x 0.75 ft.)+(1,370 sf x 2 ft. x 0.20)
  = 1,576 cf
- Green Roof
  Area = 0.67(78,375 sf) = 52,511 sf
  Assume 1.6 inch retention in 4-inch extensive green roof system
  Storage volume = 52,511 sf x (1.6 in./12) = 7,000 cf

- Total Water Quality Storage Volume = 4,132 cf + 1,576 cf + 7,000 cf
  = 12,700 cf
- > 1.5-inch Water Quality Depth

Attachment 2

# Calculations

## Alewife Watershed Area, Cambridge, MA

City of Cambridge
**Climate Change Preparedness & Resiliency (CCPR) Plan**

Prepared by Kleinfelder

May 2017

**KLEINFELDER**
Bright People. Right Solutions.

SHEET 1 OF ______

PROJECT NO. ______

PROJECT ______ REVIEWED BY ______ DATE ______

SUBJECT ______ BY ______ DATE ______

## GI calcs

**Bio retention Basin for MDR**

Ponding depth = 0.5 ft.

Engineering soil depth w/ 20% voids = 2 ft × 0.2
= 0.4 ft.

Total available depth = 0.5 + 0.4
= 0.9 ft.

1 ft² of bioretention captures 1 × 0.9
= 0.9 ft³.

WQ ~~volume~~ depth capture = $\frac{1.5}{12}$
= 0.125 ft.

1 ft² of tributary area ($A_T$) will need to capture WQV = 0.125 × 1
= 0.125 ft³

1 ft² of $A_T$ needs to capture 0.125 ft³ WQV.
0.125 ft³ WQV. ~~so~~ is captured ~~by~~ from 1 ft² $A_T$.
∴ 0.9 ft³ of bioretention is captured ~~by~~ from

$\frac{0.9}{0.125}$ = $\boxed{7.2 \text{ ft}^2 A_T}$

∴ $\boxed{1 \text{ ft}^2 \text{ of bioretention will capture } 7.2 \text{ ft}^2 A_T}$

7.2 ft² $A_T$ will ~~be~~ ~~treated~~ need for treatment by 1 ft² Bio ret.

∴ X ft² (0.3) frac. $A_T$ " " " "

$\frac{X}{7.2}$ ft² of Bio-retention

ENG-08 REV 05/08

KLEINFELDER
Bright People. Right Solutions.

SHEET 2 OF

PROJECT NO.

PROJECT  REVIEWED BY  DATE

SUBJECT  BY  DATE

Bio retention for open space (OS) & HDR

ponding depth = 0.75 ft

Engineered soil depth with 20% voids = 0.4 ft.

total available depth = 0.75 + 0.4 = 1.15 ft.

1 $ft^2$ of bio retention (OS) captures $1.15 \times 1 = 1.15\ ft^3$ WQV.

WQ depth capture required = 0.125 ft.

1 $ft^2$ of $A_T$ needs to capture $0.125\ ft^3$ WQV.

or $0.125\ ft^3$ WQV will be captured from 1 $ft^2$ $A_T$.

$\therefore$ $1.15\ ft^3$ WQV " " " from $\frac{1.15}{0.125} = \boxed{9.2\ ft^2\ A_T}$

1 $ft^2$ of bio retention (OS) will capture $9.2\ ft^2\ A_T$.

or $9.2\ ft^2$ $A_T$(OS & HDR) will need 1 $ft^2$ of bio reten (OS).

$\therefore$ Xac. $A_T$(OS & HDR) " " $\boxed{\frac{X}{9.2} \text{ ac. of bio-r (OS)}}$

KLEINFELDER
Bright People. Right Solutions.

SHEET 3. OF ______

PROJECT NO. ______

PROJECT ______ REVIEWED BY ______ DATE ______

SUBJECT curb extension BY ______ DATE ______

Bio retention for PROW.

Ponding depth = 1'

Engineered soil depth with 0.20% voids = 0.2 × 2 = 0.4 ft.

total available depth = 1.4 ft.

1 $ft^2$ of bio ret. (PROW) will treat 1.4 × 1 = 1.4 $ft^3$ WQV

WQ depth needed to be captured = 0.125 ft.

1 $ft^2$ of $A_T$ will need to treat 0.125 $ft^3$ WQV.

or 0.125 $ft^3$ WQV will be captured from 1 $ft^2$ $A_T$.

∴ 1.4 $ft^3$ WQV " " " " $\boxed{11.2\ ft^2\ A_T}$

1 $ft^2$ of bio ret. (PROW) will capture 11.2 $ft^2$ $A_T$.

or 11.2 $ft^2$ $A_T$ will need 1 $ft^2$ bio ret (PROW).

∴ X ac $A_T$ " " $\boxed{\frac{X}{11.2}\ \text{ac. bio ret (PROW)}}$

KLEINFELDER
Bright People. Right Solutions.

SHEET 4 . OF ______

PROJECT NO. ______

PROJECT ______ REVIEWED BY ______ DATE ______

SUBJECT ______ BY ______ DATE ______

Bio retention for Light Ind (LI) New.

Ponding depth = 0.75'

Engineered soil depth with 20% voids = 1.5 × 0.2
= 0.3 ft.

total available WQ depth = 0.75 + 0.3
= 1.05 ft.

1 ft² of bio ret (LI-new) can capture 1.05 ft³ WQV.

WQ depth required to be captured 0.125 ft.

1 ft² of $A_T$ will need to capture 0.125 ft³ WQV.

0.125 ft³ WQV will be captured from 1 ft² $A_T$

∴ 1.05 ft³ " " " " " $\frac{1.05}{0.125}$

$= \boxed{8.4 \text{ ft}^2 \ A_T}$

∴ 1 ft² of bio reten (LI new) will ~~be~~ capture 8.4 ft² $A_T$

8.4 ft² $A_T$ will ~~be captured~~ need 1 ft² bio ret (LI-new)

∴ X Ac $A_T$ " "

$\boxed{\frac{X}{8.4} \text{ ac. bio-ret (LI-new)}}$

ENG-08 REV 05/08

SHEET 5 OF

KLEINFELDER
Bright People. Right Solutions.

PROJECT NO.

PROJECT Assume 0.75 ft of ponding depth REVIEWED BY DATE

SUBJECT BY DATE

Above ground planter.

Planting soil depth with 20% voids = 2 x 0.2
= 0.4 ft.

1 $ft^2$ of planter will capture 0.4 $ft^3$

WQ. depth capture required = 0.125 ft.

1 $ft^2$ of $A_T$ will need to capture 0.125 $ft^3$ WQV.

or 0.125 $ft^3$ WQV will be captured from 1 $ft^2$ $A_T$.

∴ 0.4 $ft^3$ WQV " " " " $\frac{0.4}{0.125}$

$= \boxed{3.2\ ft^2\ A_T}$

∴ $\boxed{1\ ft^2 \text{ of planter will treat } 3.2\ ft^2\ A_T}$

~~3.2 $ft^2$ of $A_T$ will need for treatment~~

3.2 $ft^2$ $A_T$ will be treated by 1 $ft^2$ of planter

∴ X ac of $A_T$ " " " " $\boxed{\frac{X}{3.2} \text{ ac. of planter}}$

use 4"

Porous pavement.

reservoir stone depth with 40% voids $= \frac{9}{12} \times 0.4$ ft

$= 0.3$ ft

1 ft$^2$ of porous pavement will capture ~~treat~~ 0.3 ft$^3$ WQV.

WQV depth ~~capture~~ required to be captured 0.125 ft

i.e. 1 ft$^2$ of $A_T$ will need to capture 0.125 ft$^3$ WQV.

or 0.125 ft$^3$ WQV will be captured from ~~by~~ 1 ft$^2$ $A_T$.

∴ 0.3 ft$^3$ WQV " " " " $\frac{0.3}{0.125}$

$= \boxed{2.4 \text{ ft}^2 A_T}$

$\boxed{\text{1 ft}^2 \text{ of pp. will treat/capture 2.4 ft}^2\ A_T}$

2.4 ft$^2$ of $A_T$ will need 1 ft$^2$ of pp.

∴ Xac of $A_T$ " " $\boxed{\frac{X}{2.4} \text{ ac of pp.}}$

KLEINFELDER
Bright People. Right Solutions.

SHEET 7 OF

PROJECT NO.

PROJECT REVIEWED BY DATE

SUBJECT BY DATE

Green Roof

retention depth $= \frac{1.6}{12}$ ft $= 0.13$ ft

1 $ft^2$ of Green roof can capture $0.13\ ft^3$ WQV.

WQ depth needed to be captured $0.125$ ft.

1 $ft^2$ of $A_T$ will need to capture $0.125\ ft^3$ WQV.

or $0.125\ ft^3$ WQV will be treated from 1 $ft^2$ $A_T$

∴ $0.13\ ft^3$ WQV " " " " $\boxed{1.04\ ft^2\ A_T}$

$\boxed{1\ ft^2 \text{ of Green roof will treat/capture } 1.04\ ft^2\ A_T}$

$1.04\ ft^2\ A_T$ will need $1\ ft^2$ GR

∴ $X$ ac $A_T$ " " $\boxed{\frac{X}{1.04} \text{ ac GR}}$

Permeable Pavers for PROW (New.)

Reservoir stone depth at 40% voids $= \frac{14}{12} \times 0.4$

$= 0.47'$

$1\ ft^2$ of permeable paver will capture $0.47\ ft^3$ of WQV.

WQ depth required to be captured $0.125\ ft$.

$1\ ft^2$ of $A_T$ will need to capture $0.125\ ft^3$ WQV.

$0.125\ ft^3$ WQV will be captured from $1\ ft^2\ A_T$

$\therefore$ $0.47\ ft^3$ WQV " " " " $\frac{0.47}{0.125}$

$= \boxed{3.73\ ft^2\ A_T}$

$1\ ft^2$ of perm. paver will capture $3.73\ ft^2\ A_T$.

or $3.73\ ft^2\ A_T$ will require $1\ ft^2$ of perm paver.

$\therefore$ X ac $A_T$ " " $\boxed{\frac{X}{3.73}\ \text{ac. perm paver}}$

Attachment 3

# Green Infrastructure (GI) Flooding Analysis in the Alewife Watershed Area

Alewife Watershed Area, Cambridge, MA

City of Cambridge

**Climate Change Preparedness & Resiliency (CCPR) Plan**

Prepared by Stantec

July 2017

For

Kleinfelder

# Green Infrastructure (GI) Flooding Analysis

# in the Alewife Watershed Area, Cambridge, MA

DRAFT FOR REVIEW

Prepared for:
**Kleinfelder**

By:

Stantec

July 7, 2017

## 1.0 Purpose

This memorandum briefly summarizes the potential impact of wide-spread implementation of Green Infrastructure (GI) on street flooding within the Alewife watershed area in Cambridge, MA. The City's InfoWorks ICM v7.5 H&H model was used in this study. The GI methodology uses ICM's Sustainable Urban Drainage System (SUDS) control objects (SUDS is United Kingdom's terminology for Low Impact Development (LID) technologies). The design storm selected to evaluate the effectiveness of GI implementation on street flood reduction is the relatively large storm 10-year, 24-hour under the future climate change year 2070 time horizon (10Y24H-2070). The main objective of this work is to determine the effectiveness of GI implementation in reducing street flooding with respect to the base scenario with no GI implementation.

## 2.0 Background

Green Infrastructure technologies were implemented in 146 (combined and storm) model sub-catchments within the Alewife area. Kleinfelder provided Stantec with conceptual GI elements within each sub-catchment using specific GI parameters, GI footprints and assumed treated tributary area. In each of the Alewife model sub-catchments at least one of the four (4) GI technologies listed below was adopted. Kleinfelder also provided a table with soil infiltration input parameters associated with land uses and soil conditions in each area. The four GI technologies are:

- Bio-retention cell
- Porous pavement
- Green roof
- Infiltration trench

## 3.0 Methodology

The computational ICM-v7.5 2D model is set up with 1D/2D initial conditions, 3 pumps at Amelia Earhart Dam, Cradock Locks removed, and boundary conditions (external inflows and water levels), all consistent with the conditions used in the calibrated model. The SUDS/LID control tables were populated by using the provided parameters with minor adjustments as follows: (1) Adopting the model default value for "field capacity" and "wilting point" for sub-surface infiltration trench as these were not provided, (2)Mat roughness and thickness of the Green Roof were changed to be greater (not equal) than 0 in accordance with the SWMM rules, which ICM follows, (3) sandy loam was elected as the soil class for all LID control types where type of soil is required as an input for the GI feature.

It is worth noticing that in some sub-catchments the % impervious treated area with porous pavement was adjusted to ensure it did not exceed 100% of the total sub-catchment impervious area. In the case of green roofs, the tributary impervious area treated was adjusted to zero as it was assumed their only inflow is the rainfall. A summary of GI features footprint areas as well as areas treated by these is presented in Table 1 below.

**Table 1.** GI footprint and treatment areas assumed in the hydraulic model

| | BMP Type | Bio-Retention | Porous Pavement | Green Roof | Sub-surface Infiltration | Total GI Treated Area |
|---|---|---|---|---|---|---|
| **Alewife Watershed (1,190 ac approx)** | **GI Footprint (acres)** | 1.52 | 5.8 | 118.56 | 0.07 | 125.94 |
| | **Tributary Area Treated with GI (acres)** | 12.44 | 15.83 | 0 | 1.76 | 30.03 |
| | **GI Footprint as Percent of Total Area** | 0.13% | 0.49% | 9.96% | 0.01% | 10.58% |
| | **GI Tributary Area as Percent of Total Area** | 1.05% | 1.33% | 0% | 0.15% | 2.52% |
| **CAM004 Subcatchment (370ac approx)** | **GI Footprint (acres)** | 0.53 | 2.11 | 71.58 | 0.04 | 74.25 |
| | **Tributary Area Treated with GI (acres)** | 4.34 | 5.76 | 0 | 0.89 | 10.99 |
| | **GI Footprint as Percent of Total Area** | 0.14% | 0.57% | 19.35% | 0.01% | 20.07% |
| | **GI Tributary Area as Percent of Total Area** | 1.17% | 1.56% | 0% | 0.24% | 2.97% |

## 4.0 Results

The model was run with the 10Y24H-2070 design storm event under the scenario with LID technologies implemented within the Alewife area. Figures 1 and 2 show simulated flood inundation (peak flood depth) maps under scenarios without and with GI implementation, respectively. Figure 2 shows areas where substantial flood reduction was achieved, particularly in the areas indicated by the (red dashed) boxes. For instance, the region bounded by Smith Place, Alewife Brook Parkway, Concord Ave., and the rail road exhibits substantial flood reduction. On the other hand, flood reductions is less pronounced in some other areas, particularly in the close proximity of the Alewife brook, as flooding in such areas are dominated by river-bank overtopping. Other areas displaying substantial flood reduction are those in the vicinity of Dudley St., Cogswell Ave. and Mass. Ave.

Table 2 lists simulated maximum flood volumes within the Alewife area under various scenarios: present without GI, and year 2070 horizon with and without GI implementation. The listed flood volumes exclude the volumes within the Alewife Brook riverine banks. Not considering the flood volume within the river banks does not prevent from evaluating the effectiveness of GI implementation since such volume is the same for all scenarios. The results in Table 2 indicate flood volume in the Alewife area increases by about 160% due to the effects of climate change projected for year 2070, with respect to present conditions. On the other hand however, implementation of the various proposed GI technologies within the Alewife area reduces future flooding by 12.28 MG, i.e., from 33.06 MG to 20.78 MG, a 37% decrease.

| **Table 2** - Flood Volume under the 10-year, 24-hour | | |
|---|---|---|
| **Scenario** | **Volume (MG)** | **% Difference** |
| **Present No GI** | 12.71 | - |
| **2070 No GI** | 33.06 | 160.11 |
| **2070 with GI** | 20.78 | 63.52 |

The effectiveness of the LID implementation is not only reflected by the extent of the surface flooding but also by the reduction in both peak and volume making it to the underground combined and storm drain systems. To exemplify this, Figure 3 displays simulated flow hydrographs at three locations exhibiting the largest surface flood reduction due to GI implementation. The three flow hydrograph locations are mapped (full circles) in Figure 2; two readings are on storm drains while a third hydrograph is on a combined sewer. Implementation of GI technologies induce reduction in both peak flow and volume at the three conduit locations as indicated in Table 3. The effectiveness of the implementation of GI is variable across the

Alewife system (also observed by the surface flooding extents), manifested by peak flow reduction varying from 23% to 32%; while volume reduction fall within the range 11% to 40%.

| **Table 3.** Simulated peak flow and volume with and without GI implementation under the 10-year, 24-hour 2070 horizon storm event | | | | | | |
|---|---|---|---|---|---|---|
| | **Peak Flow (MGD)** | | | **Volume (MG)** | | |
| **Location** | **No GI** | **With GI** | **% Difference** | **No GI** | **With GI** | **% Difference** |
| Wheeler St. | 11.34 | 8.23 | **-27.4** | 11.34 | 8.23 | **-27.4** |
| Alpine St. @ Field St. | 9.24 | 6.26 | **-32.3** | 1.35 | 1.21 | **-10.6** |
| Mass. Ave. @ Walden St. | 10.33 | 7.93 | **-23.2** | 2.05 | 1.23 | **-39.8** |

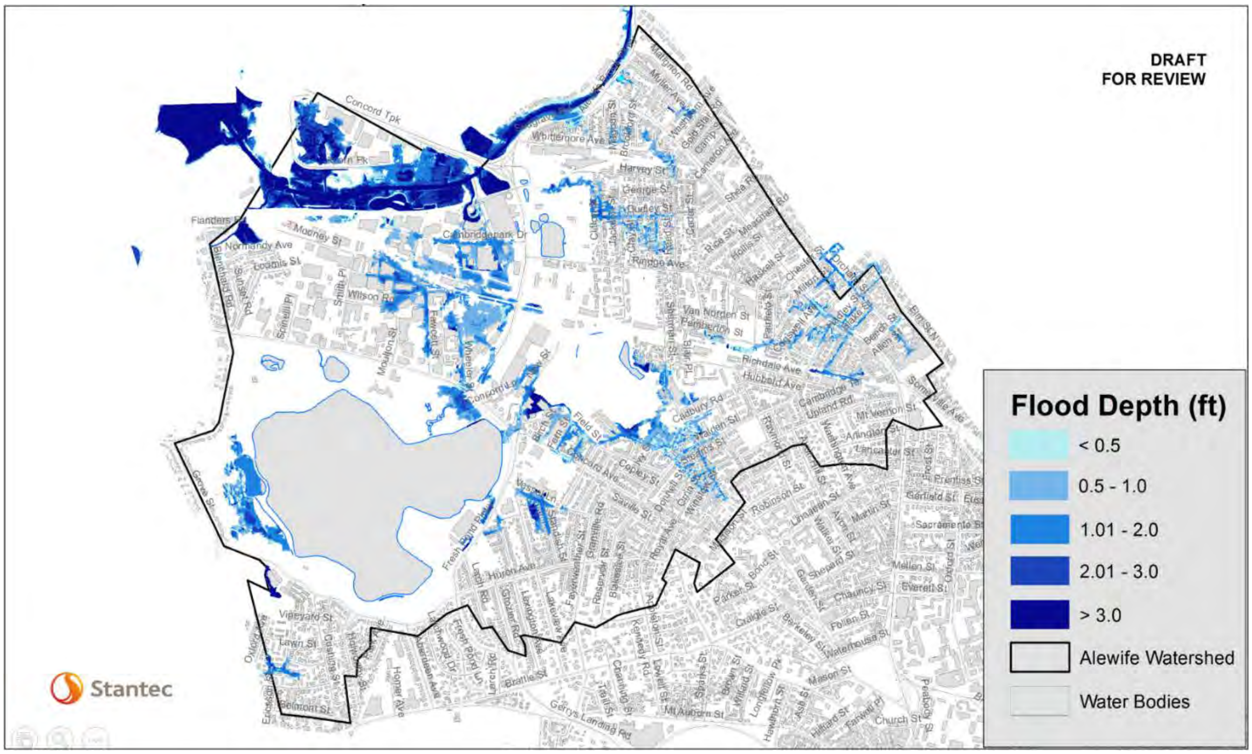



**Figure 1.** Alewife Brook InfoWorks ICM Integrated Model (10yr, 24hr-2070) with No GI
3 Pumps at the Amelia Earhart Dam, Cradock Locks Removed.

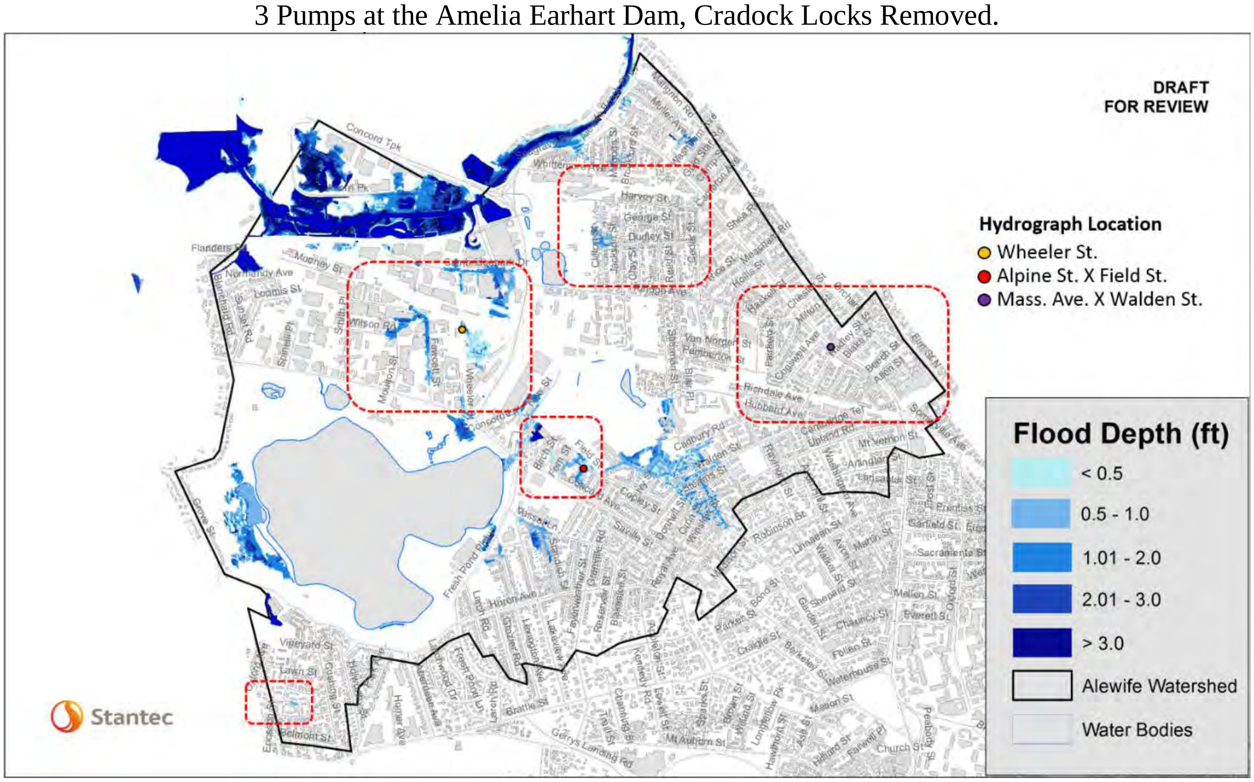



**Figure 2.** Alewife Brook InfoWorks ICM Integrated Model (10yr, 24hr-2070) with GI
3 Pumps at the Amelia Earhart Dam, Cradock Locks Removed.

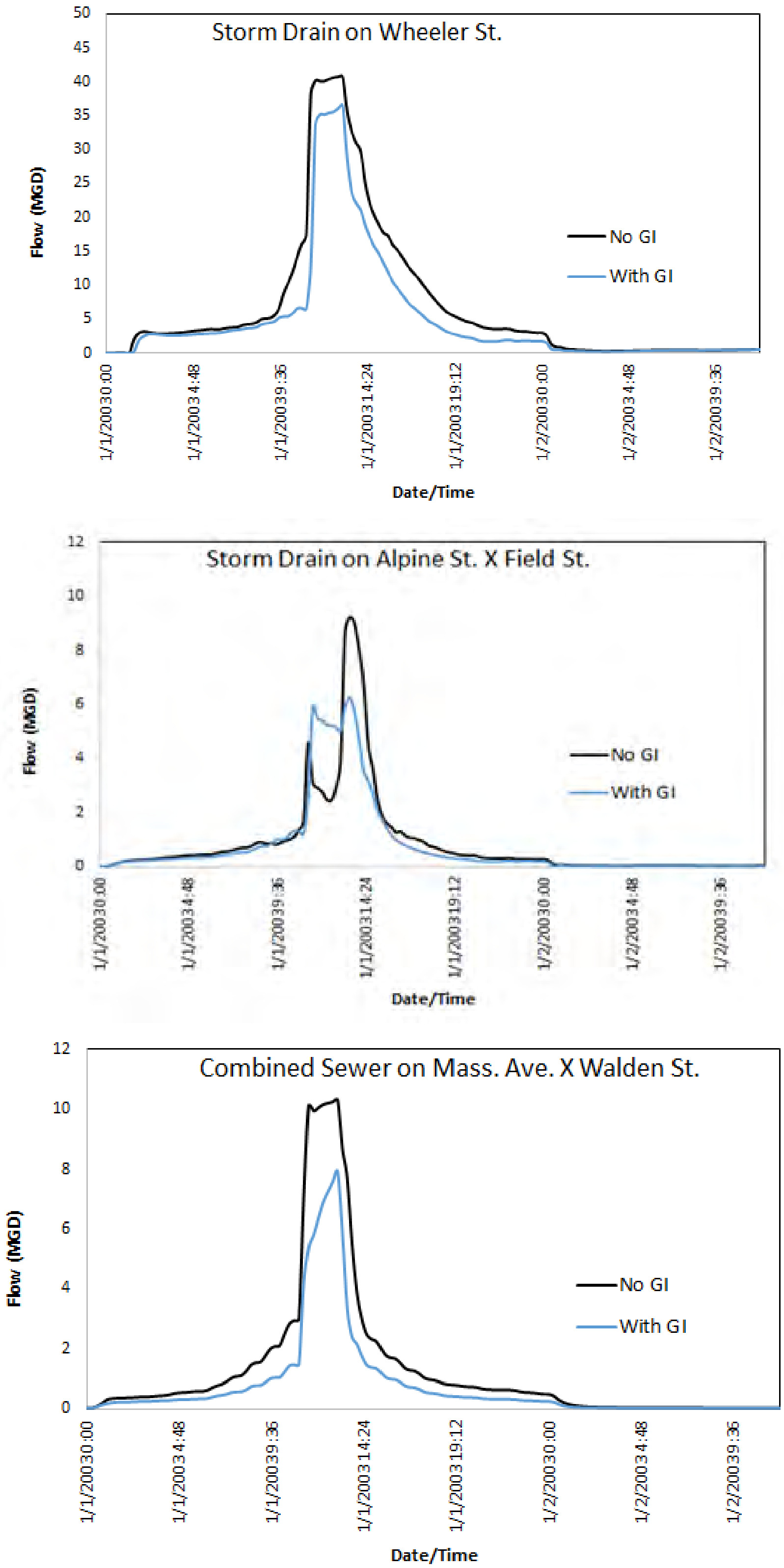



**Figure 3.** Flow hydrographs for the 10-year, 24-hour under 2070 horizon with and without GI implementation in Alewife.

## 5.0 Conclusions and Remarks

The implementation of the four LID/GI technologies investigated in this work effectively reduced street flooding in the Alewife area. Likewise, the underground combined and storm pipe system experiences reduction in both flow peak and volumes. The reduction of surface flooding extents varies across the system in response of local pipe flow capacity, and ground surface conditions (slope, land use, soil characteristics).

Results of this study should be considered with caution as they only serve as an indicator of the overall effectiveness of LID implementation. Results from this study should be considered as a theoretical maximum benefit that could potentially be achieved with full LID implementation. Actual feasibility of implementation as well as BMP effectiveness need to be evaluated on a case by case basis or at a parcel or neighborhood scale as outcomes are highly site-specific.

Finally, it is important to bear in mind that the effectiveness of the GI is expected to be less dramatic for larger storm events, e.g., the 25-, 50-, or 100-year design events. It is worth pointing out that the effectiveness of the LID technologies are time dependent as these can be affected by many environmental conditions such as antecedent rainfall as well as operational conditions. It is well documented that porous pavements decay in efficiency overtime as particles fill the pavement cavities and clogging the unit overtime. Therefore maintenance is a factor that must be carefully considered for all measures.