Urban Watershed Renewal
in Berry Brook, NH An
Examination of Impervious
Cover, Stream Restoration,
and Ecosystem Resilience

Tom Ballestero, James Houle, Daniel Macadam
4 May 2019
Lake George, NY
Participants at the Beginning:

• City of Dover Staff

• UNH Stormwater Center

• NH Department of Environmental Services

• Environmental Protection Agency
NY Lakes – Part of My Youth
Stormwater

IT'S NO JOKE:
WHATEVER ENTERS A
STORM DRAIN FLOWS
DIRECTLY INTO OUR
LOCAL WATERS.

THE STORM DRAIN SYSTEM
PROVIDES NO FILTERS AND
NO TREATMENT.

HELP US KEEP
OUR WATERS CLEAN.

NEVER DUMP, WASH, OR
RAKE ANYTHING INTO THE
PATH OF STORM DRAINS.

[Image: A cartoon image with a sign that reads: "IT'S NO JOKE: WHATEVER ENTERS A STORM DRAIN FLOWS DIRECTLY INTO OUR LOCAL WATERS. THE STORM DRAIN SYSTEM PROVIDES NO FILTERS AND NO TREATMENT. HELP US KEEP OUR WATERS CLEAN. NEVER DUMP, WASH, OR RAKE ANYTHING INTO THE PATH OF STORM DRAINS."
Figure. Adapted from WSB 2010 & Bulluci 2007.
TSS Removal Efficiencies

<table>
<thead>
<tr>
<th>Method</th>
<th>TSS % Removal Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone-lined Swale</td>
<td>60</td>
</tr>
<tr>
<td>Vegetated Swale</td>
<td>70</td>
</tr>
<tr>
<td>Berm Swale</td>
<td>80</td>
</tr>
<tr>
<td>Retention Pond</td>
<td>90</td>
</tr>
<tr>
<td>HDS Systems</td>
<td>100</td>
</tr>
<tr>
<td>ADS infiltration</td>
<td>90</td>
</tr>
<tr>
<td>StormTech infiltration</td>
<td>80</td>
</tr>
<tr>
<td>AquaFilter filtration</td>
<td>70</td>
</tr>
<tr>
<td>Bioretention</td>
<td>60</td>
</tr>
<tr>
<td>Tree Filter</td>
<td>50</td>
</tr>
<tr>
<td>Gravel Wetland</td>
<td>40</td>
</tr>
<tr>
<td>Porous Asphalt</td>
<td>30</td>
</tr>
</tbody>
</table>
TP Removal Efficiencies

TP Removal Efficiencies

- Stone Swale
- Veg Swale
- Berm Swale
- Retention Pond
- HDS Systems
- Pipe det/ infiltration
- Chamber det/
- MID Filter
- Bioretention (3)
- Tree Filter (2)
- Gravel Wettl
- Porous Asphalt
Thermal Impacts

T (°F)

Trout Lethality Limit

Upper Optimum Limit

Lower Optimum Limit

T (°F)

01/01/2005 12:00 AM
04/01/2005 12:00 AM
07/01/2005 12:00 AM
10/01/2005 12:00 AM
01/01/2006 12:00 AM
04/01/2006 12:00 AM
07/01/2006 12:00 AM
10/01/2006 12:00 AM
01/01/2007 12:00 AM

Dbx Date

Y

9

T (°F)
Introduction: Bioretention Filters
Site Study: Bioretention (during 1 in. storm)
Site Study: Horne St., Dover, NH

- Watershed area 22 acres
- Subdivision of 1/3 ac. lots
- 38% impervious cover
- CN 60
- Time of concentration
  - Estimated with TR-55 Velocity method: 17 minutes
  - Median observed: 16.5 minutes
- Median observed lag time of 9 minutes
- Filter is 2,100 ft² (140 ft x 15 ft)
- Watershed to bioretention area ratio of 455:1
- Current design rainfall 0.16 inch
Site Study: Performance

Medians

64%  36%  1190 ft³

0.55 in.  1.1 in.

Event Ponding and Rainfall
Grove St. System

System Diagram

Grove St SGF Drainage Area
GI: Subsurface Gravel Filter
Pipe installation

Pipe installation between CB#1 & CB#2

October 8, 2015
Grove St. Native Soil Composition

Composition of Sample #1 (Elev = 96.52')
- Sand: 18%
- Silt: 65%
- Clay: 17%

Composition of Sample #2 (Elev = 98.52')
- Sand: 33%
- Silt: 31%
- Clay: 37%

Composition of Sample #3 (Elev = 99.22')
- Sand: 43%
- Silt: 10%
- Clay: 47%
System Water Level History

Grove St : Subsurface Gravel Filter - Water Elevation

- Total Rain (in)
- Depth (ft)
- 6" Pipe Invert
- 12" Pipe Invert
- Pavement

Elevation (ft)

101 100 99 98 97 96


Rainfall Depth (in)

1.22 in 1.42 in 1.43 in

System Full Line (1" rainfall)
## Grove Street Design Specs

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Grove St SGF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original Values</td>
</tr>
<tr>
<td>Drainage Area (acres)</td>
<td>1.44</td>
</tr>
<tr>
<td>Time of Concentration (min)</td>
<td>8.3</td>
</tr>
<tr>
<td>Weighted Curve Number (-)</td>
<td>88</td>
</tr>
<tr>
<td>Potential Maximum Retention (in)</td>
<td>1.36</td>
</tr>
<tr>
<td>Initial Abstraction (in)</td>
<td>0.27</td>
</tr>
<tr>
<td>% Impervious Area</td>
<td>22%</td>
</tr>
<tr>
<td>WQV (Ac-In)</td>
<td>0.36</td>
</tr>
<tr>
<td>WQV (ft³)</td>
<td>1307</td>
</tr>
<tr>
<td>Constructed Storage Volume (ft³)</td>
<td>1320</td>
</tr>
<tr>
<td>% of WQV</td>
<td>101%</td>
</tr>
</tbody>
</table>
Develop Storm Hydrographs

Grove St SGF Hydrograph - 11/30/2016

- Total Outflow
- Total Inflow
- Rainfall

Rainfall rate based on 5 min. time step (in/hr)

Flow (cfm) vs. Time

Total Outflow and Total Inflow graphs are plotted against time. The rainfall rate is also shown with its corresponding time step.
Performance Analysis using Water Balances

Grove St Performance Summary:

- Cumulative runoff volume reduction of 84%
- Peak flow reduction of 88%
- System never completely filled
  - Maximum water depth of 1.94 ft for 1.25-inch rain event on 4/6/2017

<table>
<thead>
<tr>
<th>Maximum Recorded Flow Rates (ft³/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflow</td>
</tr>
<tr>
<td>Outflow</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cumulative Flow Volumes (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Inflow Volume</td>
</tr>
<tr>
<td>System Inflow Volume</td>
</tr>
<tr>
<td>Infiltration Volume</td>
</tr>
</tbody>
</table>
Maintenance Must be Included in the Design Process

Not by the designers, but by the people who are expected to do it or pay for it
Comparison of Pollutant Removal Efficiency
Planted vs Grassed Bioretention

Percent Removal Efficiency

- TSS
- TP
- DIN
- TN

Pollutant

Planted Bio (Avg. 3) vs Grassed Bio

Graph showing the comparison of pollutant removal efficiency between planted and grassed bioretention areas for TSS, TP, DIN, and TN.
Grassed vs Planted Surface Infiltration Rates

Average Infiltration Rates of a Planted (blue) versus Grassed (green) Bioretention Systems Over Time

Infiltration Rate (in/hr)

Grassed Bioretention  Planted Bioretention
Sectional Media Box Filter Design – version 3

NOTES:

1. FILTER MEDIA COMPOSITION IS MIXED BY TOTAL VOLUME REQUIRED.
   1.1. 75-85% COARSE SAND (ASTM C-33 OR EQUIVALENT)
   1.2. 15-25% LOAM OR TOP SOIL
   1.3. 0-5% WATER TREATMENT RESIDUALS OR FINE FILINGS. THIS IS AN AMENDMENT USED FOR ENHANCED PHOSPHORUS ABSORPTION

2. WOVEN GEOTEXTILE LAYER OR SILT FENCE MATERIAL. THIS LAYER IS TO REMOVE ALL SILT SIZE PARTICLES AND LARGER AND PROTECT THE RESERVOIR STONE FROM FILLING WITH FINES. THIS IS ALSO THE DEPTH OF ROUTINE MAINTENANCE, WHICH INCLUDES REMOVING FILTER MEDIA AND GEOTEXTILE AND REPLACING WITH NEW.

3. RESERVOIR STONE CAN CONSIST OF A WIDE RANGE OF STONE SIZES, PREFERABLY A WASHED STONE OF CONSISTENT GRADATION, e.g. 1/2” OR 1/4” STONE.

4. SYSTEM OUTLET CONFIGURATION CONSISTS OF A SPILL FLOW AND SHORT STUB PIECES OF HOPE DOUBLE WALLED OR SDR 35. THE ELEVATION AND DIRECTION THAT THE OUTLET CATS THE SYSTEM WILL BE DETERMINED BY THE RESIDENT ENGINEER. THE OUTLET CAN BE PLUMBING TO BEST FIT THE EXISTING INFRASTRUCTURE. THE OUTLET PIPE SHALL BE SIZED TO PASS THE PREFERRED DESIGN STORM.

5. DRAINAGE HOLES SHOULD BE DRILLED IN THE OUTLET ELBOW TO DRAIN THE WATER DURING AND BETWEEN STORMS. THE HOLES SHALL BE IN A VERTICAL PLACEMENT TO PROVIDE ADDITIONAL CAPACITY AS THE SYSTEM FILLS. THE HOLES SHOULD BE SMALL ENOUGH TO PREVENT RESERVOIR STONE FROM DRAINING THROUGH.

6. OPTIONAL 1/2” HOLES IN EXTERIOR WALLS OF BOX STRUCTURE CAN BE REMOVED FROM PRODUCTION OR PLUGGED IF PRESCRIBED. BENEFITS INCLUDE: SYSTEM DRAIN DOWN BETWEEN STORMS, GROUNDWATER RECHARGE, AND VOLUME REDUCTION.

Date: February 22, 2017

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Retrofits and Sizing
<table>
<thead>
<tr>
<th>System</th>
<th>TSS</th>
<th>TN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conv. Bioretention Average (4)</td>
<td>91%</td>
<td>36%</td>
<td>34%</td>
</tr>
<tr>
<td>Durham Bioretention (23% IBSC)</td>
<td>81%</td>
<td>27%</td>
<td>45%</td>
</tr>
<tr>
<td>Conv. Subsurface Gravel Wetland</td>
<td>96%</td>
<td>54%</td>
<td>58%</td>
</tr>
<tr>
<td>Subsurface Gravel Wetland (10% SGWSC)</td>
<td>75%</td>
<td>23%</td>
<td>53%</td>
</tr>
</tbody>
</table>
Population Growth and Impervious Cover

Last 20 years

Percent Increase, Great Bay Population

Next 30 years

Population Growth, 26%

From 1990 to 2010 (Source: US Census; UNH earth systems research center; PREP; 2010-2040 Projections, UNHSC)
Yes, climate change gives us pause to think, but IC is the 800-pound gorilla
Urban Watershed Renewal through LID and Stream Restoration

**LID Stormwater Management**

**Outcome:** Water quality treatment, volume reduction, and baseflow augmentation

**Wetland and Stream Restoration**

**Outcome:** Stream provides aquatic habitat, reduce/eliminate fish passage barriers, restore ecosystem services
Berry Brook Watershed Overview Impervious Surfaces

<table>
<thead>
<tr>
<th>Surface</th>
<th>Area (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Watershed</td>
<td>185</td>
</tr>
<tr>
<td>Pervious</td>
<td>129.4</td>
</tr>
<tr>
<td>Asphalt Roads</td>
<td>14.3</td>
</tr>
<tr>
<td>Asphalt Driveways</td>
<td>12.4</td>
</tr>
<tr>
<td>Compacted Soil</td>
<td>1.0</td>
</tr>
<tr>
<td>Parking Lots</td>
<td>7.0</td>
</tr>
<tr>
<td>Rooftops</td>
<td>17.6</td>
</tr>
<tr>
<td>Other Asphalt</td>
<td>1.7</td>
</tr>
<tr>
<td>Other (decks, patios)</td>
<td>1.3</td>
</tr>
<tr>
<td>Impervious Total</td>
<td>55.3 (30%)</td>
</tr>
</tbody>
</table>

Source: Adapted from Mapping Impervious Surfaces in the Berry Brook Watershed Complex Systems Research Center, August, 2011
Berry Brook Watershed Renewal Project

Berry Brook Dover, NH
- NHDES named Berry Brook to the 303d list of impaired surface waters due to lack of aquatic life support.

Project Comprised of 2 Components
1) Stream and wetland restoration (~800ft)
2) Stormwater management (24 LID Systems)
   - Treatment of 20.7 IC acres

Berry Brook Watershed area ~185 acres
Berry Brook stream length is approx. 1.15 miles

Urbanized - high density area (30% EIC)
Retrofit Locations
Gravel Wetland
DA=11.0 ac, Treated IC = 9.55 ac (86.8%)

Stream Restoration
~800 ft, including C, A and Aa - channel

Page Ave
DA = 5.23 ac, Treated IC = 1.88 ac (36.0%)

Wetland Expansion
~0.6 acres

Crescent Ave
DA = 2.97 ac
Treated IC = 1.5 ac (28.5%)

Glencrest Ave
DA = 6.8 ac
Treated IC = 2.3 ac (33%)

Upper Horne Street
DA = 12.2 ac
Treated IC = 3.7 ac (31%)

Wetland Expansion
~0.6 acres

Roosevelt Ave
DA = 12.2 ac
Treated IC = 3.7 ac (31%)

Lowell Ave
DA = 2.6 ac
Treated IC = ac (43%)
Installed Green Stormwater Infrastructure

- 12 bioretention systems,
- 1 tree filter,
- 1 subsurface gravel wetland,
- One-acre of new wetland,
- Day-lighted and restored 1,100 linear feet of stream at the headwaters and restored 500 linear feet of stream at the confluence including two new geomorphically-designed stream crossings
- 3 grass-lined swales
- 2 subsurface gravel filters
- 1 infiltration trench system
- 3 innovative filtering catch basin designs
Getting to 10% EIC

EIC Reduction Target Rates for Berry Brook, Dover, NH

- 2010 Existing
- 2011 (16.9 Ac/yr)
Reducing Runoff Volume

Direct Runoff Vs Rainfall Depth (Station/Downstream)

- Pre-LID 30% EIC
- Mid-LID 20% EIC
- Post-LID 14% EIC
## Effect of Reducing Watershed CN

<table>
<thead>
<tr>
<th>CN</th>
<th>Amount of Rain to Generate Runoff (in)</th>
<th>Pn</th>
<th>Pe</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>0.4</td>
<td>68.1%</td>
<td>31.9%</td>
</tr>
<tr>
<td>64</td>
<td>0.5</td>
<td>74.4%</td>
<td>25.6%</td>
</tr>
<tr>
<td>59</td>
<td>0.6</td>
<td>80.1%</td>
<td>19.9%</td>
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</table>
Storm Event Pollutant Loads at Upper Watershed (Roosevelt, DA = 46.4 acres) for 6 Storms Pre-GI (06/11-10/11) and 4 Storms Post-GI (10/12-12/12)
Storm Event Pollutant Loads at Upper Watershed (Roosevelt, DA = 46.4 acres) for 6 Storms Pre-GI (06/11-10/11) and 4 Storms Post-GI (10/12-12/12)
Storm Event

Water Quality at Lower Watershed (Station, DA = 184.8 acres) for 11 Storms Pre-GI (06/11-10/11) and 4 Storms Post-GI (10/12-12/12)
Storm Event
Water Quality at Lower Watershed (Station, DA = 184.8 acres) for 11 Storms Pre-GI (06/11-10/11) and 4 Storms Post-GI (10/12-12/12)

Pre-LID (IC=30.1%, EIC=15.6%) Post-LID (IC=18.9%, EIC = 11.2%)

Phases
## Modeled Water Quality

<table>
<thead>
<tr>
<th>Year</th>
<th>A</th>
<th>P</th>
<th>CN</th>
<th>TSS (lbs)</th>
<th>TP (lbs)</th>
<th>TN (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008-2011</td>
<td>185</td>
<td>56.14</td>
<td>74</td>
<td>92,719</td>
<td>188</td>
<td>2,428</td>
</tr>
<tr>
<td>20012-2016</td>
<td>185</td>
<td>42.20</td>
<td>62</td>
<td>27,575</td>
<td>38</td>
<td>1,762</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>65,144</strong></td>
<td><strong>149</strong></td>
<td><strong>667</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>57,223</strong></td>
<td><strong>201</strong></td>
<td><strong>1,127</strong></td>
</tr>
</tbody>
</table>

### Annual Reductions (lb./yr.)

- Simple Method (lb./yr.)

### Mass Pollutant Export (lbs)

- TSS (lbs)
- TP (lbs)
- TN (lbs)
Stream Headwaters
Wetland Outflow to Buried Pipe
Wetlands Followed by Storage Yard
Initial Design
Expanded Wetlands, Shrinking Stream
Design Profile

- **Approximate Sand Filter Ground**
- **Existing Ground at the Valley Centerline**
- **Proposed Type C Stream**; Stream Slope = 2.1%, Valley Slope = 3.1%
- **12" Abandoned Sewer Line**
- **15" Sewer Line**
- **8" Water Line**

**Note:** The profile is based off the valley centerline, not the stream centerline.
Planting Plan

**Shallow Wetland Zone (8,875 sf, 0.23 ac)**
- Plant with wetland species at 10' centers;
- Covers 0.5' deep portion of the wetland.

**Deep Wetland Zone (5,474 sf, 0.13 ac)**
- Plant with aquatic species at 10' centers;
- Covers the 1' deep portion of the wetland.

**Forested Wetland Zone (12,929 sf, 2.59 ac)**
- Plant with riparian upland species at 10' centers;
- Approximate lower boundary at elevation 134.00'.

**Riparian Wetland Zone (16,209 sf, 0.37 ac)**
- Plant with riparian wetland species at 10' centers within floodplain of channel;
- 15' centers on all other land;
- Covers all lands below 134.00' that lie outside the top of the wetland & stream.
Construct Aa Step-Pools
At-Grade Stream Crossing

APPROXIMATELY
6" DEEP, 1' WIDE
SLAB SALVAGED
Created Wetland
<table>
<thead>
<tr>
<th>Treatment Period</th>
<th>Start</th>
<th>End</th>
<th>BB EIC (End of TP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>June 2011</td>
<td>September 2011</td>
<td>30.0%</td>
</tr>
<tr>
<td>TP1</td>
<td>October 2011</td>
<td>December 2011</td>
<td>20.0%</td>
</tr>
<tr>
<td>TP2</td>
<td>January 2012</td>
<td>December 2012</td>
<td>15.8%</td>
</tr>
<tr>
<td>TP3</td>
<td>January 2013</td>
<td>December 2013</td>
<td>14.8%</td>
</tr>
<tr>
<td>TP4</td>
<td>January 2014</td>
<td>December 2014</td>
<td>14.3%</td>
</tr>
<tr>
<td>TP5</td>
<td>January 2015</td>
<td>December 2015</td>
<td>12.5%</td>
</tr>
<tr>
<td>TP6</td>
<td>January 2016</td>
<td>December 2016</td>
<td>11.7%</td>
</tr>
</tbody>
</table>
Summer Cooling

One degree day is a day when the average stream temperature is one degree Fahrenheit above 65 degrees F. This is important as the temperature that a Brook Trout begins to feel heat stress is 65 °F. Therefore a day with an average daily stream temperature of 71 degrees would represent 6 degree days.
Thermal Response
The Rare Chiquita Fish
Funding and Results

- Funding: 3 watershed assistance grants and 1 aquatic resource mitigation grant with match from the city.

<table>
<thead>
<tr>
<th>Berry Brook Project: Getting to 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>Grant Funds</td>
</tr>
<tr>
<td>Match (min estimate)</td>
</tr>
<tr>
<td># GI Systems</td>
</tr>
<tr>
<td>DCIA Reduced</td>
</tr>
<tr>
<td>TSS Reductions (lb./yr.)</td>
</tr>
<tr>
<td>TP Reductions (lb./yr.)</td>
</tr>
<tr>
<td>TN Reductions (lb./yr.)</td>
</tr>
</tbody>
</table>