HERO 2021
Sustainable Worcester

HERO Team

Apple Gould-Schultz, David Henriques, Sarah Hughes, Caleigh McLaren, Madeline Regenye

GREEN WORCESTER

Meet the Research Team

Graduate Mentors: Marc Healy and Nicholas Geron

Directors: John Rogan, Ph.D. and Deborah Martin, Ph.D

Undergraduate Research Team: (left to right) Apple Gould-Schultz, Caleigh McLaren, Madeline Regenye (Regs), David Henriques, Sarah Hughes

Overview

Background and Introduction

Historical Wetland Mapping

Flood Mitigation Solutions

Spatial Dynamics of the Urban Heat Island

Modeling Green Infrastructure

HERO Over the Years

2014

HERO fellows research the Asian Longhorned Beetle infestation in Worcester

2017

HERO fellows focus on DCR Greening the Gateway Cities and the impact of planting programs

2019

HERO fellows research tree survivorship in the Gateway Cities of Pittsfield and Leominster

2021-2022

This year we are conducting research to understand the impact of tree canopy on the Urban Heat Island Effect, and the locations of historic wetlands.

Research Question

How can the human and biophysical legacies of land use and land cover in Worcester inform future green infrastructure to create a more resilient and sustainable city?

Broad Meadow Brook

Tree Planting Strip on Harding Street

Research Objectives

Historical Wetlands and Flooding Solutions

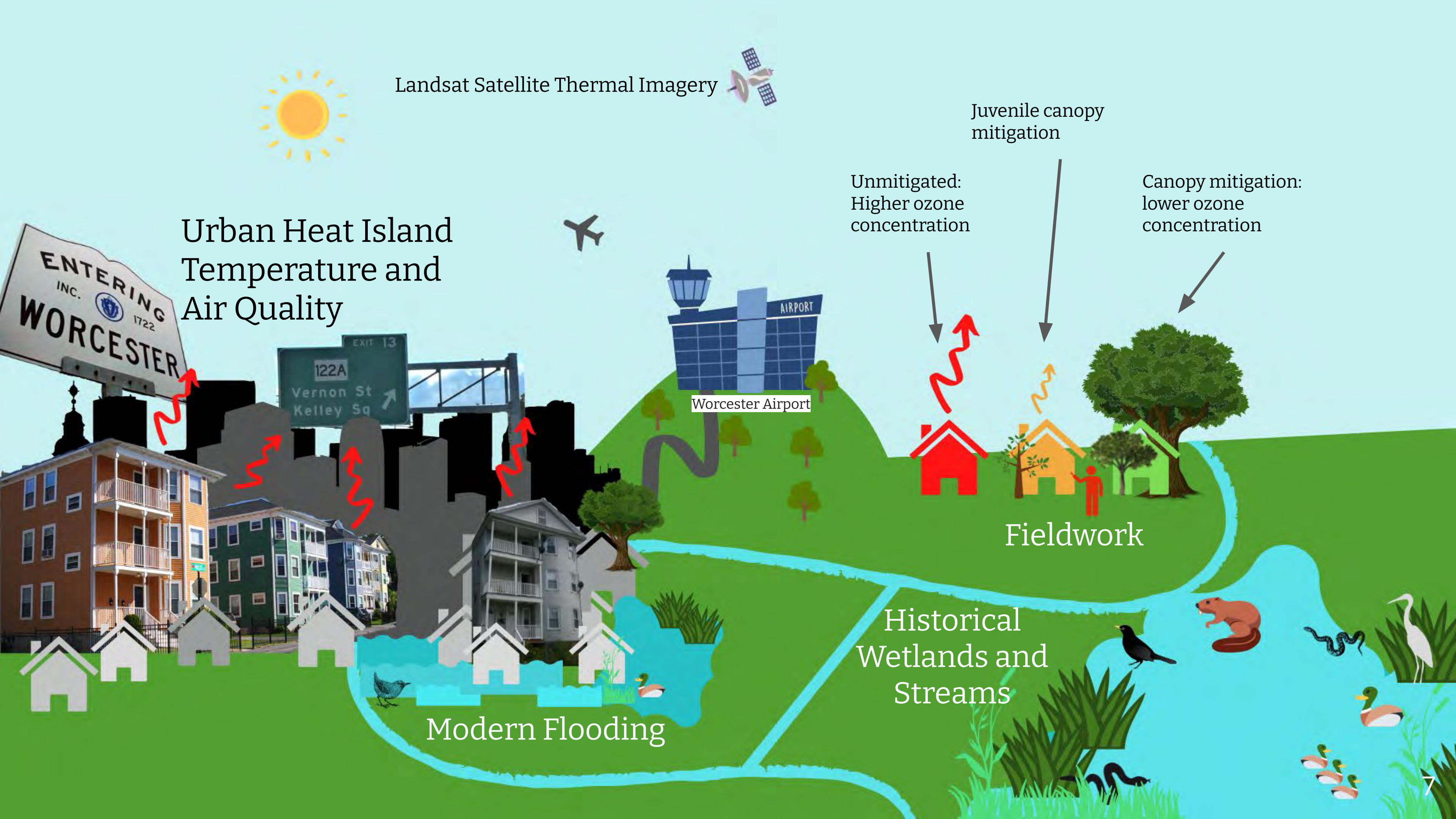
01 Delineate historical wetlands in Worcester and compare them with modern day floodplain characteristics.

02 Identify potential green infrastructure solutions for flood mitigation in Green Island.

Urban Heat Island Mitigation

03 Compare surface/air temperature and ozone variability of Green Island and Columbus Park at a high resolution with in situ measurements.

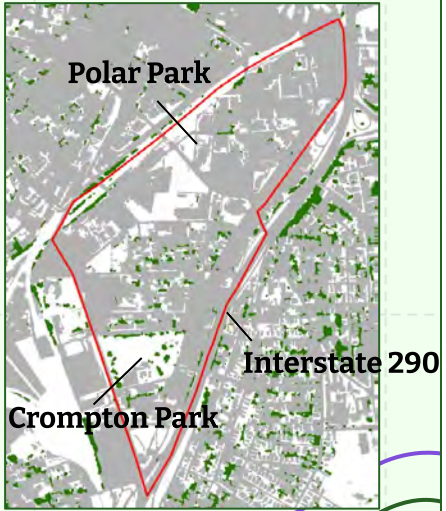
04 Model the role of street trees and treated roofs/solar panels on surface temperature in Worcester.

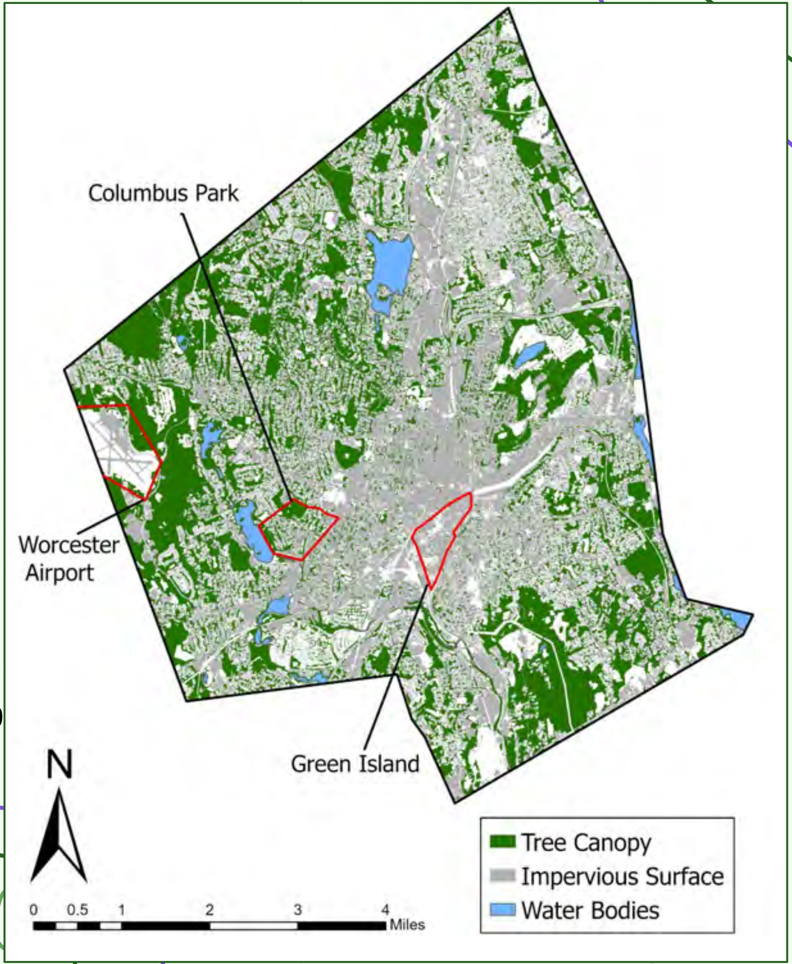

Landsat Satellite Thermal Imagery
Juvenile canopy mitigation
Unmitigated: Higher ozone concentration
Canopy mitigation: lower ozone concentration
Urban Heat Island Temperature and Air Quality
ENTERING
INC. 1722
WORCESTER
EXIT 13
122A
Vernon St
Kelley Sq
AIRPORT
Worcester Airport
Fieldwork
Historical Wetlands and Streams
Modern Flooding

Study Area

Columbus Park

Green Island





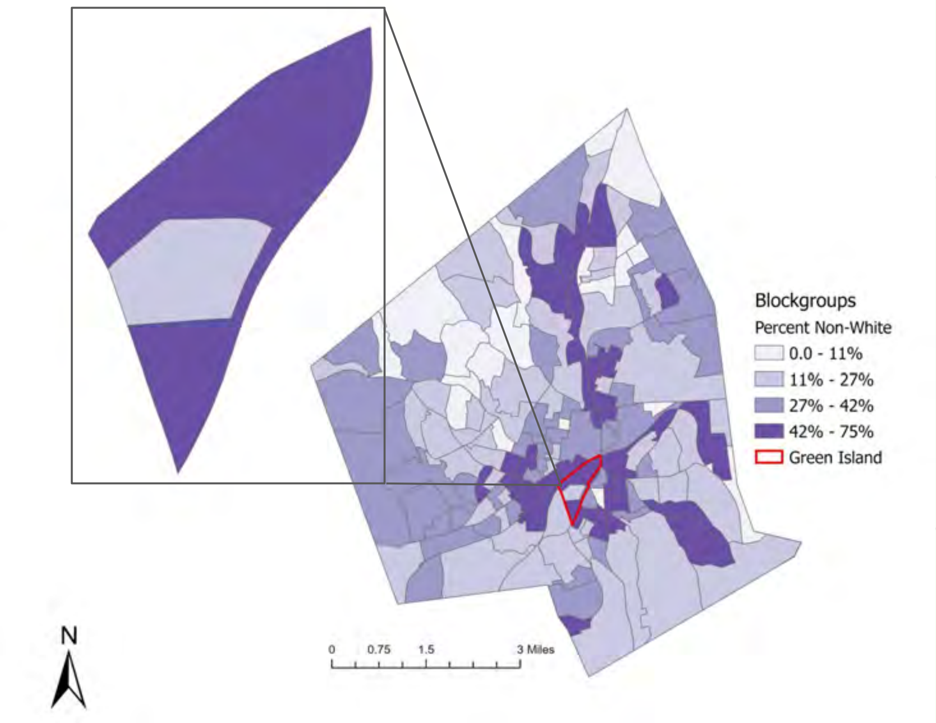
Characteristics of Green Island

Population: 1,583

<u>Economic</u>
Median Household Income: $30,396*
Percent Renter: 88.5%*

<u>Demographic</u>
Population Demographic Distribution: 48% White; 15% Black; 10% Asian; 27% Other
Percent Population with Limited English: 12.25%*
Environmental Justice Group: Minority and Income

<u>Education</u>
>25 with Bachelor's Degree: 10%*
>25 with HS Degree: 25%*



*Average of Block Groups

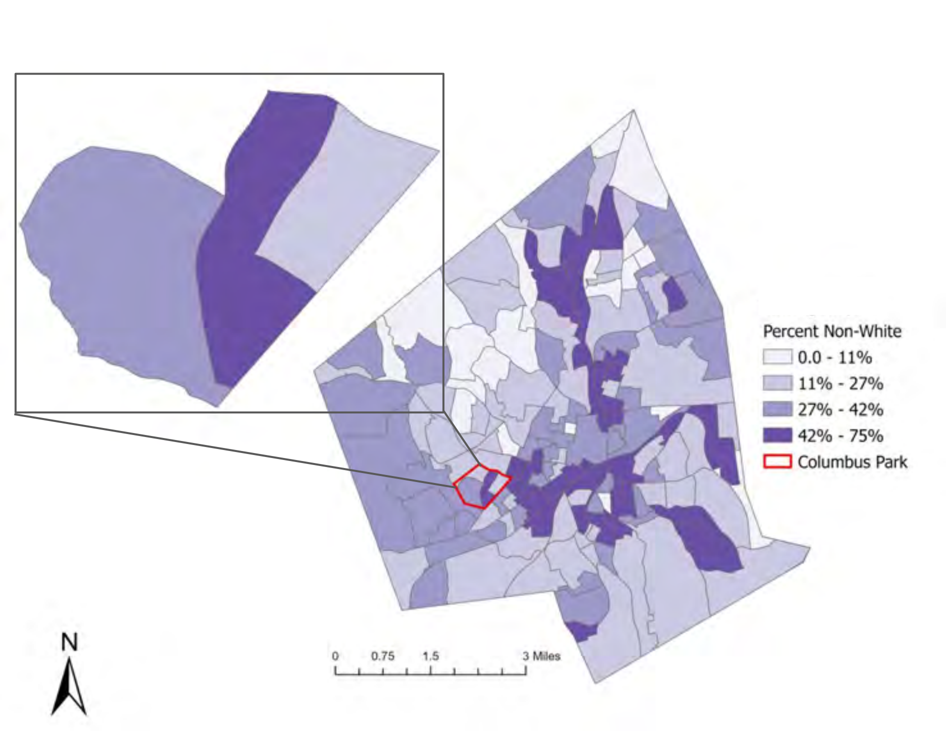
Characteristics of Columbus Park

Population: 3,037

Economic
Median Household Income: $37,135*
Percent Renter: 66%*

Demographics
Population Demographic Distribution: 49% White, 17% Black, 15% Asian, 0.5% American Indian,
17% Other
Percent Population with Limited English: 9.42%*
Environmental Justice Group: Minority and Income

Education
>25 with Bachelor's Degree: 13.4%*
>25 with HS Degree: 15.5%*



*Average of Block Groups

01

Delineate historical wetlands in Worcester and compare them with modern day floodplain characteristics

Historical Wetland Mapping

1833

1891

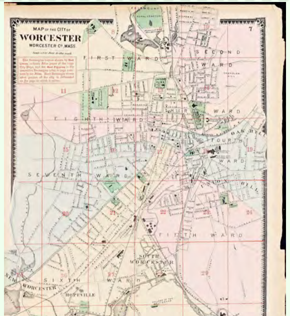
1946-56

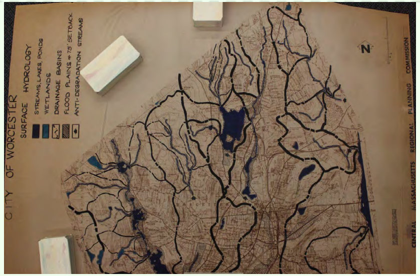
1980

1870

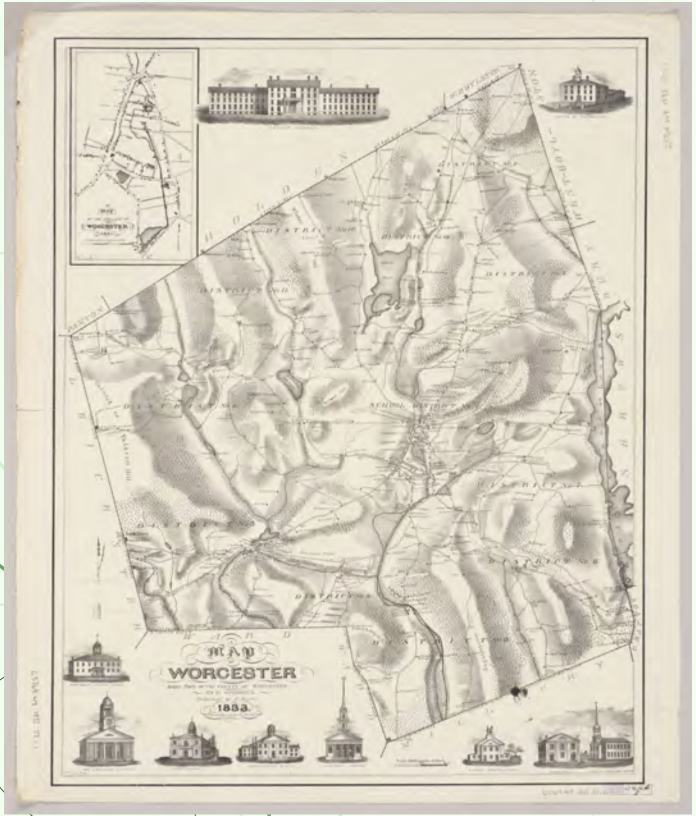
1908

1960s





Historical Wetland Mapping



1833 Worcester Map

1908 Worcester Map

1891 Worcester Map

1870 Worcester Map

Historical Wetland Mapping

1940s-1950s Topography Map

1960s Wetlands Map

1980 FEMA Flood Insurance Maps

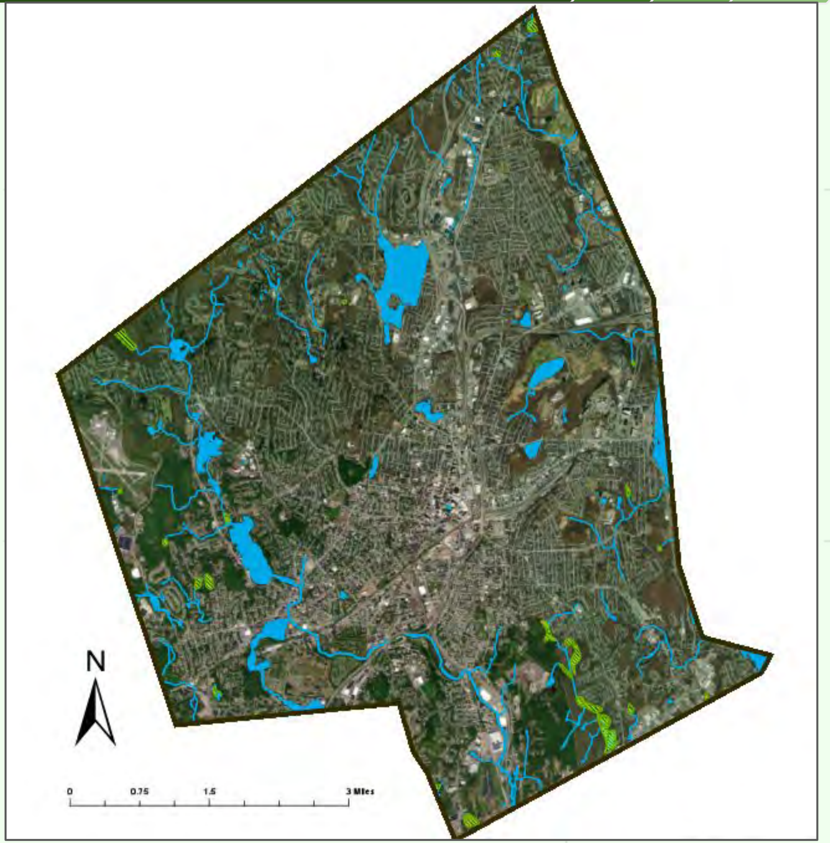
Wetland Mapping Methods

Historical Map Collection

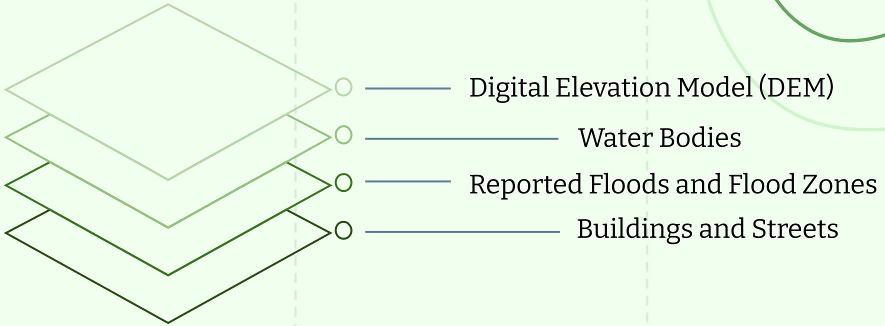
Georeferencing: ArcGIS

Digitizing of Features QGIS

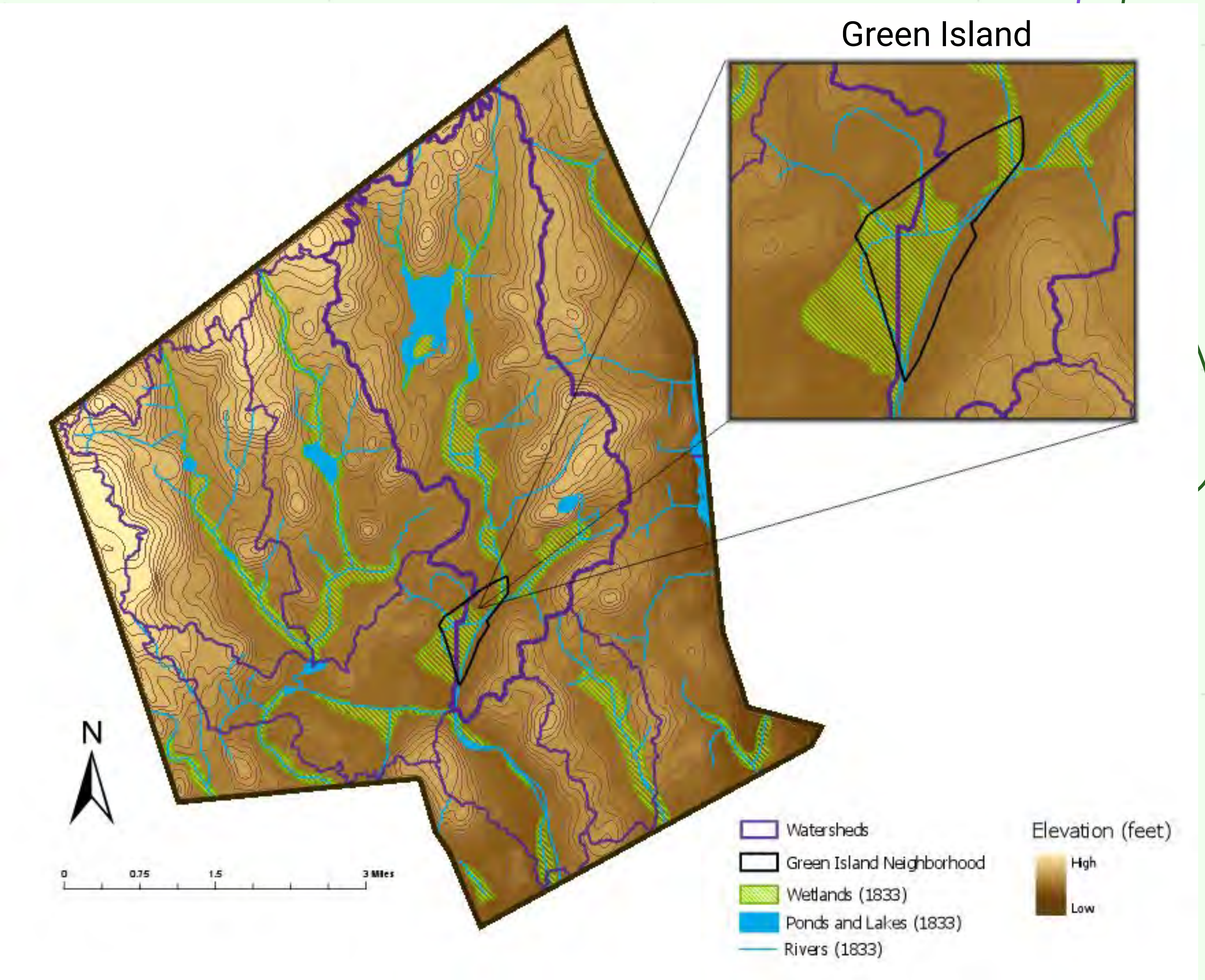
Wetland Mapping Methods Continued



Historical Features Overlaid Over Current Layers

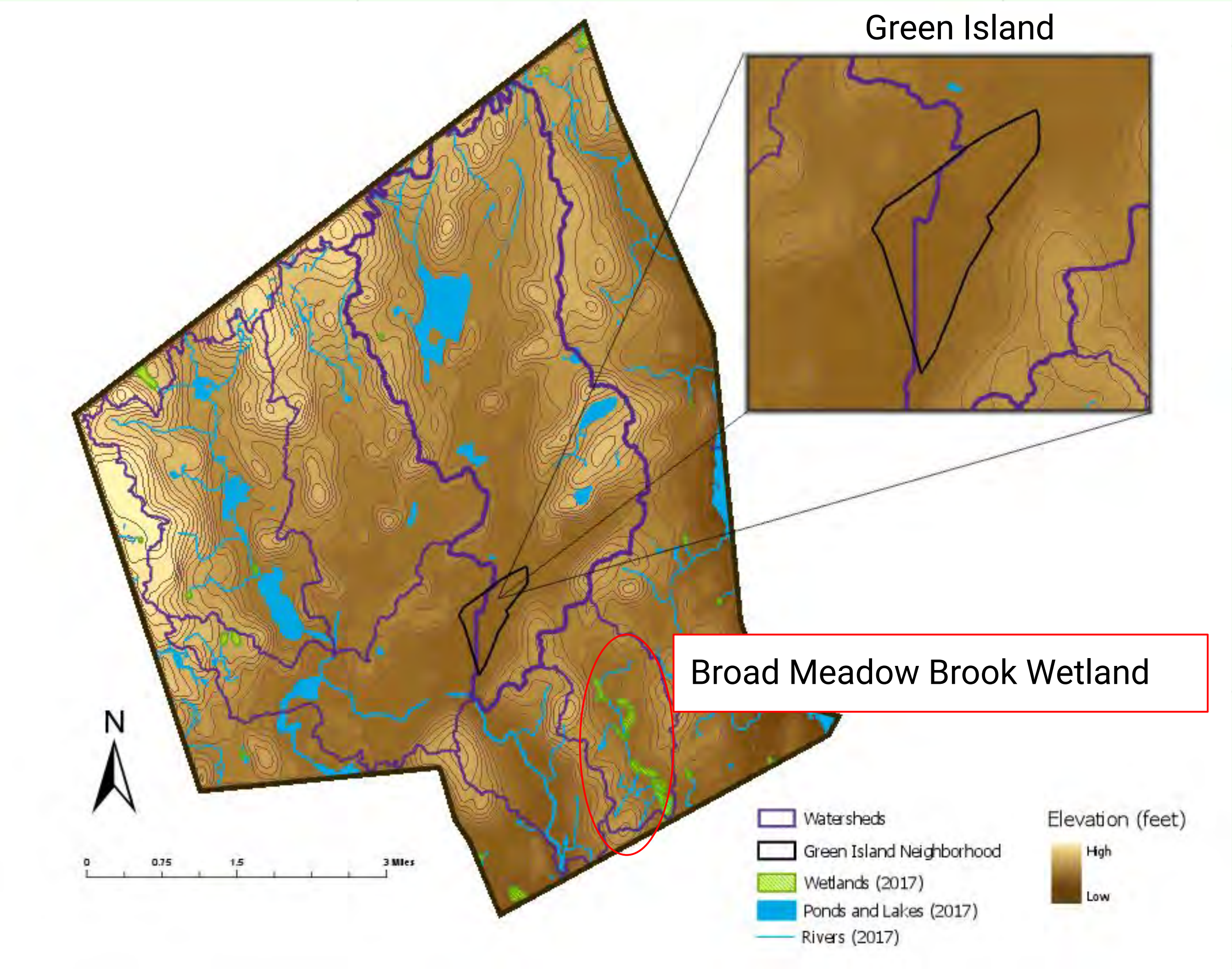


1833 Hydrography



2017 Hydrography

1,853.3 acres of wetland lost from 1833 to 2017



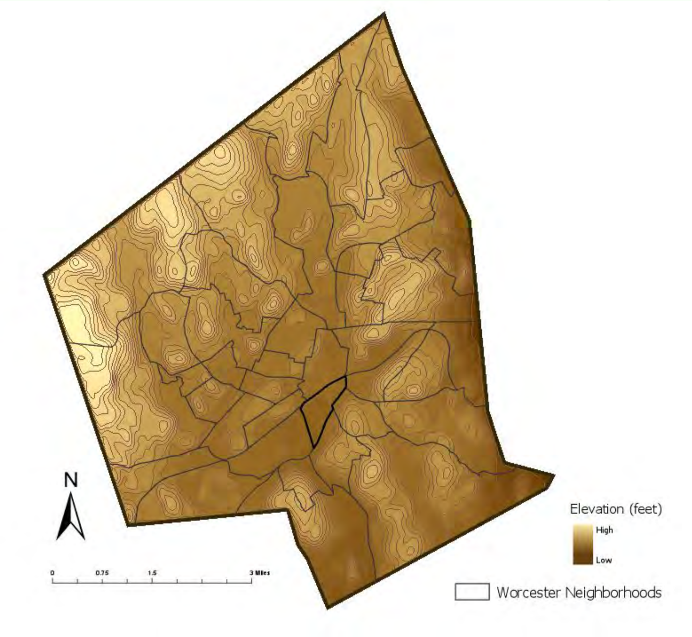
147.4 Polar Parks

worth of wetlands were drained in Worcester between 1833 to present.

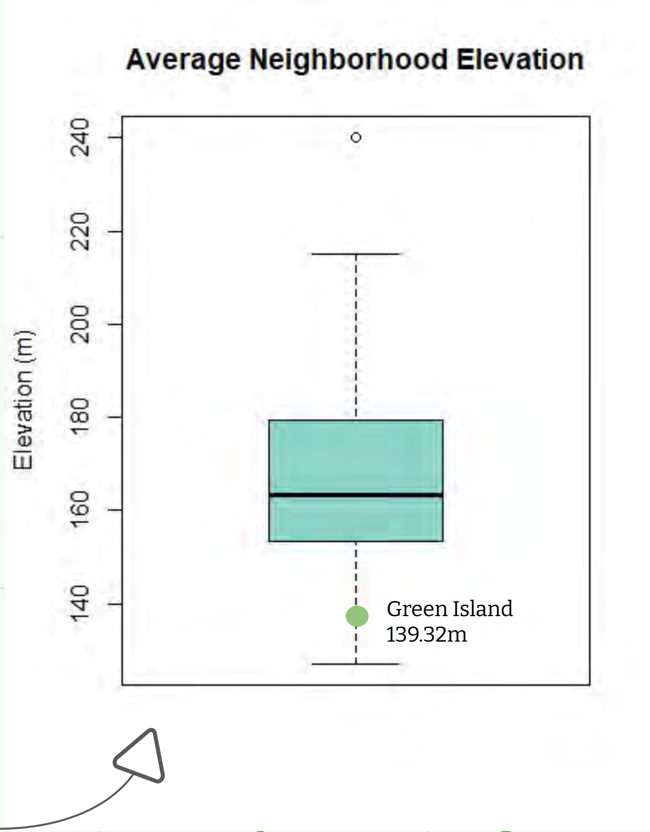
96.6 Polar Parks

worth of reservoirs, lakes, and ponds were created in Worcester between 1833 to present.

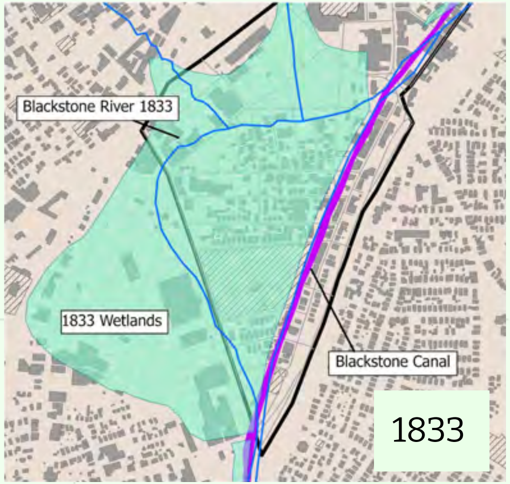
Elevation of Worcester Neighborhoods

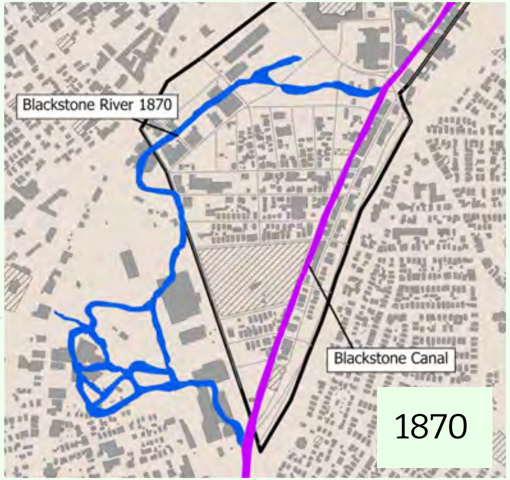


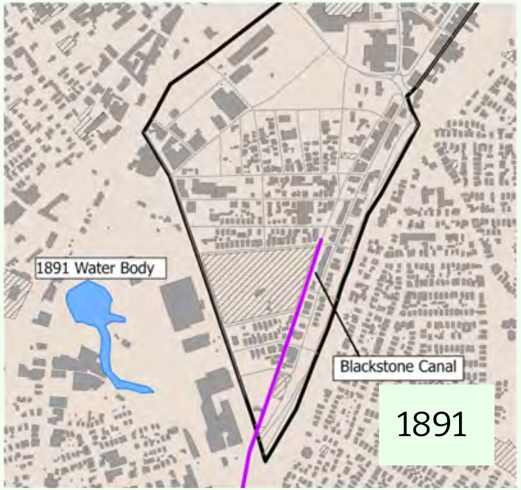
Green Island has the second lowest neighborhood elevation in Worcester.

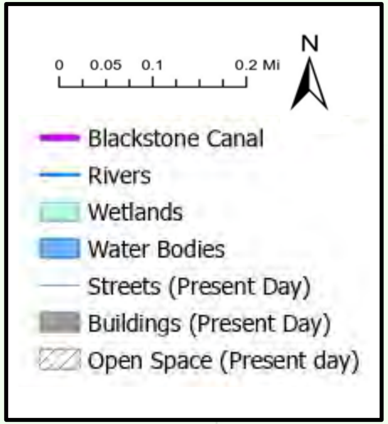


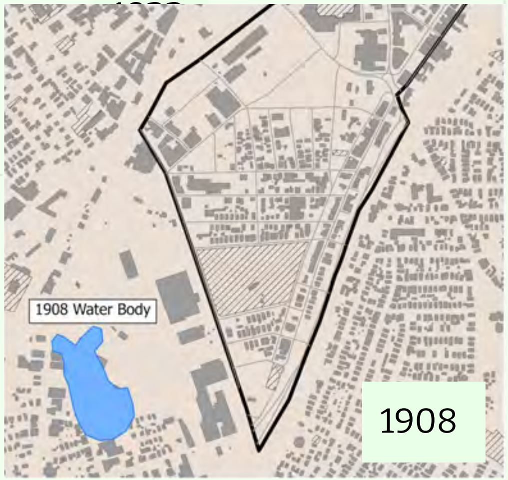
Disappearing Hydrology in Green Island

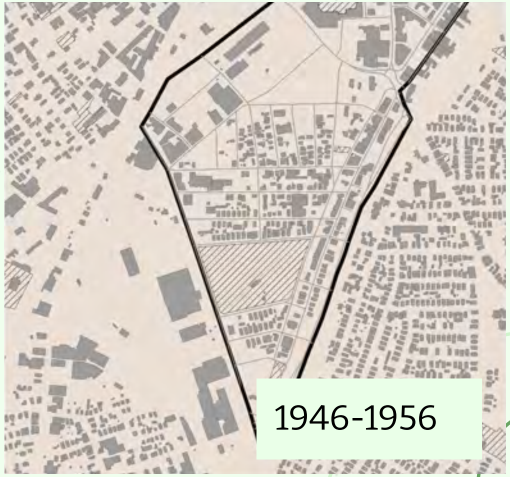




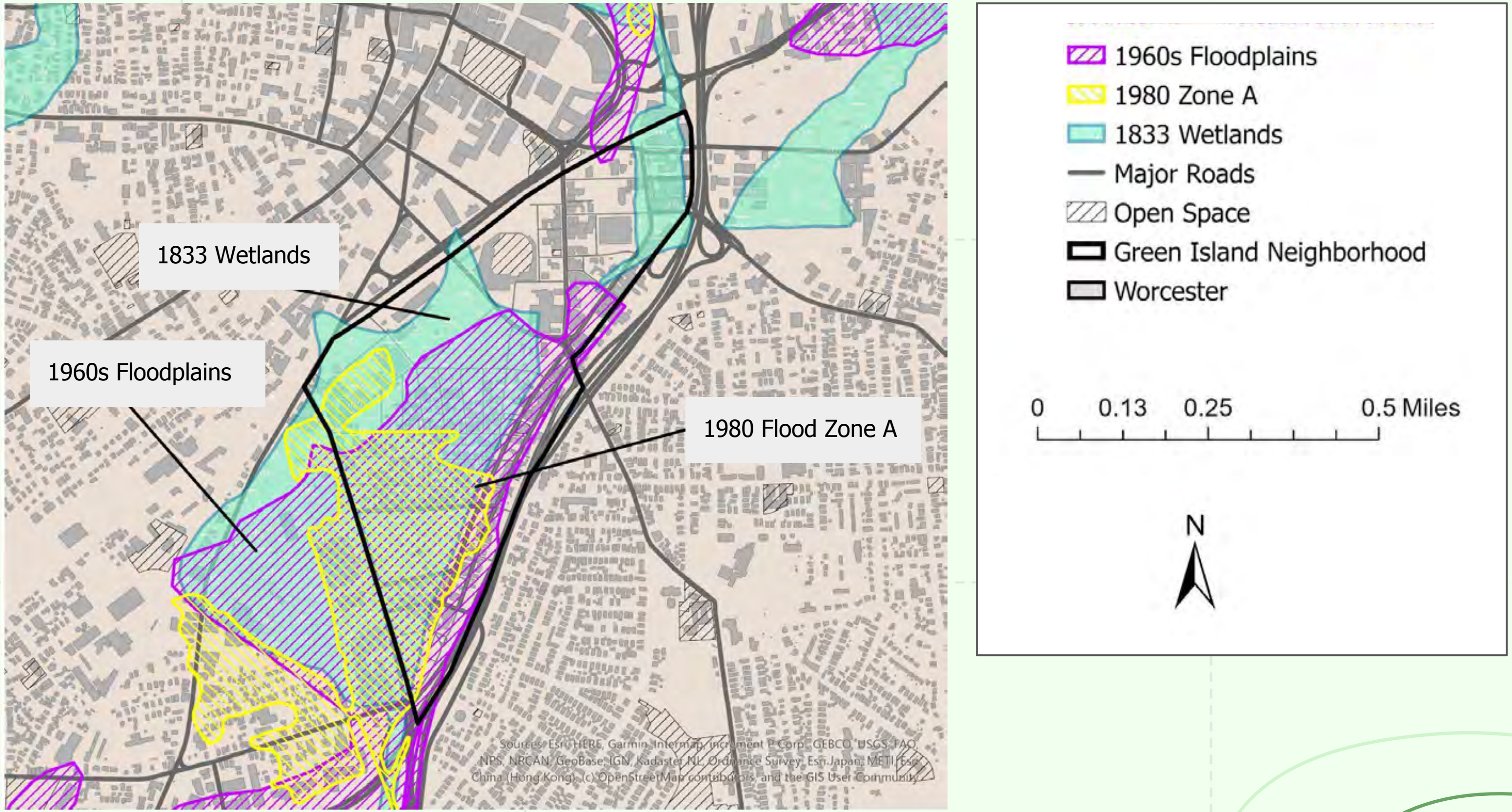




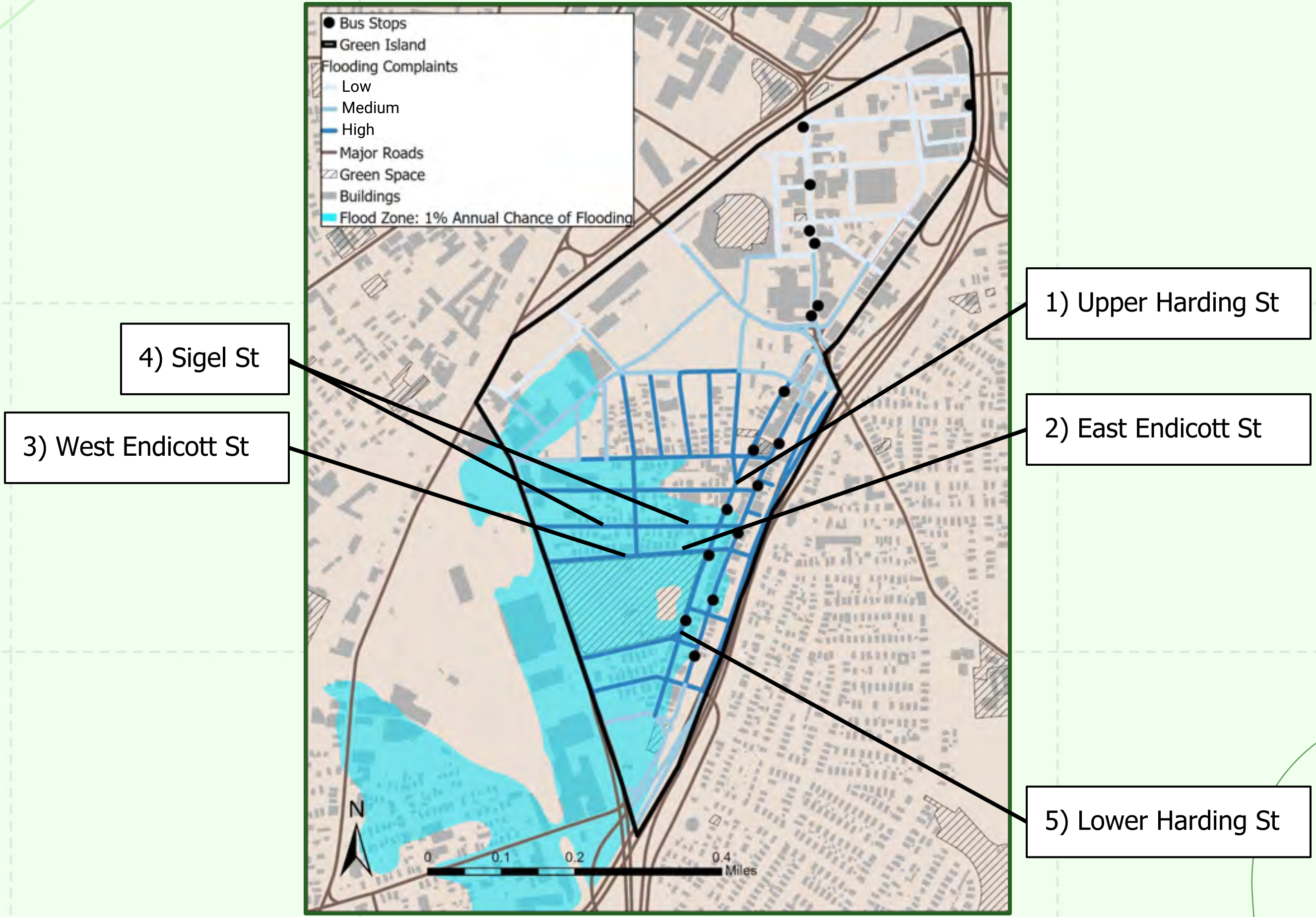




Evidence of Consistent Flooding in Green Island



FEMA 2017 Flood Zones and Top 5 Reported Flooded Streets



Historical Wetlands Summary

01 Delineate historical wetlands in Worcester and compare them with modern day floodplain characteristics

1. Several of Worcester’s current water bodies were formally wetlands
2. Green Island’s low elevation, high impervious cover, and hydrologic history explain the high rates of flooding seen today
3. There is consistent flooding in southern Green Island, especially around the streets of Harding, Endicott, and Sigel

02

Identify potential green infrastructure solutions for flood mitigation in Green Island

Two Approaches: Localized and Watershed

Localized Approach:

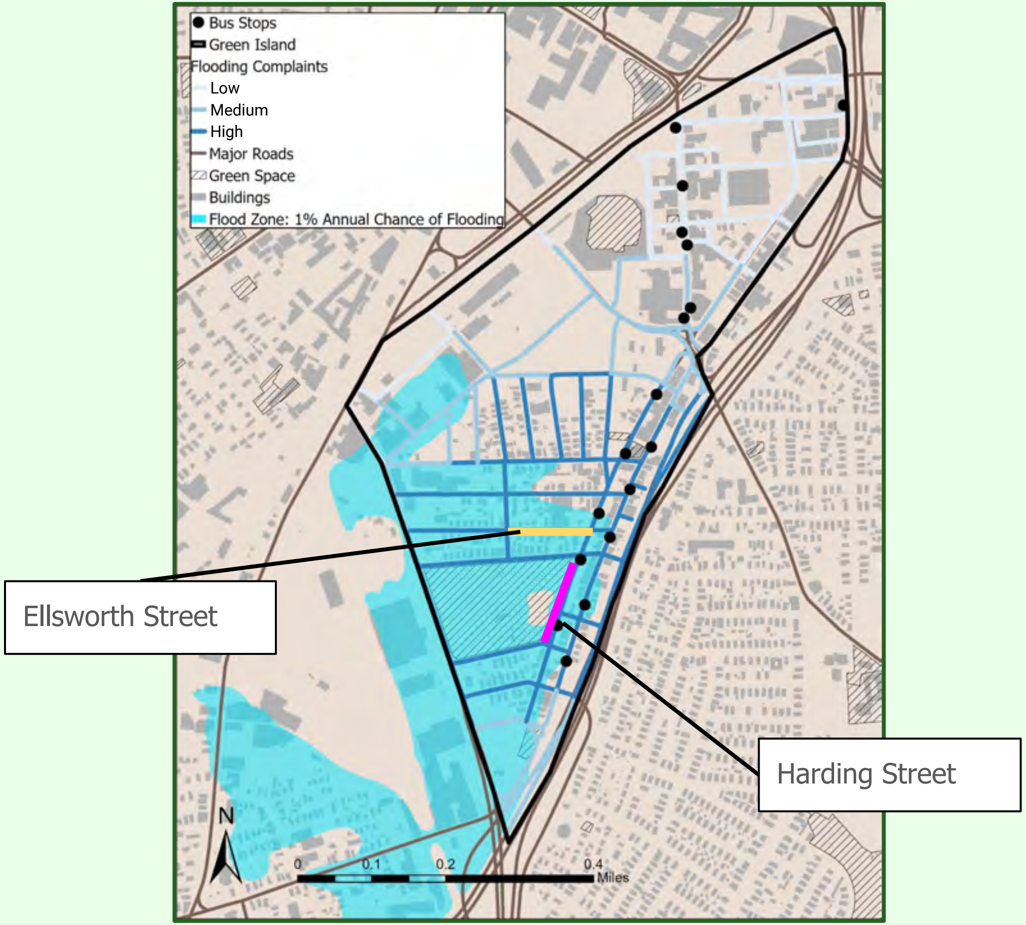
Bioswales at the street level

Watershed Approach:

Green infrastructure within the watershed

Localized Flood Mitigation

Localized Flood Mitigation Example Streets



Harding Street:

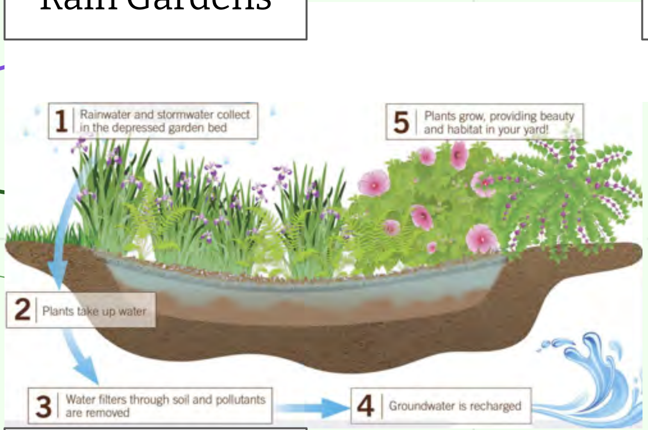
- Upper Harding: Street with **the highest** reported flooding
- Lower Harding: Street with the 5th highest reported flooding

Ellsworth Street:

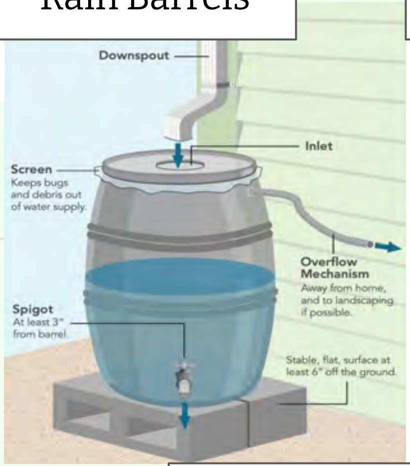
- Street with the 13th highest reported flooding

Watershed Scale Flood Mitigation

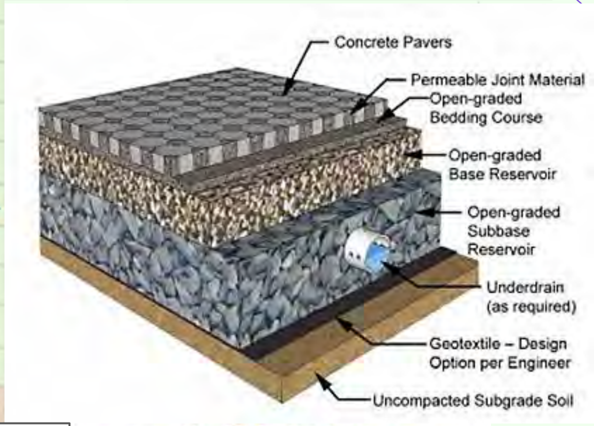
Rain Gardens



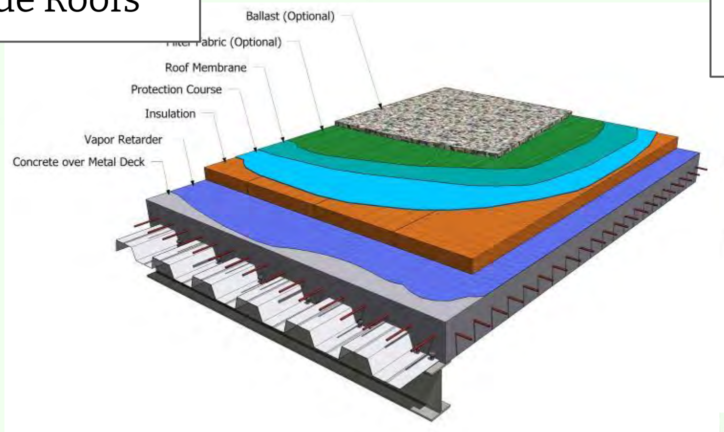
Rain Barrels



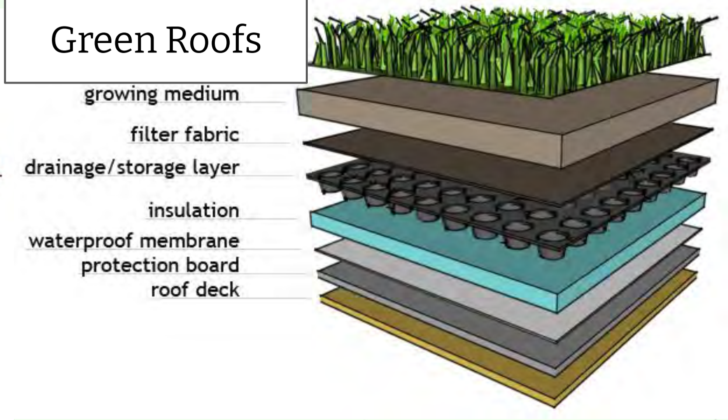
Permeable Pavements



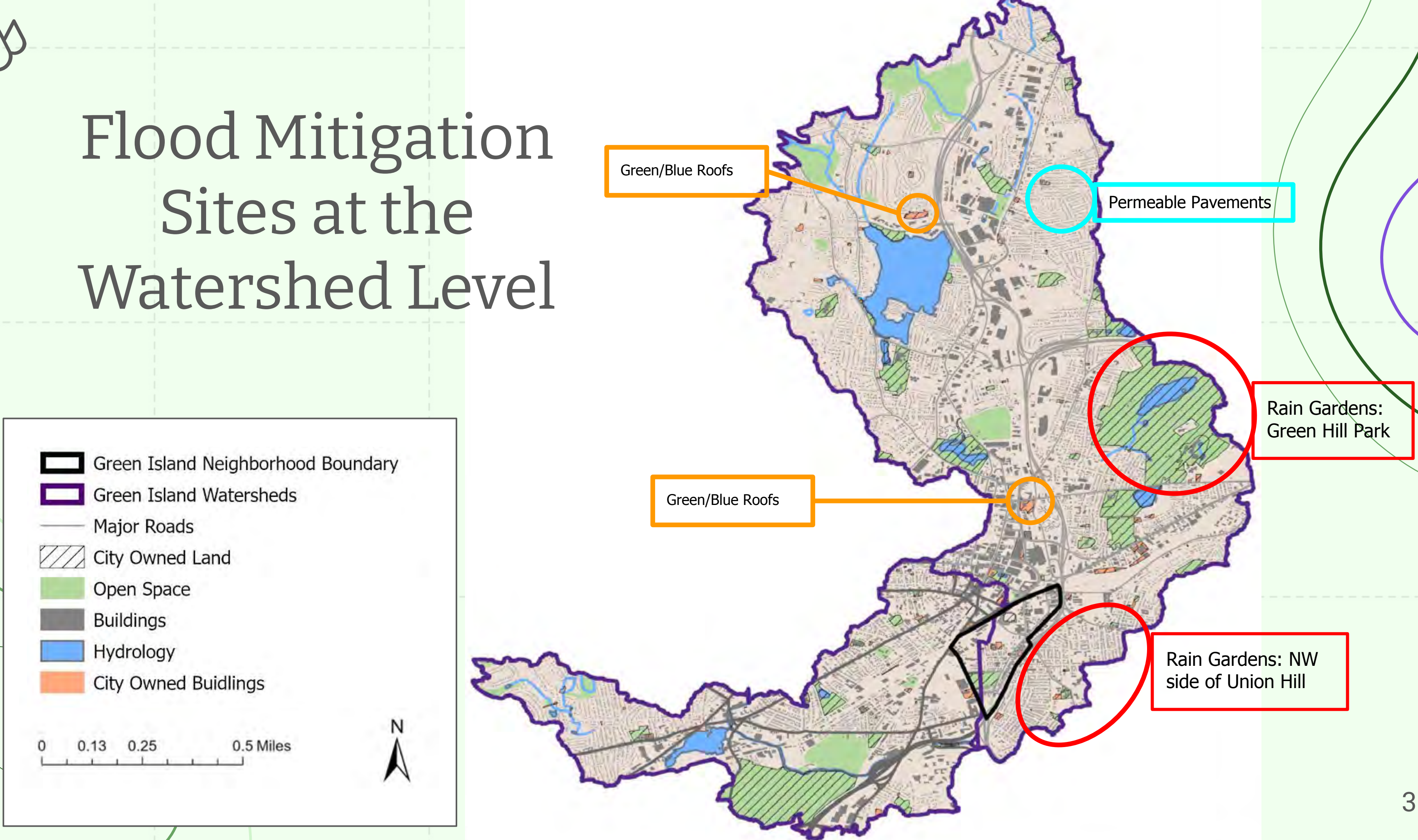
Blue Roofs



Green Roofs



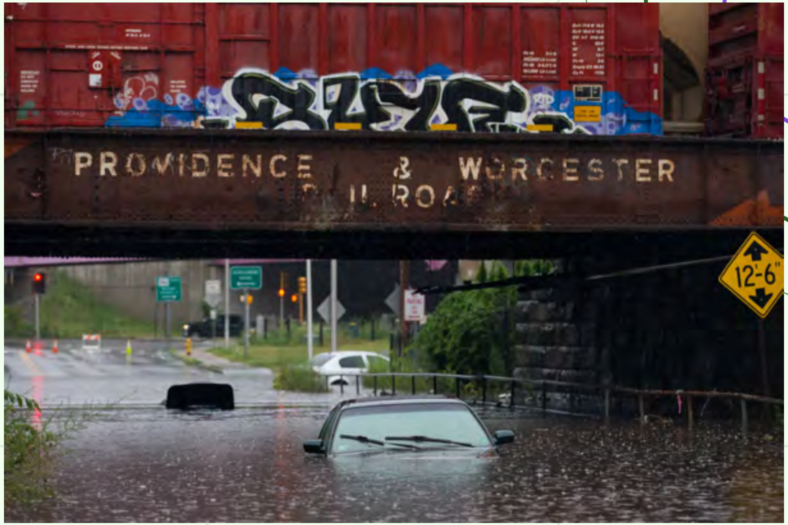
Flood Mitigation Sites at the Watershed Level



Flood Mitigation Solutions Summary

02 Identify potential green infrastructure solutions for flood mitigation in Green Island

1. There are many solutions to mitigate flooding, some fall within a localized approach such as Bioswales, others at a watershed approach such as rain gardens and green roofs
2. Holistically, changes from gray to green infrastructure at a watershed scale is key for long term resiliency
3. Each solution is case by case; focusing on city owned land and buildings to implement green infrastructure is a good place to start



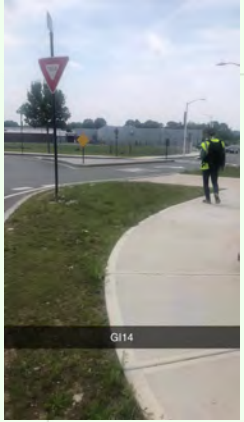
03

Compare surface/air temperature and ozone variability of Green Island and Columbus Park at a high resolution with in situ measurements

Land Use Examples

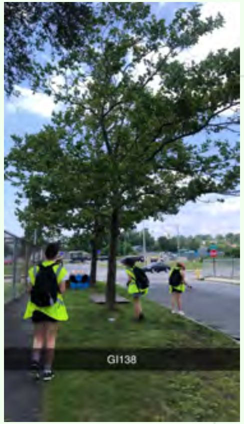
Single Family Residential

Multi Family Residential



Vacant

Small Commercial



Maintained Park

Large Commercial

Institution

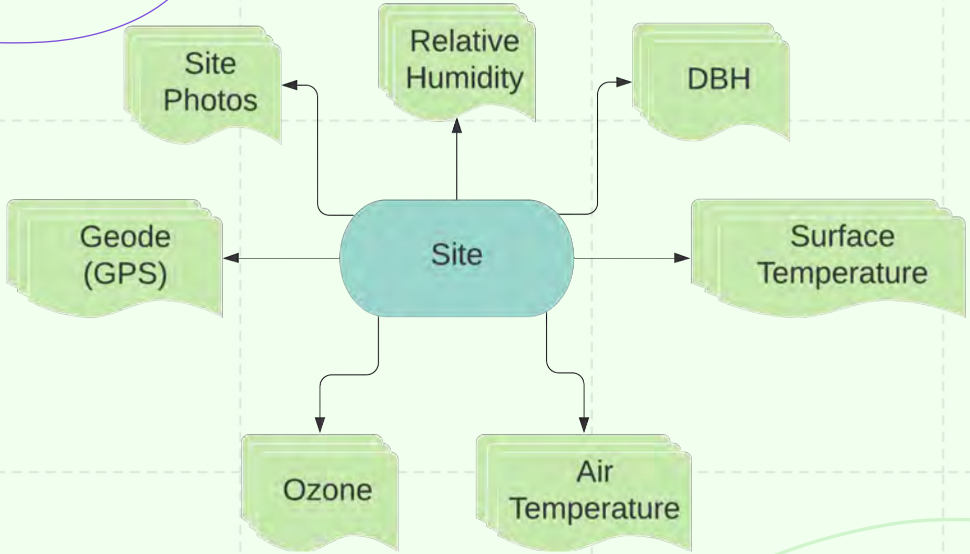
Tree Infrastructure Examples

Median

Planting Strip

Sidewalk Cutout

Field Data Collection and Sampling



Field Data Collection

DBH

Use Diameter at Breast Height tape to wrap around trunk at 54 inches or next available height if juvenile

Site Photos

Take full photo of site and surrounding area and supplementary photos if any more information is needed (ex. Tree has fungus)

Field Data Collection

Air Temperature

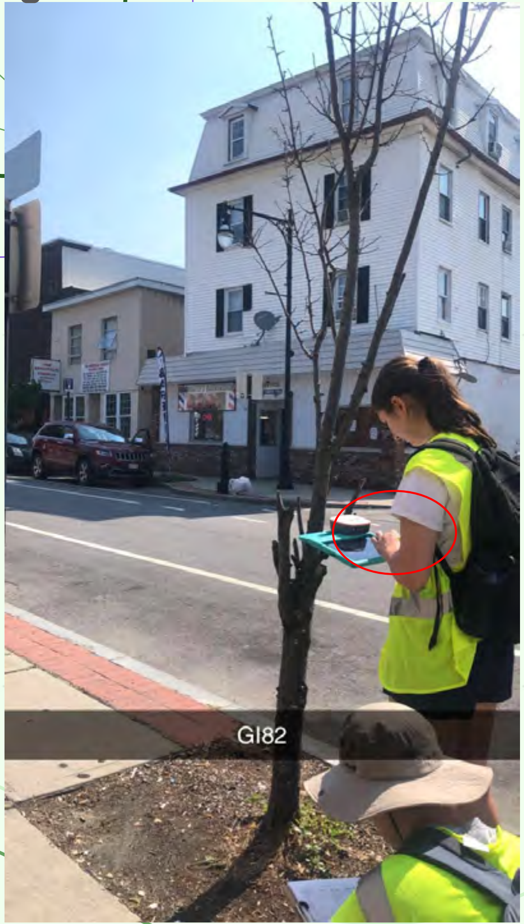
Relative Humidity

Hold under cover of cup to protect from wind and direct sunlight

Surface Temperature

Sun: Point directly at road next to site and read the numbers

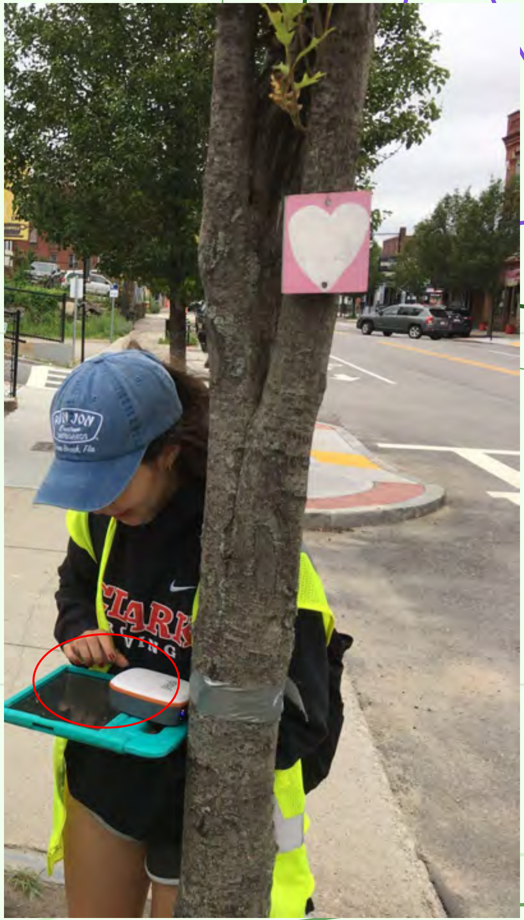
Shade: Point directly under road shaded by tree canopy at the site and read numbers



Field Data Collection

Geode (GPS)

Hold steady at site, waiting until estimated horizontal error reads below 3.0 meters and save point under Tree ID



Field Data Collection

Ozone

Allow ozone reader to cycle through twice to give reading of ozone level at site

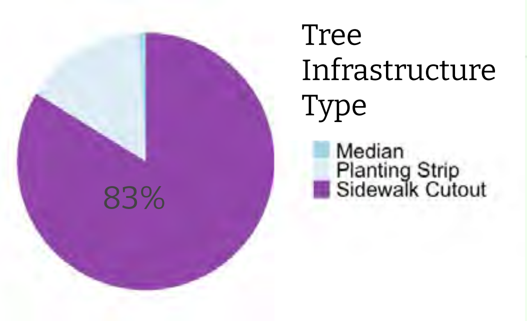
Revised Ozone AQI Breakpoints				
Category	AQI Value	8-Hour Average (ppm) 1997	2008	2015
Good	0-50	0.000-0.064	0.000-0.059	0.000-0.054
Moderate	51-100	0.065-0.084	0.060-0.075	0.055-0.070
Unhealthy for Sensitve Groups	101-150	0.085-0.104	0.076-0.095	0.071-0.085
Unhealthy	151-200	0.105-0.124	0.096-0.115	0.086-0.105
Very Unhealthy	201-300	0.125-0.374	0.116-0.374	0.106-0.200

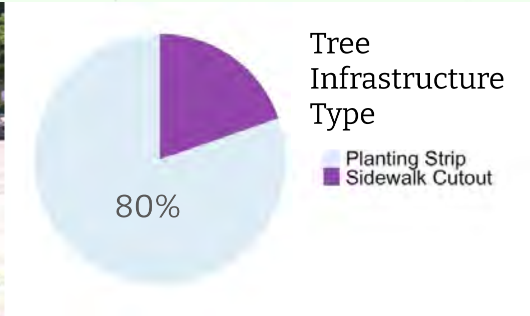
Green Island Census

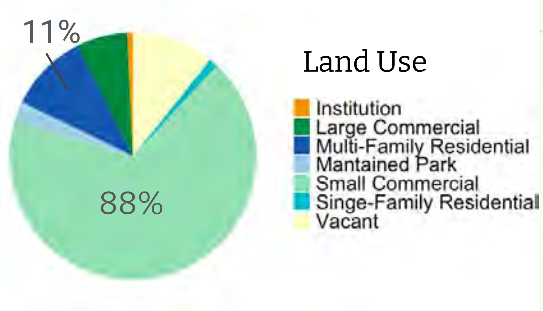
Tree Canopy Cover = 9.2%
Impervious Surface = 71%

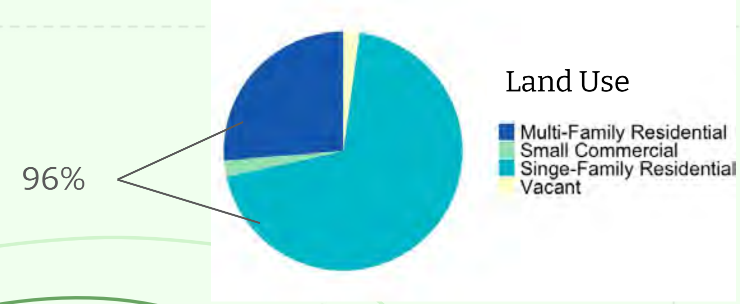
Columbus Park Survey

Tree Canopy Cover = 45%
Impervious Surface= 44%



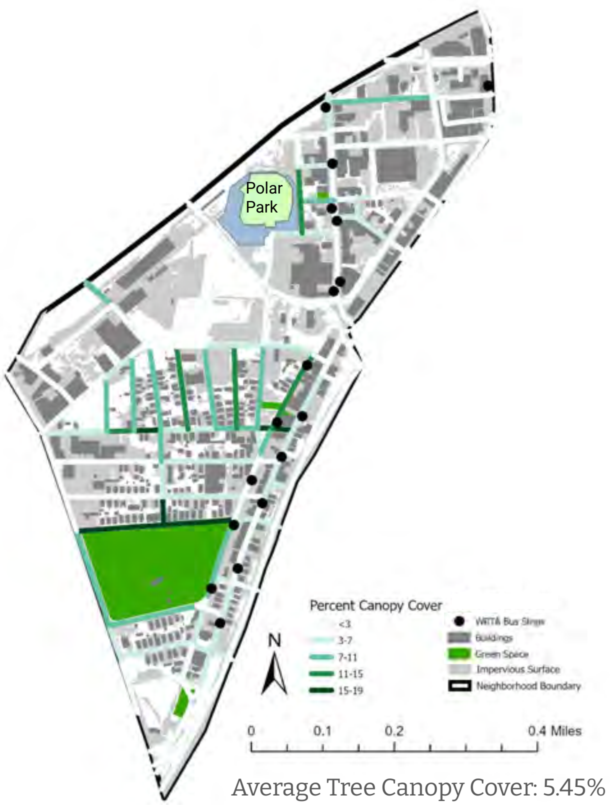






Canopy Cover and Impervious Surface Cover

Tree Canopy Within 100 ft. of Street Centerlines



Average Tree Canopy Cover: 5.45%

Average difference from Worcester Temp.

+6.2℉

Sun/Shadow Surface Temperature

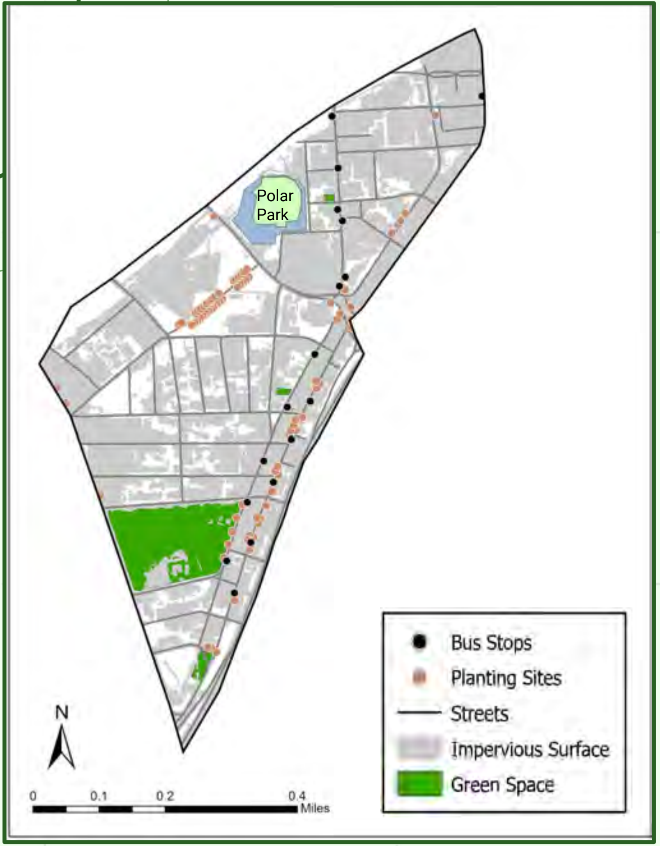
Average: +15℉
Maximum: +30℉

Impervious Surface Within 100 ft. of Street Centerlines

Average Impervious Cover: 66.77%

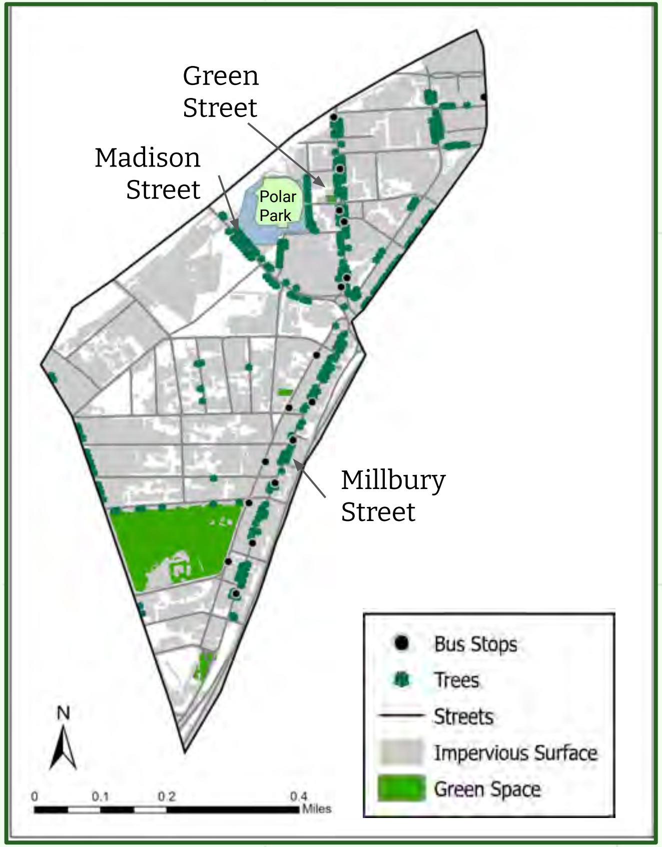
Empty Sites and Existing Street Trees

Available Planting Sites



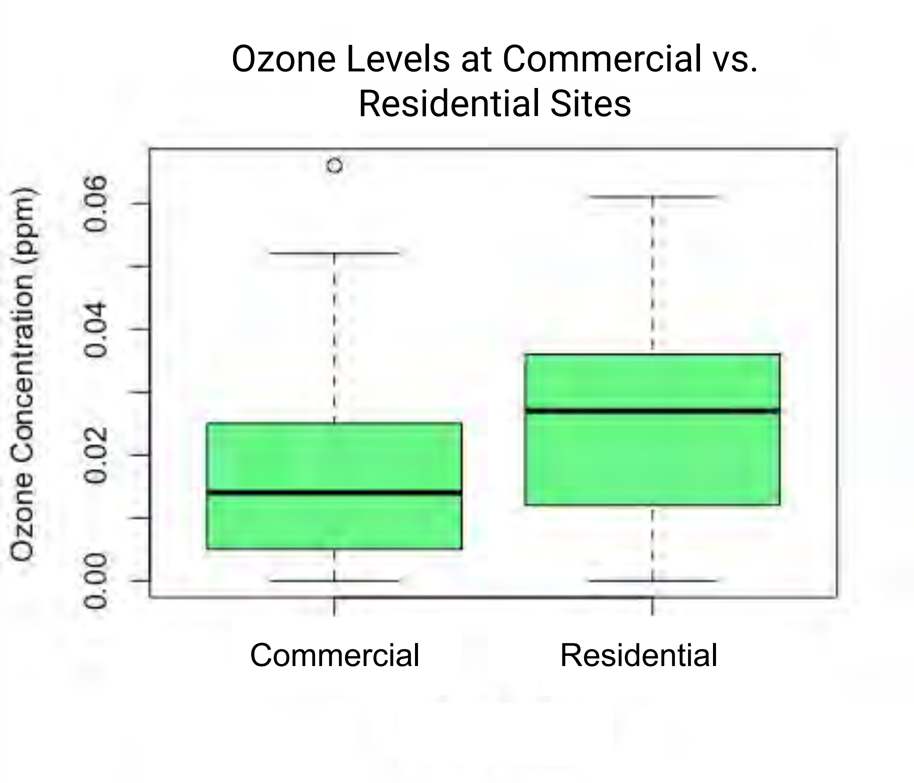
83 Planting Sites

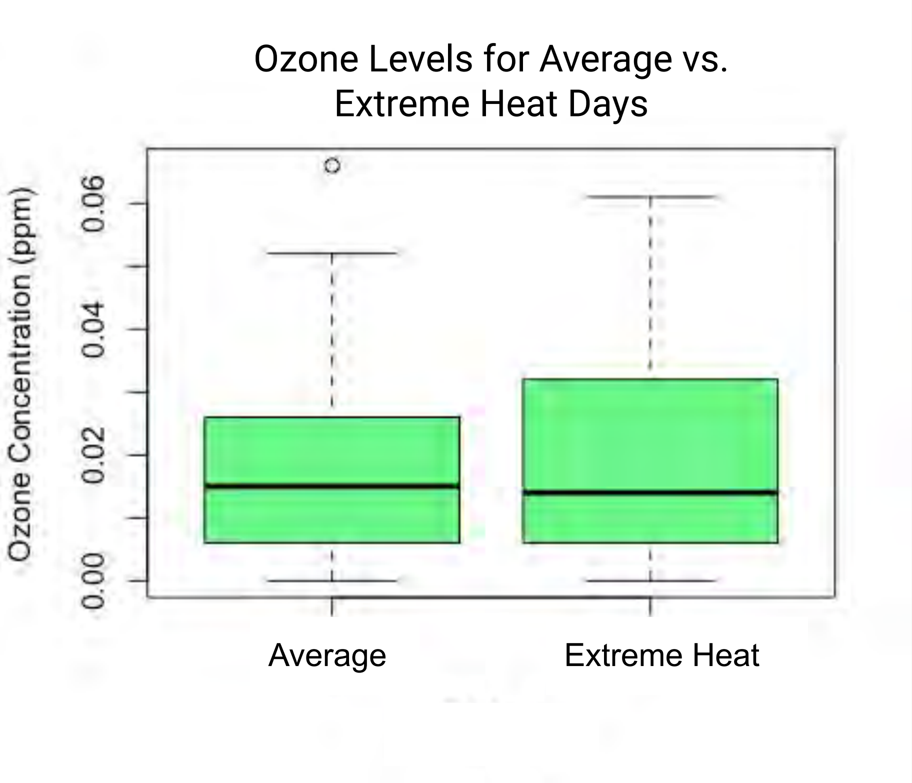
Existing Street Trees



298 Street Trees

Green Island Study: Ozone Levels

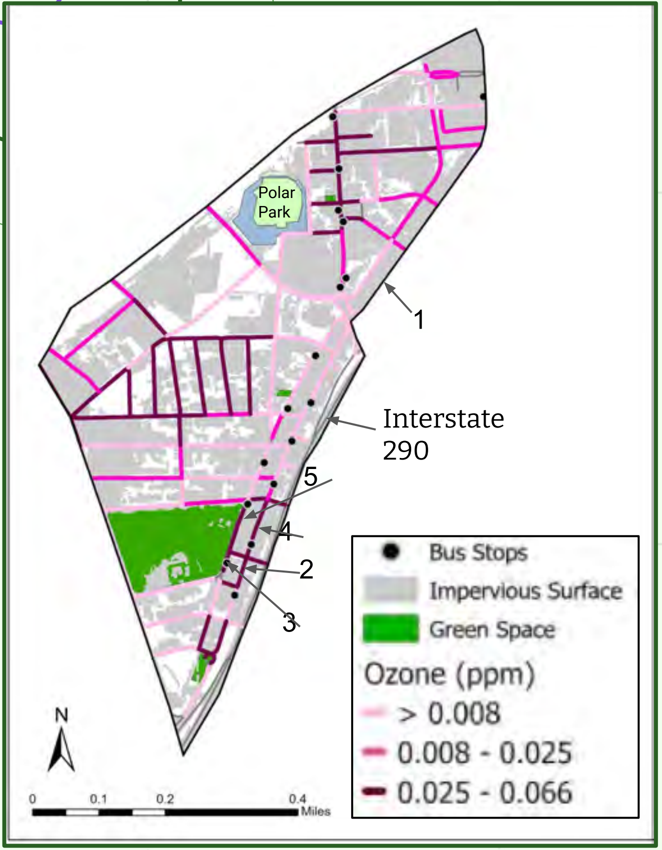




The EPA standard states that ozone levels over 0.07 ppm are unhealthy; our maximum measurement was 0.066 ppm.

Ozone Concentration Analysis

Ozone Concentration by Street Segment



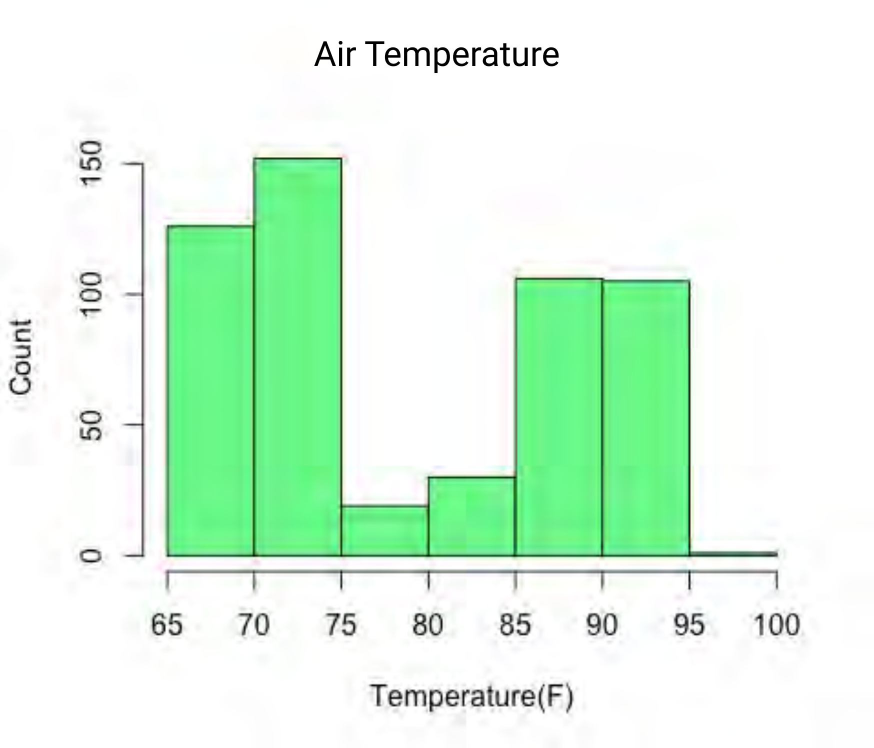
Sites with Highest Ozone Concentration:

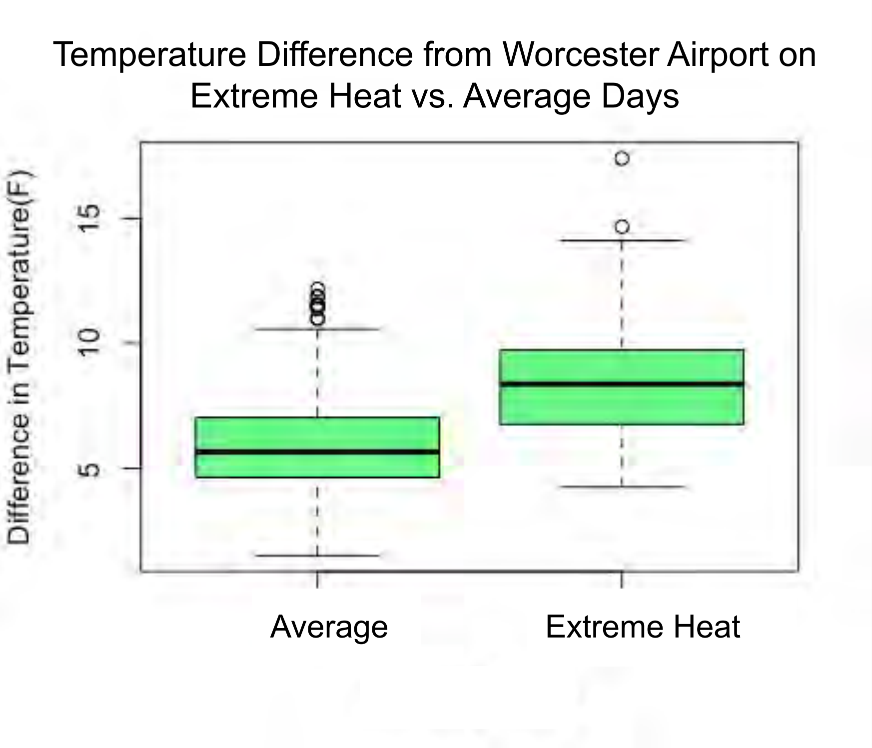
1. Water St (0.066 ppm)
2. Millbury St (0.045 ppm)
3. Harding St (0.042 ppm)
4. (Upper) Millbury St (0.042 ppm)
5. (Upper) Harding St (0.041 ppm)

Average: 0.017 ppm (Median: 0.014 ppm)

EPA standards state that ozone concentrations over 0.070 ppm pose a health risk. All of our measurements were below this benchmark.

Air Temperature Analysis

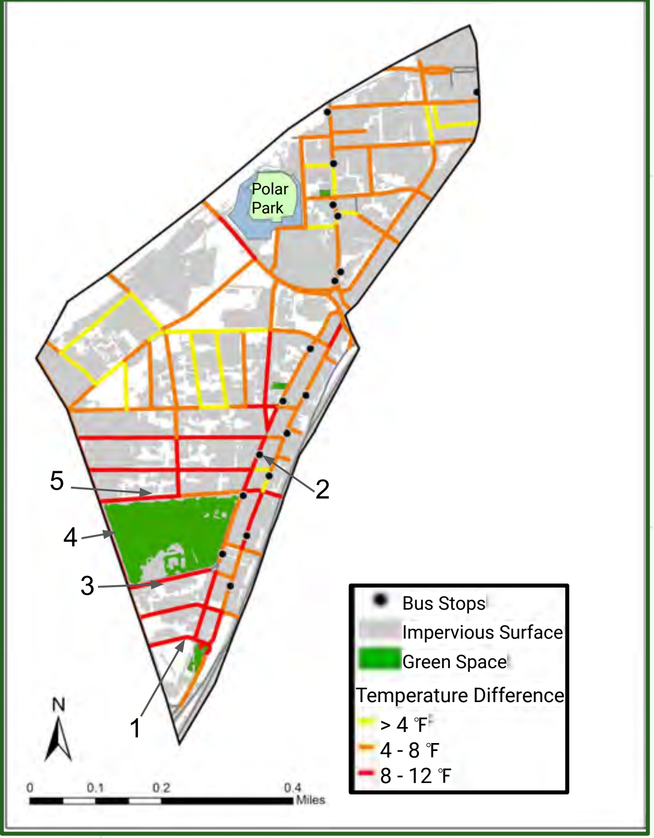




Extreme heat days were 8.5℉ hotter on average than the Worcester temperature, while normal days were 5.9℉ hotter

Air Temperature

Temperature Difference from Worcester Airport by Street Segment



Hottest Sites by Temperature Difference:

1. Arwick Ave (+10.9℉)
2. Harding St (+10.7℉)
3. Canton St (+10.7℉)
4. Quinsigamond Ave (+10.4℉)
5. Sigel St (+10.2℉)

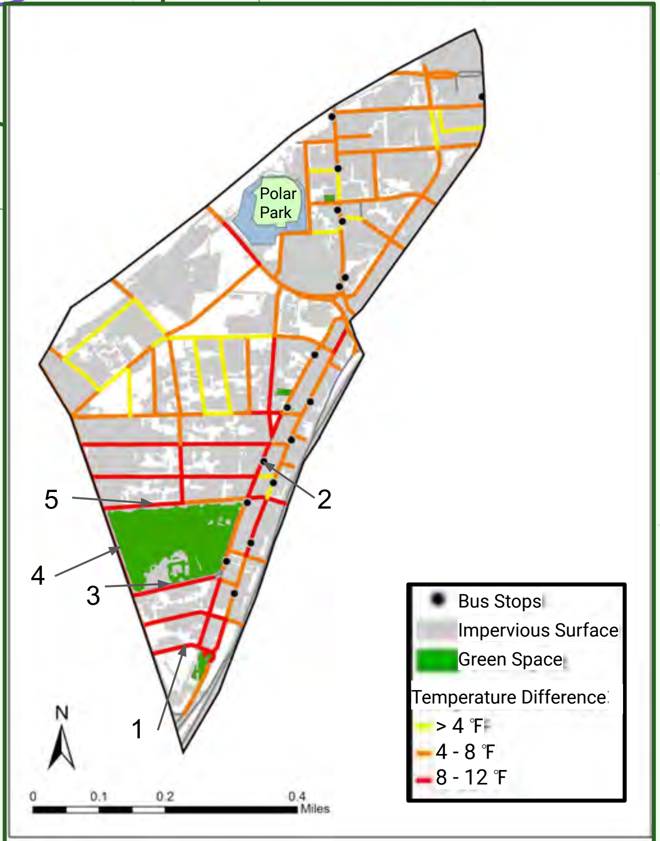
Honorable mention:

Ellsworth St (9.1℉)

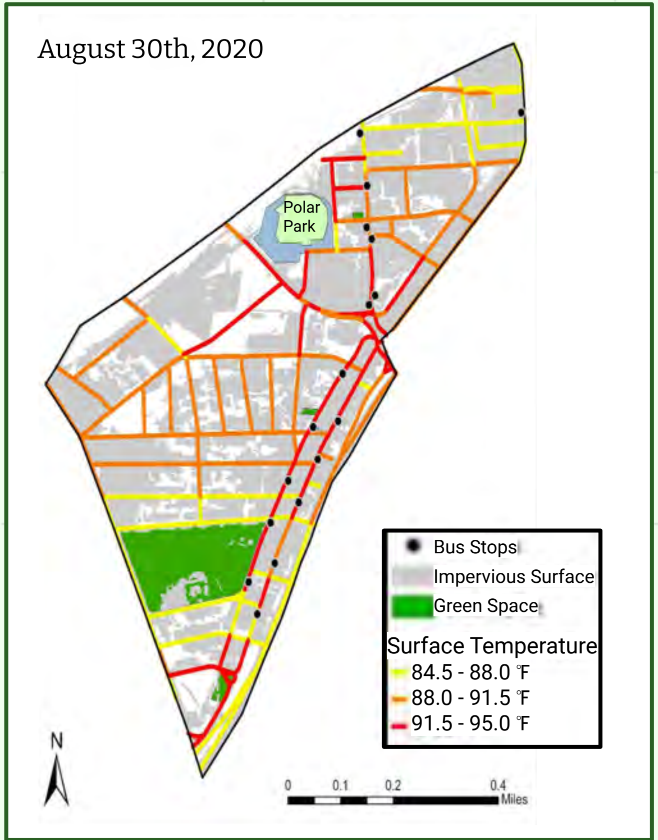
Average: +6.2℉

Air vs. Surface Temperature

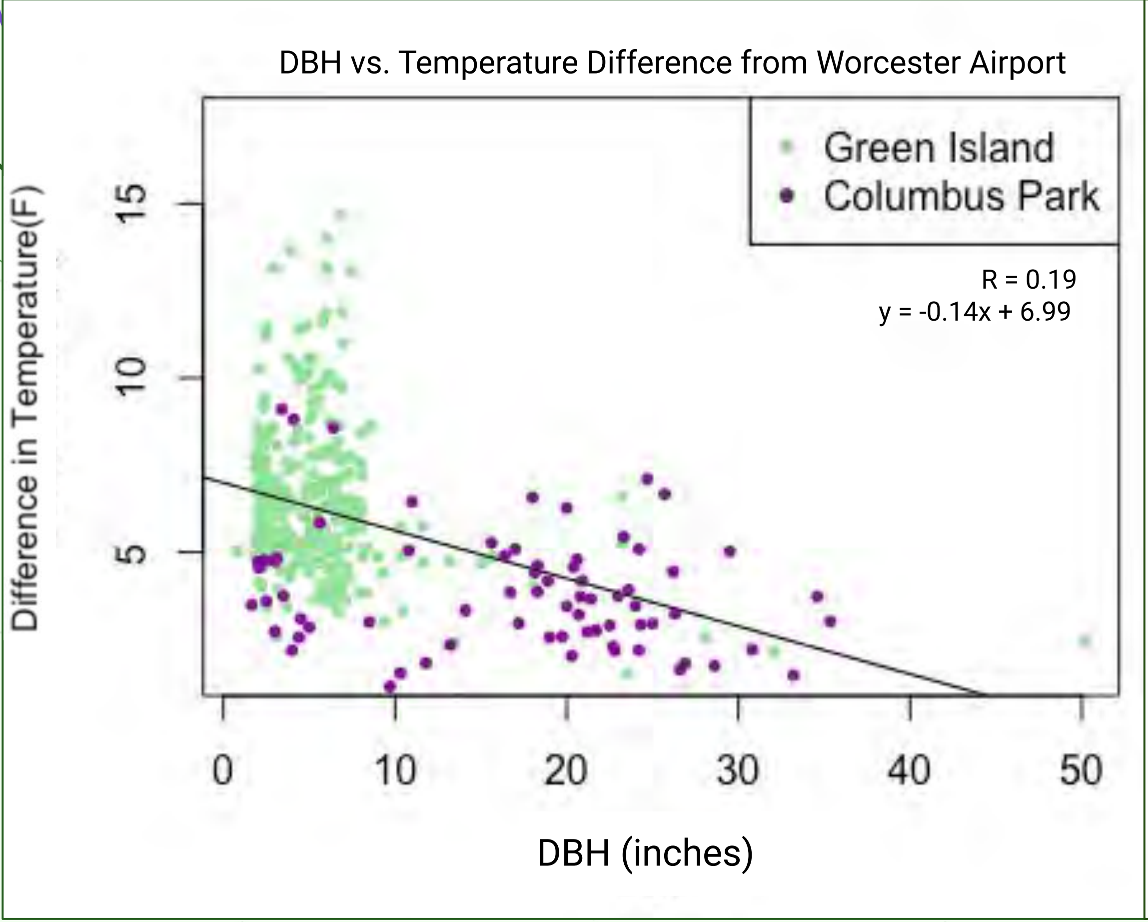
Temperature Difference from Worcester Airport by Street Segment



Surface Temperature by Street Segment

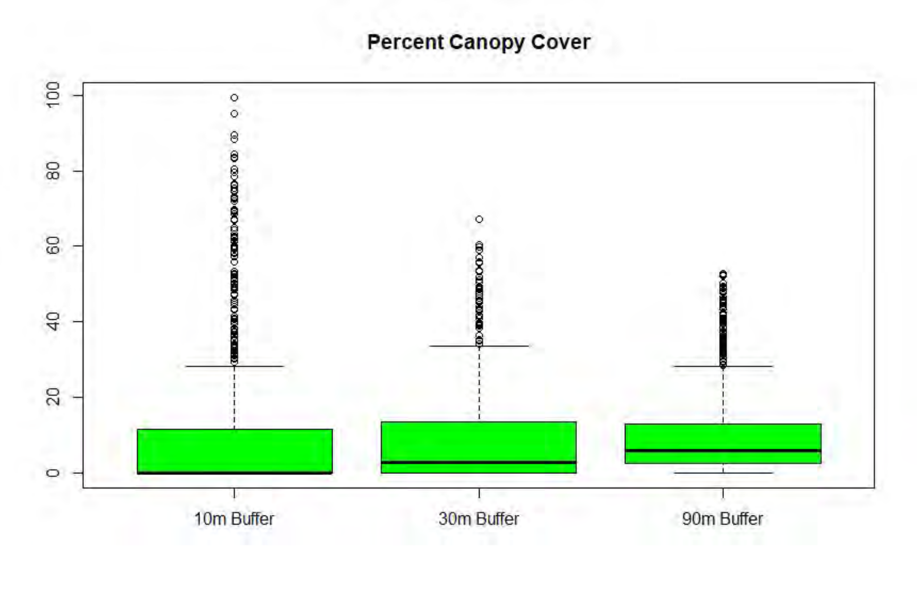


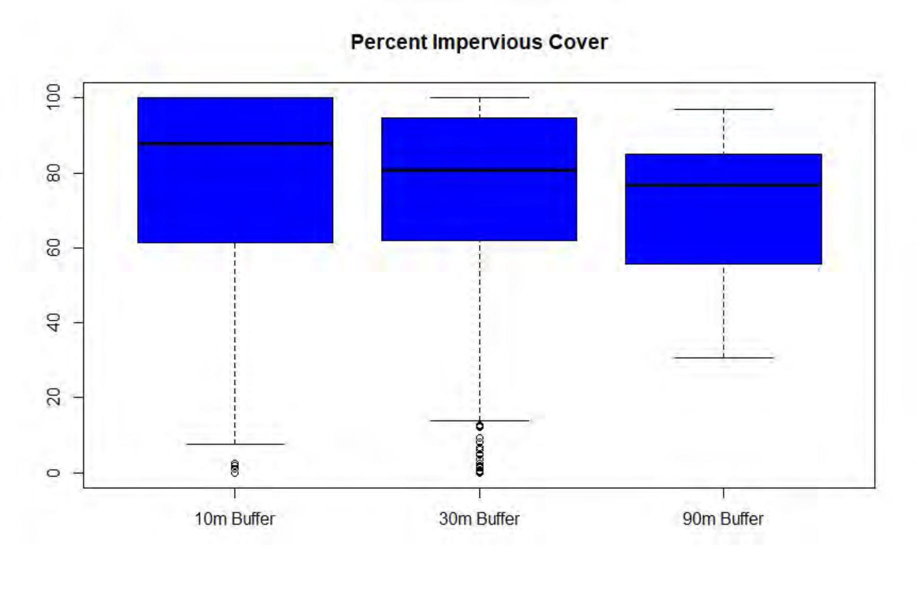
DBH and Temperature



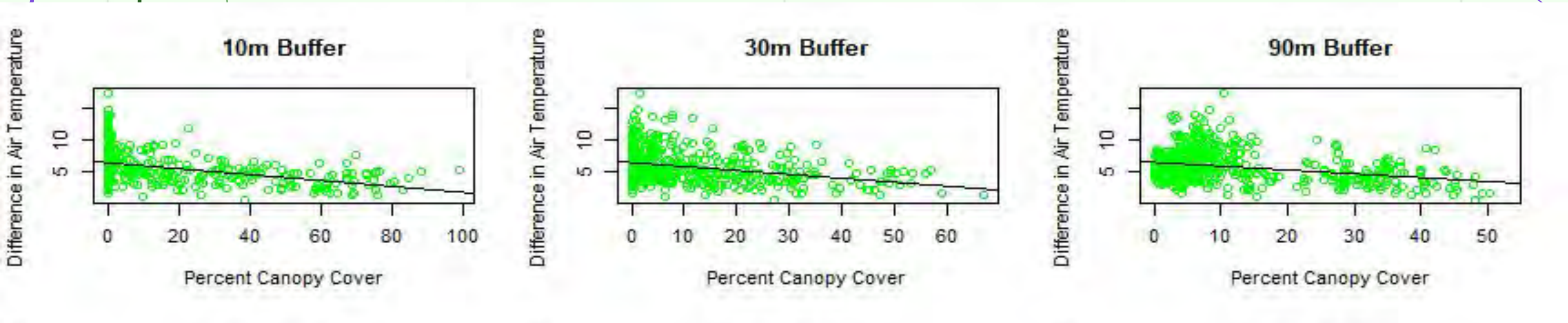
Sensitivity Analysis

Previous urban forestry research has conducted sensitivity tests across circular areas with 10, 30, and 90m radii.

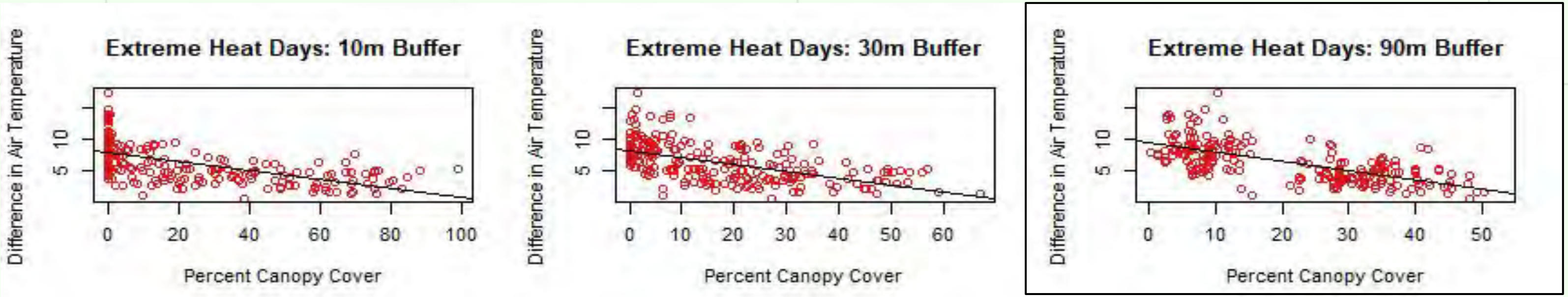




Sensitivity Analysis



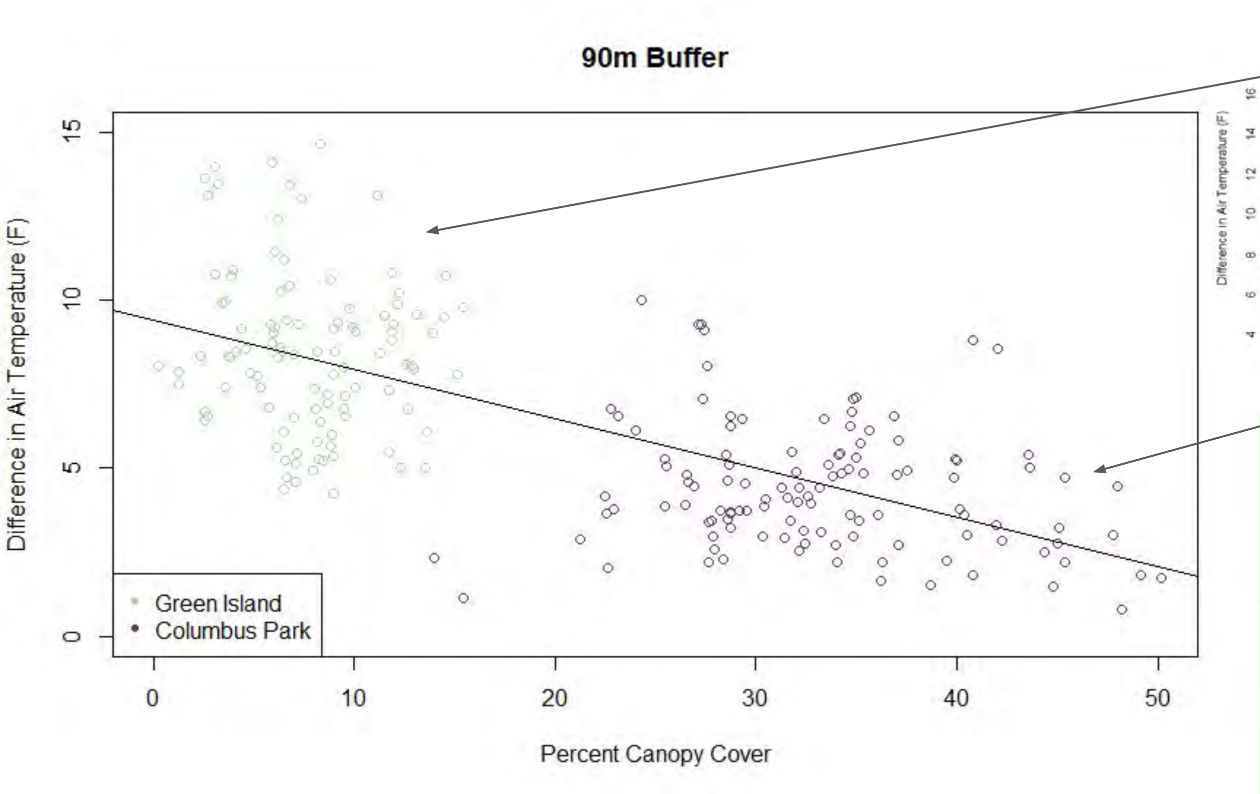
As % Canopy Cover increases, the difference in site air temperature and Worcester temperature decreases.

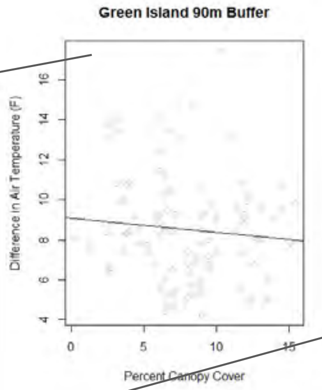


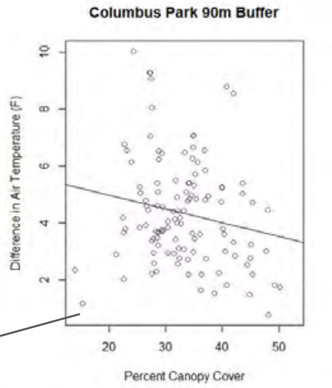
$R^2 = 0.4469$

$y=-0.14672x + 9.4227$

Air Temperature Sensitivity Analysis



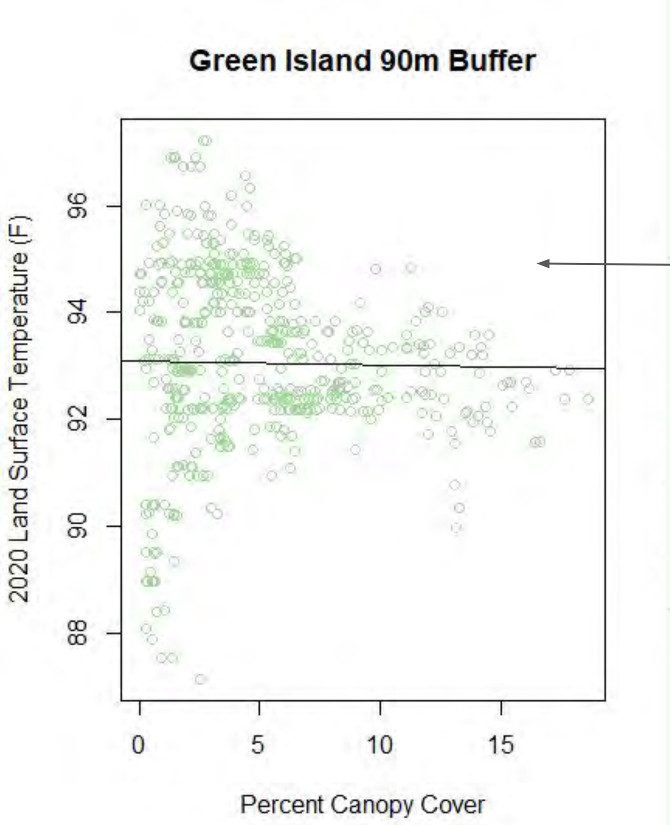




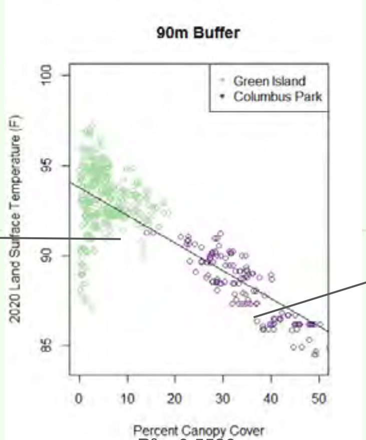
For every 6.8% increase in canopy cover over a 90m buffer, the air temperature decreases by 1°F.

6.8% of a 90m buffer = 0.427 Acres

Surface Temperature Sensitivity Analysis



$R^2 = 0.0002728$

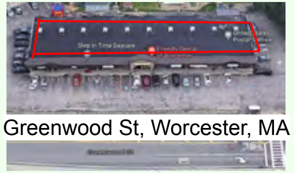


$R^2 = 0.5526$

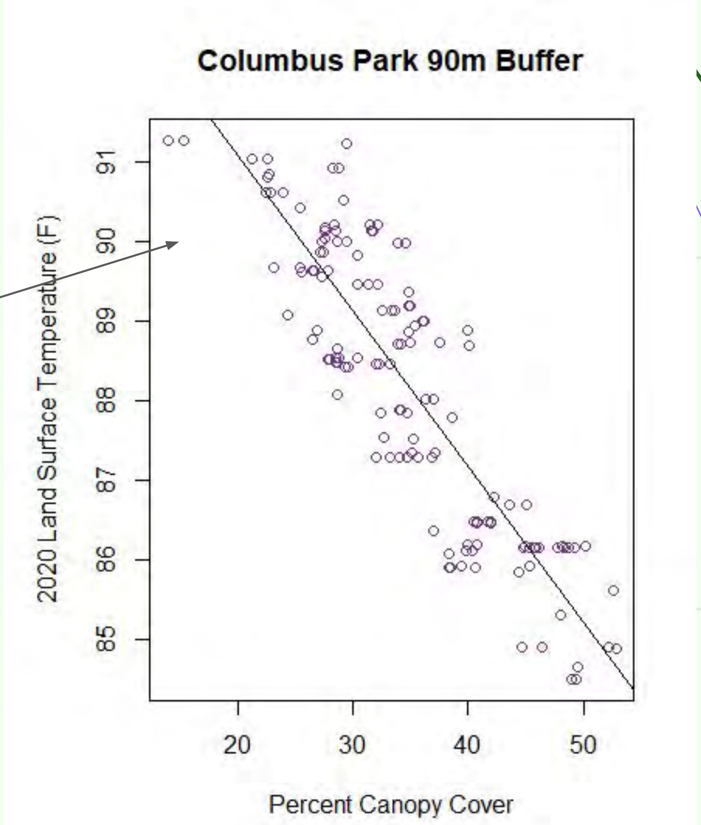
y = -0.147961x + 93.705820

For every 5% increase in canopy cover over a 90m buffer, the land surface temperature decreases by 1°F.

5% of a 90m buffer = 0.314 Acres



347 Greenwood St, Worcester, MA 01607



$R^2 = 0.7748$

y= -0.196521x + 95.039354

Urban Heat Island Summary

03 Compare surface/air temperature and ozone variability of Green Island and Columbus Park at a high resolution with in situ measurements.

Green Infrastructure

Available planting sites tend to be on streets with existing trees in Green Island.

Existing trees are mainly juvenile, so they currently do not provide much canopy cover.

Greater canopy cover in Columbus Park has a cooling effect

Temperature

In Green Island, sites with the greatest temperature difference from Worcester Airport were found in residential areas surrounding Crompton Park.

Ozone

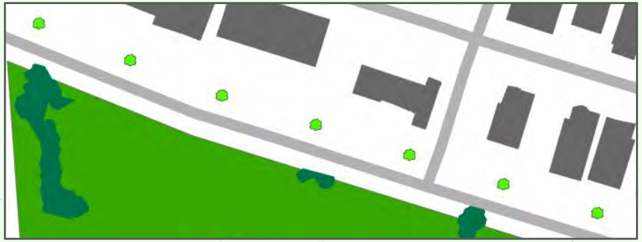
Maximum recorded concentration in Green Island is twice as high as Columbus Park.

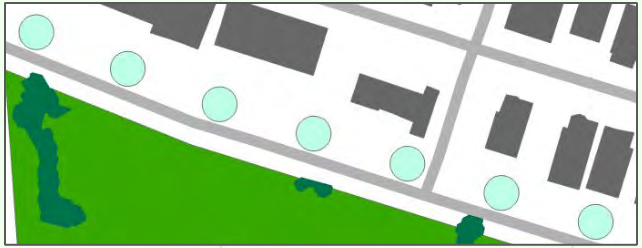
Highest concentrations were found along Interstate 290.

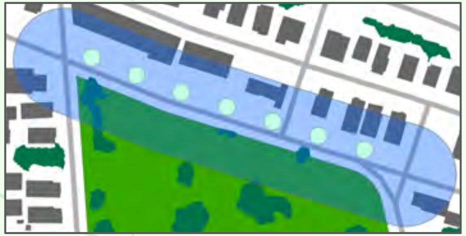
04

Model the role of street trees and treated roofs/solar panels on surface temperature in Worcester

Green Island Study: Model Methods







Expected Tree Growth

$$y = 10^{0.269+1.165\log x - 0.192\log^2 x}$$

$$z = 10^{0.007+0.825\log y - 0.077\log^2 y}$$

[where x = year, y = DBH and z=Canopy Diameter]

Decrease in Surface Temperature

$$T=-0.14672c$$

[where c = % canopy cover and T = decrease in surface temp.]

Assumptions

1. No species diversity, planting only Honey Locust (*Gleditsia triacanthos*)
2. All trees are planted at 5 years old, and no tree mortality occurs between Planting Year 0 and Year 30
3. All trees grow at the same rate and maintain the same diameter at breast height
4. Median, mean, and maximum tree density refer to current tree spacing on Green Island street segments

Green Island Study: Existing Green Infrastructure

Available Planting Sites by Street Segment

Average: 1 tree every 5 meters (~16 ft)

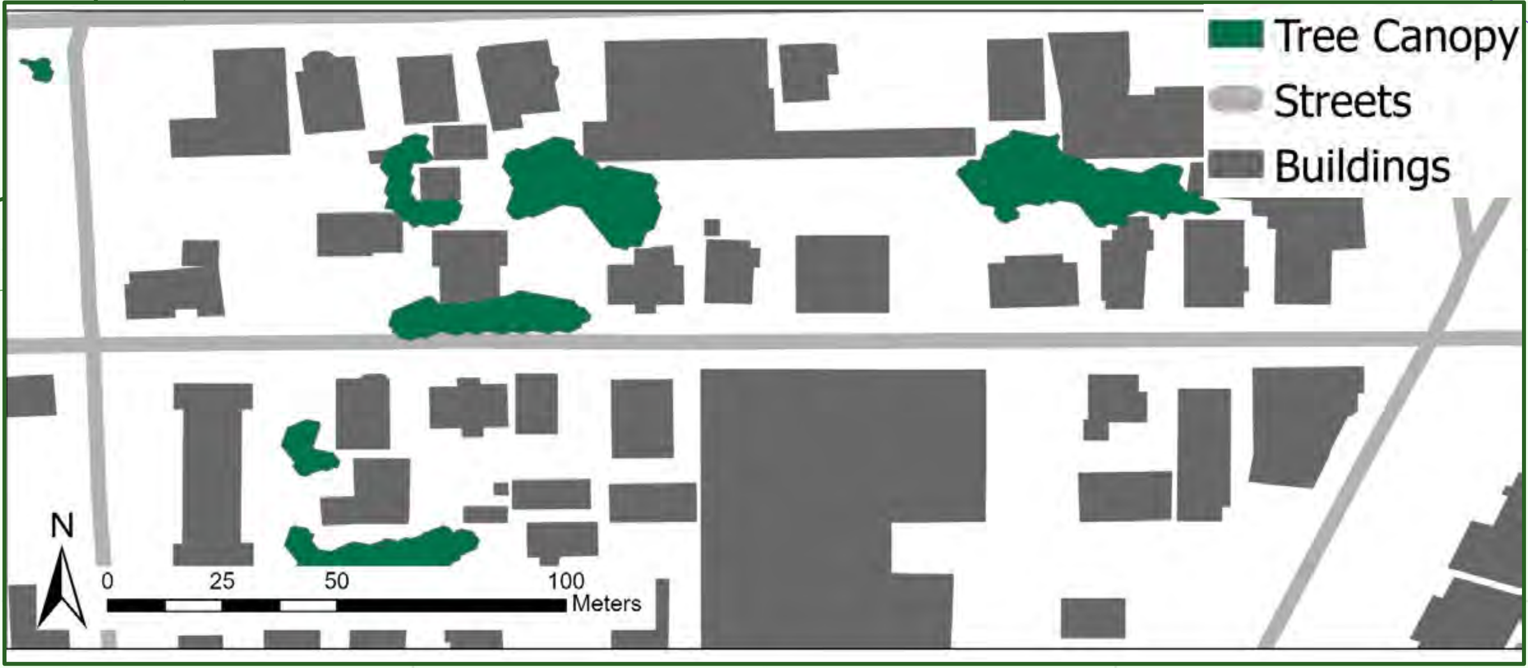
The median street segment in Green Island currently has one planting site every 30 meters (~ 90ft) , while the average segment has one tree every 7 meters (~23 ft).

The highest density segment currently has a tree every 3.5 meters (~11.5ft).

Existing Street Trees by Street Segment

Average: 1 tree every 7 meters (~23 ft)

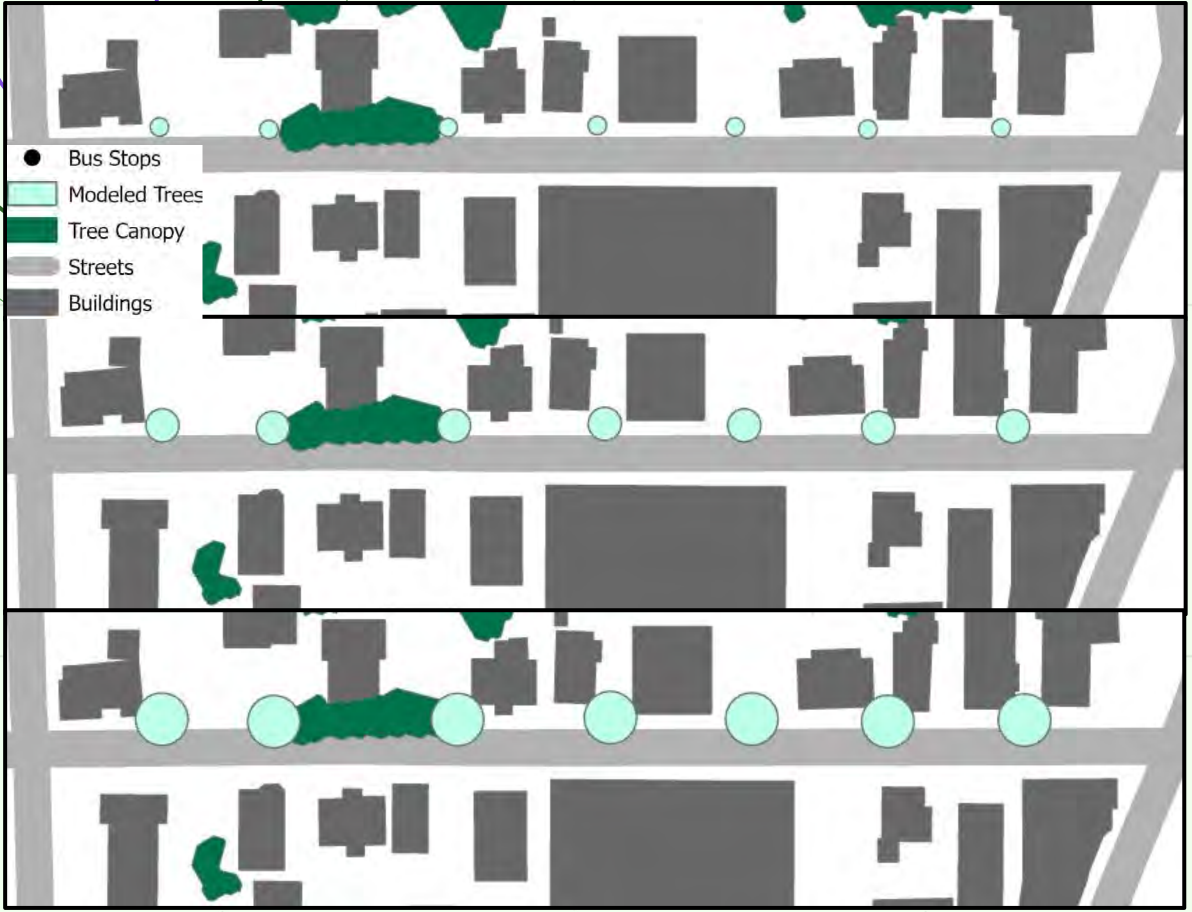
Ellsworth Street Model



Temperature Difference: +9.1℉ | Air Temperature: 93.1℉ | Surface Temperature (Sun): 124.8℉

Ozone: 0.009 ppm | Humidity: 43 % | Street Trees: 0 | Canopy Cover: 3.45% | Zoning: General Residential

Ellsworth Street Model: Median Tree Density



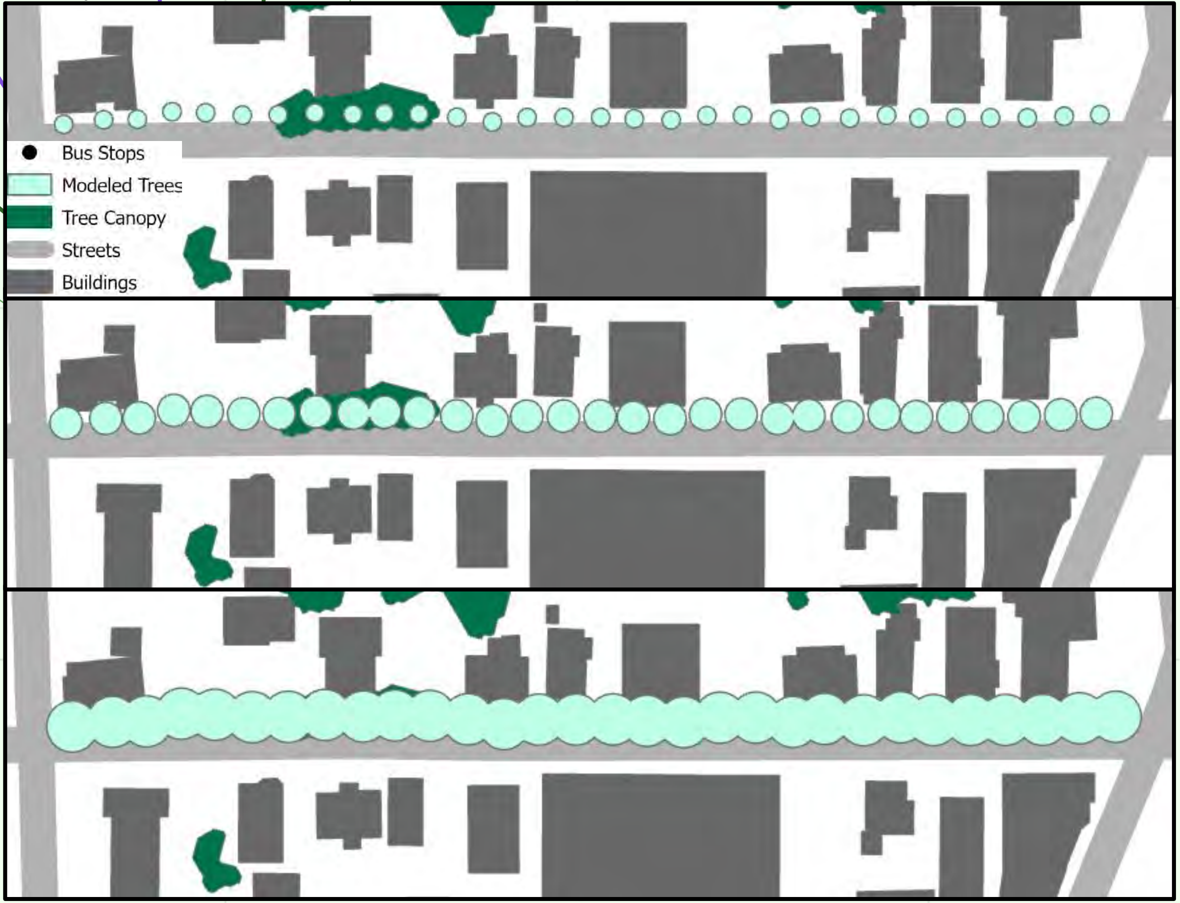
At Planting: 3.9% Canopy
-0.07℉ Surface Temp.

After 10 Years: 4.85% Canopy
-0.21℉ Surface Temp.

After 30 Years: 6.86% Canopy
-0.51℉ Surface Temp.

7 trees = 1 tree every 28m (~90 feet)

Ellsworth Street Model: Mean Tree Density



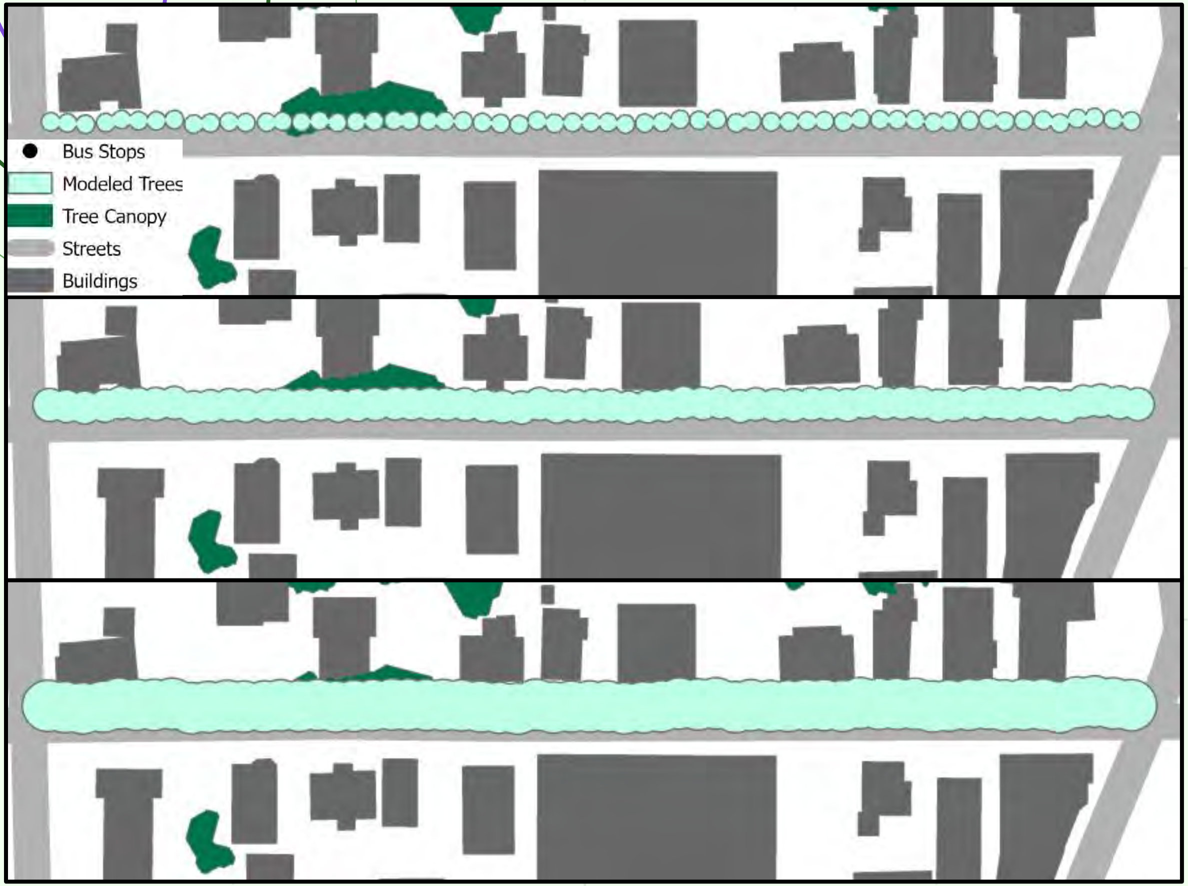
At Planting: 5.34% Canopy
-0.28℉ Surface Temp.

After 10 Years: 9.45% Canopy
-0.89℉ Surface Temp.

After 30 Years: 12.04% Canopy
-1.23℉ Surface Temp.

30 trees = 1 tree every 7m (~23 feet)

Ellsworth Street Model: Maximum Tree Density



61 trees = 1 tree every 3.5 meters (~11 feet)

At Planting: 7.26% Canopy
-0.56℉ Surface Temp.

After 10 Years: 11.63% Canopy
-1.21℉ Surface Temp.

After 30 Years: 16.82% Canopy
-1.98℉ Surface Temp.

Harding Street Model

Temperature Difference: +5.75℉ | Air Temperature: 91.1℉ | Surface Temperature (Sun): 112.14℉

Ozone: 0.040 ppm | Humidity: 57.5 % | Street Trees: 0 | Canopy Cover: 11.42% |

Zoning: General Residential, Commercial, Public

Harding Street Model: Median Tree Density

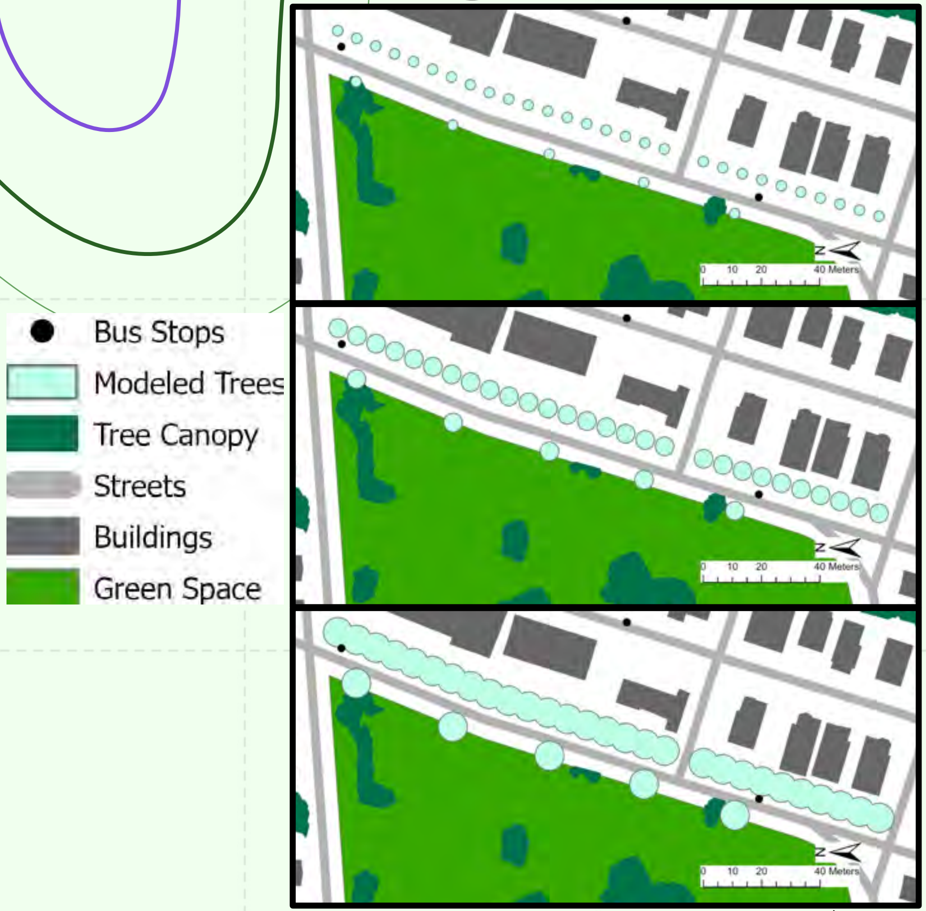
At Planting: 12.2% Canopy
-0.12℉ Surface Temp.

After 10 Years: 13.88% Canopy
-0.36℉ Surface Temp.

After 30 Years: 17.42% Canopy
-0.89℉ Surface Temp.

Median Tree Density: 7 trees = 1 tree every 28m (~90 feet)

Harding Street Model: Mean Tree Density



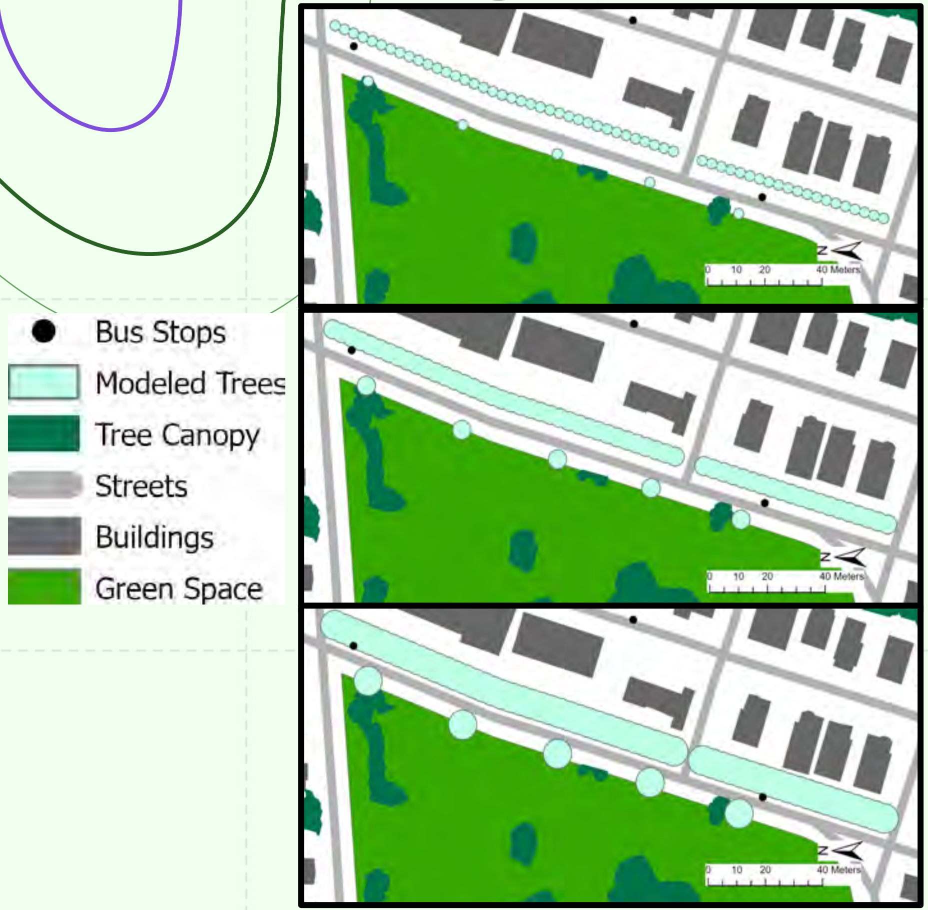
Mean Tree Density: 28 trees = 1 tree every 7m (~23 feet)

At Planting: 13.56% Canopy
-0.42℉ Surface Temp.

After 10 Years: 16.43% Canopy
-0.74℉ Surface Temp.

After 30 Years: 18.19% Canopy
-1.00℉ Surface Temp.

Harding Street Model: Max Tree Density



At Planting: 15.45% Canopy
-0.60℉ Surface Temp.

After 10 Years: 20.38% Canopy
-1.33℉ Surface Temp.

After 30 Years: 27.06% Canopy
-2.31℉ Surface Temp.

Maximum Tree Density: 57 trees = 1 tree every 3.5 meters (~11 feet)

Street Model: Discussion

Why is a small reduction in temperature important?

- Reduce intensity and duration of heat waves
- Health benefits
  - With a 1.8℉ increase in temperature, likelihood of death from respiratory disease increases by 25%, and from cardiovascular disease by 7%
  - Temperatures over 82℉ start to have a negative impact on emotional health.
- Mitigating effect on surrounding area
  - Cooling effect of green space can extend over half a mile
- Potential energy savings for residents
  - Decreasing outdoor temperature by 1.8℉ can decrease cooling costs by 6%.

Benefits of Residential Action

Focusing resources and benefits only on street trees does not maximize canopy benefits

Expanding the potential of existing green spaces to increase tree canopy cover over roads

Residential Tree Planting

GREENING
THE GATEWAY CITIES
MA Urban Canopy Project

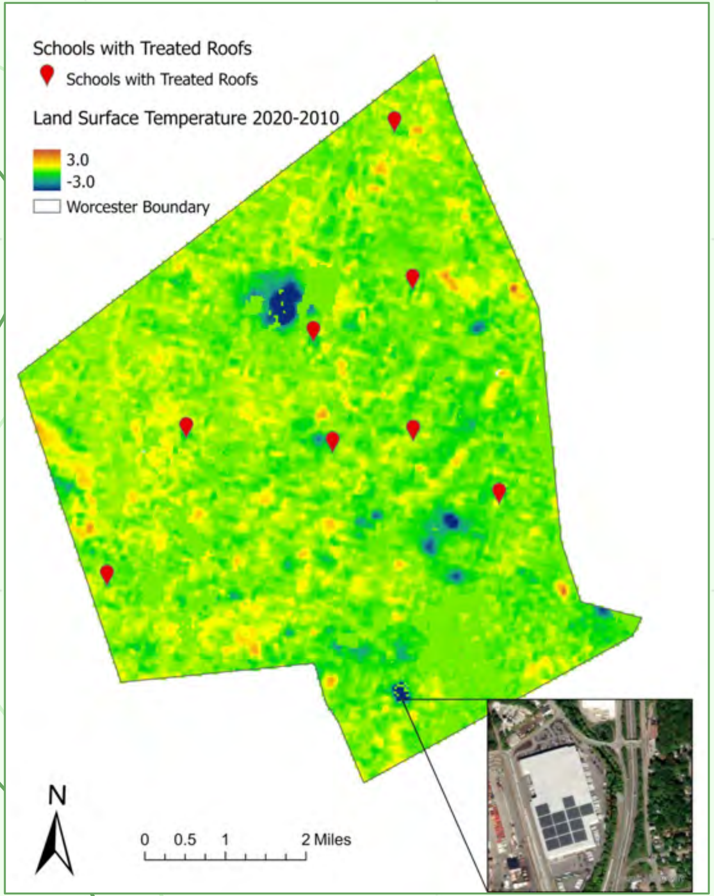
Benefits

Direct electricity savings

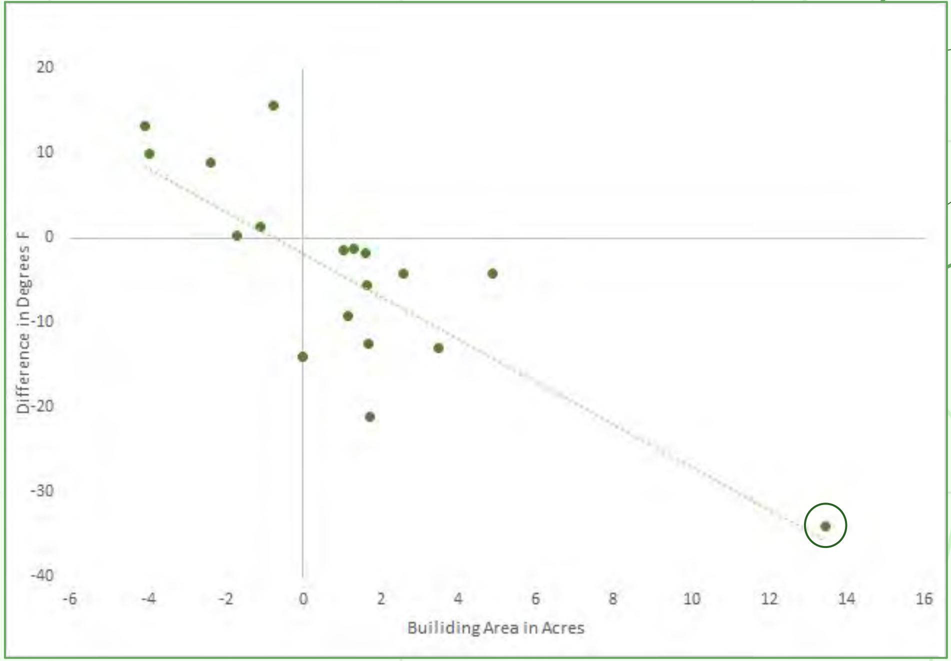
Indirect air conditioning and smog (Ozone) reduction benefits

Landsat Roof Treatment/Tree Loss Modeling

Surface Temperature Image Difference 2020-2010

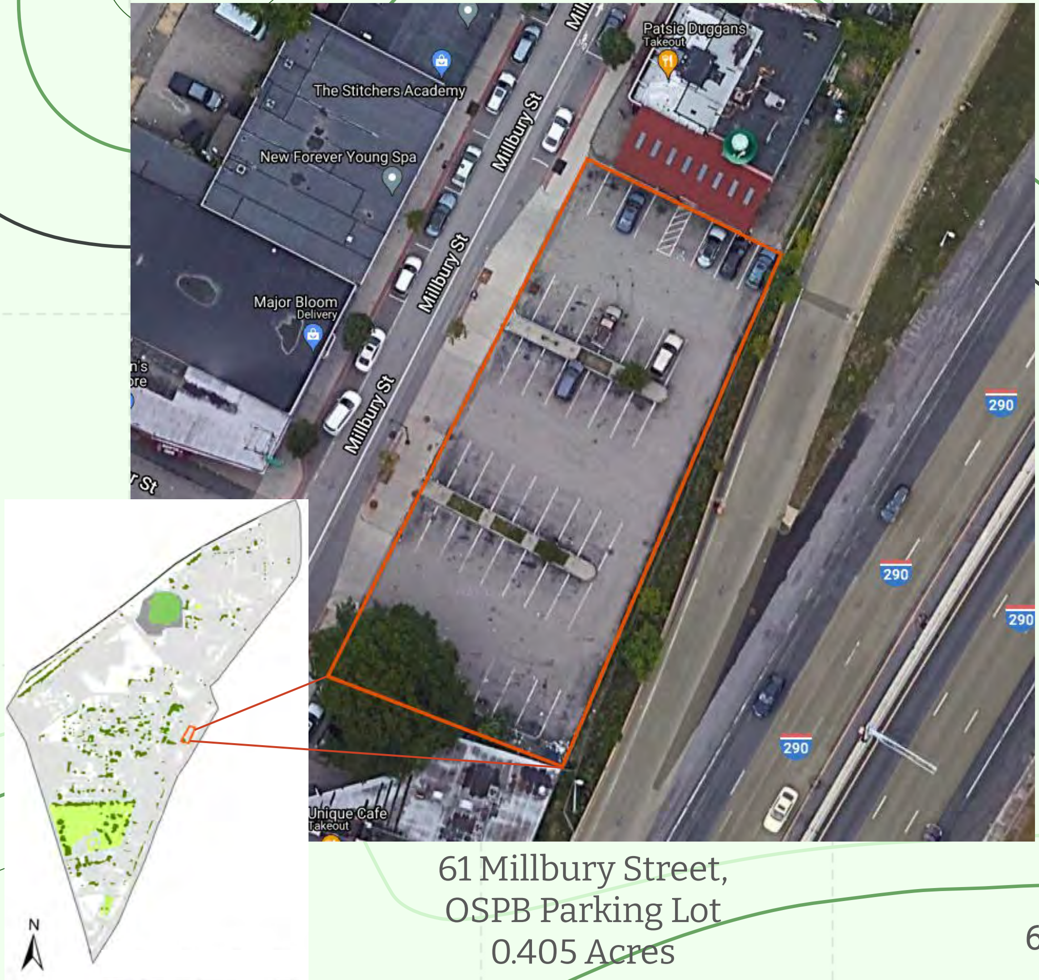


Sites with Treated/Untreated Roof:
Building Acres vs. Difference in ° F



R-square: 0.609

For every 0.411 acre of roof painted white and/or installed with solar panels, temperature decreases by 1° F

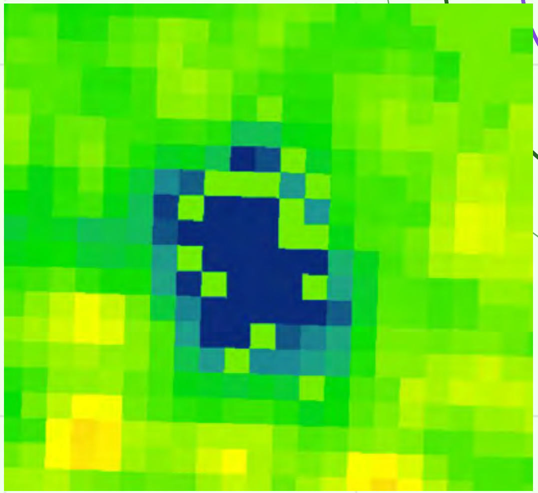


61 Millbury Street,
OSPB Parking Lot
0.405 Acres

White roof and Solar Panel Treatment

Site: Distribution Center in Quinsigamond Village

Building area is 13.44 Acres

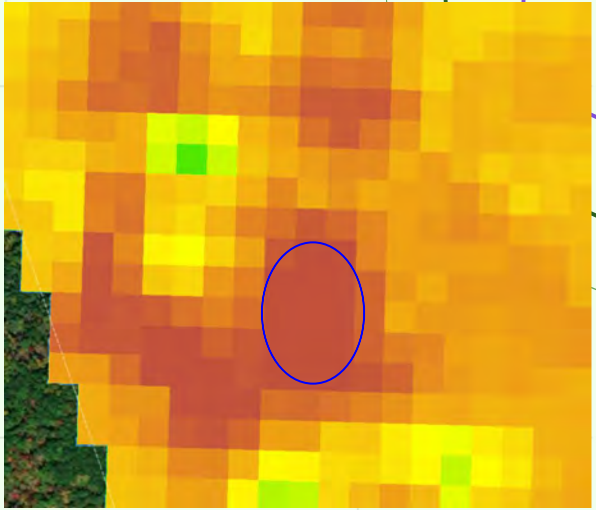


Decrease of 33° F from 2010 to 2020

Tree Loss Example

Site: Worcester State University Satellite Resident Parking

5.14 acres of area deforested

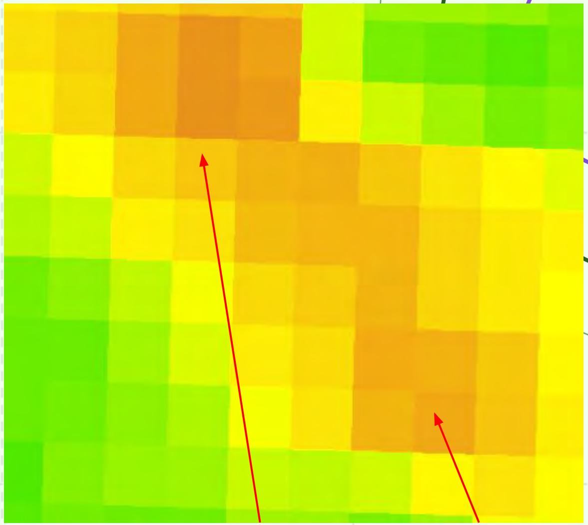


Increase of 11° F from 2010 to 2020

Tree Loss to Development Example

Site Names: Silver Linden Lane and Sourwood Circle

14.64 acres of deforested area

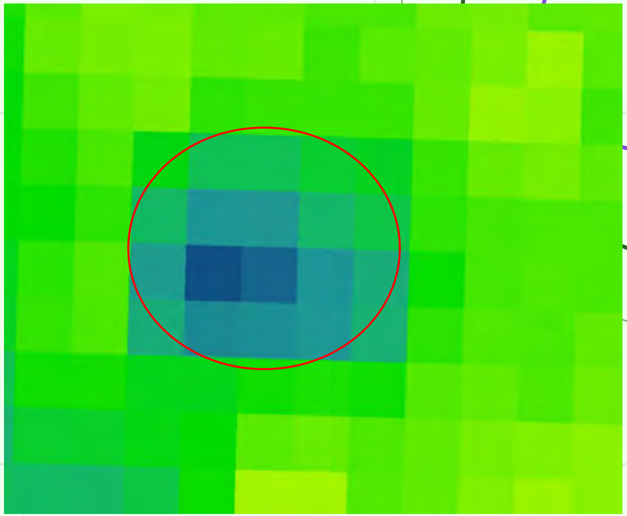


Increase by 10° F and 8.7° F from 2010 to 2020

White Roof Treatment Examples In Green Island

Site Name:
Worcester Ice Center

Building area of 1.68 acres

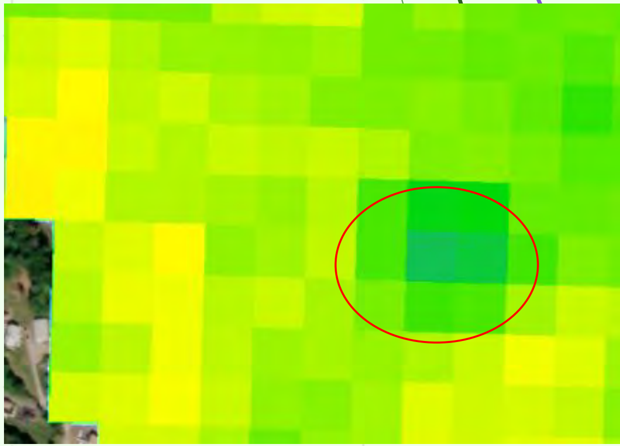


Decrease of 12° F from 2010 to 2020

School with Solar Treated Roof

Site Name:
Dr. Arthur F. Sullivan Middle School

Building Area 1.66 acres, not including parking area



Decrease of 5.6° F from 2010 to 2020

Potential White Roof/Solar Panel Treatment in Green Island

Green Island Public Buildings	Area in Acres	Expected Reduction in LST (° F)
City of Worcester Health and Code	0.733	-2.069
Tax Tile Custodian Building	0.056	-0.426
Health and Code Parking	1.097	-2.955
OSPB Parking	0.406	-1.275
Union Station Parking Garage	0.891	-2.453

Modeling Summary

04 Model the role of street trees and treated roofs/solar panels on surface temperature in Worcester

Street Tree Model

1. Increased canopy cover will provide surface temperature cooling
2. Tree planting should not be limited to existing green infrastructure
3. Residential tree planting is key to increasing overall neighborhood/city canopy cover

Roof Treatment/Tree Loss Model

1. Change from light to dark roof and deforestation causes increase in temperature
2. Tree Maturation, Painting roof White/adding solar panels cause decrease in temperature
3. As area increases so does the change in temperature (acres vs. difference in temp.)

Main Takeaways

1. Historical wetlands and waterways overlap with current flood zones and should be used to plan future green infrastructure interventions
2. In South Green Island, north of Crompton Park streets such as Sigel, Endicott, Ellsworth, and Harding are high in reported flooding and extreme heat instances
   a. These streets would benefit the most from flood mitigation solutions (bioswales) and street tree planting
3. The highest ozone concentration is in pockets around heavy industry and I-290 in Green Island
4. Many green infrastructure solutions will have positive effects on reducing both UHI and flood mitigation
   a. **A 5% increase in tree canopy cover, 1 degree F in temperature reduction**
5. Other green infrastructure will only reduce UHI such as white roofs
   a. **0.411 Acres treated with white roof/solar panels, 1 degree F in temperature reduction**

Future Research/Next steps

Flood Mitigation:

- More specific green infrastructure recommendations as well as possible sites
- Cost benefit analysis of green infrastructure options
- Explore Worcester's capacity to implement green infrastructure for flooding focusing on institutions

Urban Heat:

- Further research into benefits of green roofs
- Finish Columbus Park Tree Census
- Look at a neighborhood with the highest canopy cover in Worcester

Acknowledgements

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Janet & Steve McLaren

Remy Geron

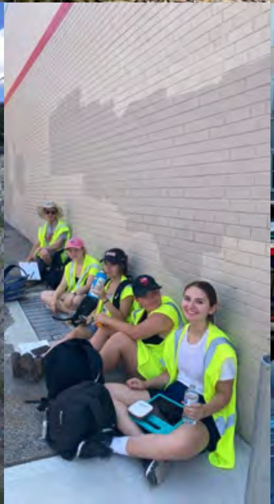
*City of Worcester Conservation Planning Office

Other

Clark University Geography Department

Residents of Green Island & Columbus Park

Thank You!
Any Questions?



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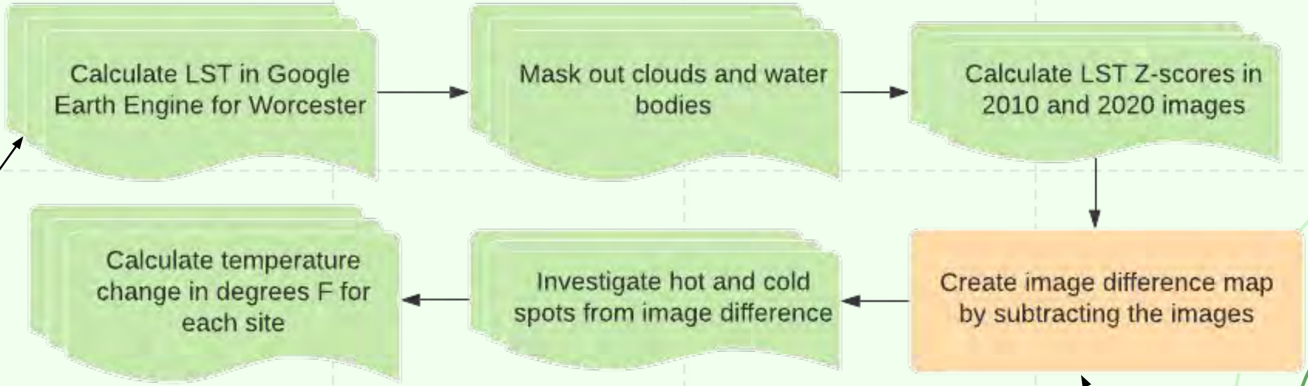
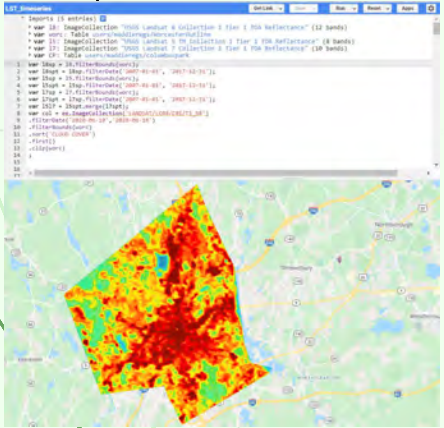
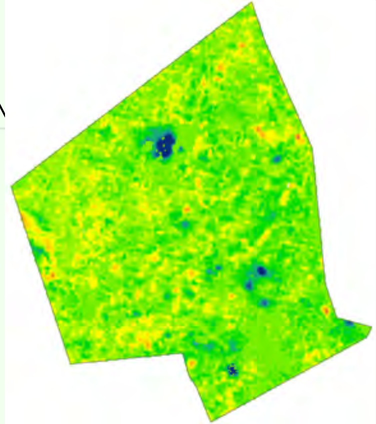
Raster Processing of Surface Temperature Data for 2010 and 2020







Green Roof Benefits

1. Cools the building through shading and insulation
2. Reduces peak storm runoff
3. Potential to grow food
4. Can be combined with Solar Panels
5. Rooftop ponds can be used to treat greywater
    a. Can store and disperse rainwater incrementally for flood prevention

Cost Benefit Analysis of Green Roofs at WPI

Green Roof Size (Acre)	Cost of Traditional Roof	Cost of Green Roof (Low)	Cost of White Roof	Cost of Green Roof (High)	Cost Difference between Traditional and Green Roof Low	Cost Difference between Traditional and Green Roof High
0.115	$39,900	$60,900	$75,000	$140,750	$22,000	$100,850
0.172	$58,350	$91,350	$112,500	$211,125	$33,000	$152,775
0.230	$77,800	$121,800	$150,000	$281,500	$44,000	$203,700