Creating a Green Infrastructure Pilot Program for Yale University

Final Report - May 7, 2014
Prepared for Yale Office of Facilities as part of F&ES 724 - Watershed Processes and Cycles
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1.0 Introduction

In fall 2013, Yale University's Offices of Facilities and Sustainability published the "Sustainable Stormwater Management Plan" as part of a larger effort to grow Yale's efforts toward sustainability (Yale, 2013). The plan described the contribution of stormwater created by the impervious surfaces on campus to larger environmental impacts in New Haven in the form of combined sewer overflows and polluted stormwater discharging to New Haven's rivers and the Long Island Sound. To mitigate these impacts, the plan outlined strategies to improve Yale's understanding of its impact and move toward reducing the volume of stormwater runoff off the campus into New Haven's stormwater and combined sewer systems.

The plan also identified the potential of green infrastructure to serve as an important tool in achieving the future reduction goal. Yale described the success of green infrastructure to reduce stormwater from impervious surfaces, but recognized the influence of local conditions on the performance of green infrastructure (Spatari, 2010). In stating this vision, Yale recognized the need to understand the potential for green infrastructure to effectively perform. To increase this understanding and move toward mitigating Yale's stormwater impact, the plan included a strategy to "[i]nvestigate the potential of green infrastructure techniques on campus" by creating "…a pilot program to implement green infrastructure, monitor its progress, and understand its maintenance needs."

As students that were part of the spring semester class F&ES 724, Watershed Processes and Cycles, we saw the opportunity to begin developing the green infrastructure pilot program. We spent the semester investigating the needs for developing the pilot program and starting the initial phases of helping Yale create this pilot program. This following report documents the work we completed this semester as well as highlights the future work needed to move this pilot program forward.

2.0 Pilot Program Development Process

As part of the semester work, we identified the steps to creating a pilot program to monitor performance of future green infrastructure. Modeling the pilot program off a similar study in Waterford, CT by University of Connecticut, we identified that the program should follow the five steps shown in **Figure 1** (Dietz, 2007):

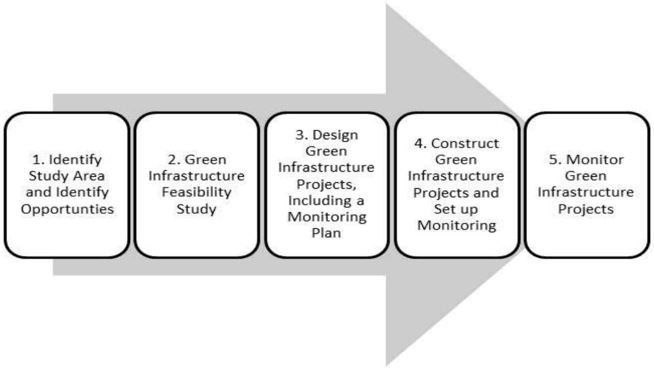


Figure 1: The Five Steps in a Green Infrastructure Pilot Program.

As part of this semester's work, we work toward three main objectives:

1. Identify a study area and the locations and types of green infrastructure opportunities within the study area.
2. Conduct a feasibility assessment by modeling the opportunities and evaluating them against a set of goals for the projects.
3. Work with Yale's Office of Facilities to develop the concepts for one of the identified green infrastructure opportunities into a project that can be built and monitored to understand its performance.

With this work, we believe we accomplished steps 1 and 2 and began the process for step 3. To move this program forward, final designs for the projects will be necessary as well as designing how these projects will be monitored over time.

3.0 Methods

To achieve our identified objectives, we spent the semester working on the following tasks:

- Identify a pilot program study area;
- Develop a model to estimate green infrastructure's potential;
- Identify green infrastructure opportunities and model their potential to achieve Yale's stormwater goals;
- Assess the feasibility of these opportunities through discussions with Yale's Office of Facilities; and
- Identify a feasible opportunity to move forward for the pilot program and create a concept for its design.

The following section discusses how we accomplished each of these pieces.

3.1 Pilot Program Study Area

The Yale Experimental Watershed, also known as the Yale Swale Watershed, is located on Yale's campus and drains an approximately 19.2 acre watershed area, with 46% of watershed runoff flowing into a wetland area referred to as the "Swale" and the other 54% of runoff diverted into the City of New Haven's separate storm sewer system. **Figure 2** shows the boundaries of the watershed and its location within the Yale campus. For the past three years, researchers at the Yale University Hixon Center for Urban Ecology have conducted Swale research related to: a) tree and vegetation inventories; and b) site characterizations related to hydrology, soils, and bird habitat. In addition, instrumentation has been installed throughout the Swale in order to accurately determine the site's water budget. This instrumentation includes: a) an inlet and outlet V-Notch Weir with pressure transducers; b) a tipping rain gauge; c) groundwater monitoring wells; and d) two YSI EcoNet Dataloggers.

Figure 2: The Yale Swale Watershed.

The current level of instrumentation documenting the baseline flows in through the watershed offers the opportunity for the impact of the green infrastructure projects to be monitored on a watershed level. Additionally, the watershed is located in an area of campus with more potential for experimentation with landscaping.

3.2 Model Development

To better understand the stormwater flows throughout the watershed, we developed a hydrologic model to quantify the baseline stormwater flows in the system and eventually quantify the potential of green infrastructure opportunities to reduce these flows, once they were identified. The model was built using HydroCAD, a stormwater modeling software. The inputs to create the model included: subcatchment areas that were delineated from the watershed area, surface conditions of the subcatchments, and the estimated time for water to move through each subcatchment (referred to as the time of concentration). Each of these inputs is explained below. With the model built, the model generated hydrographs indicating the runoff volume for a designated storm event from each subcatchment.

Once the green infrastructure opportunities were identified the baseline model was used to create a proposed conditions model to quantify the green infrastructure interventions and hydrographs were generated.

3.2.1 Subcatchment Delineation

The Swale watershed had been previously delineated by student research assistants working for the Hixon Center for Urban Ecology (see **Figure 2**). After investigation, the boundary was slightly modified to include entirety of the Yale buildings along Prospect St., as their roof drainage systems convey stormwater to the sewer system along Prospect St (see **Figure 3**). Under recommendation from Nicole Holmes from Nitsch Engineering, who served as a resource on this project, visual observations were used to delineate the watershed into subcatchments depending on which areas drained to the swale or the sewer system and the subcatchments were drawn in ArcGIS (see **Figure 4**).

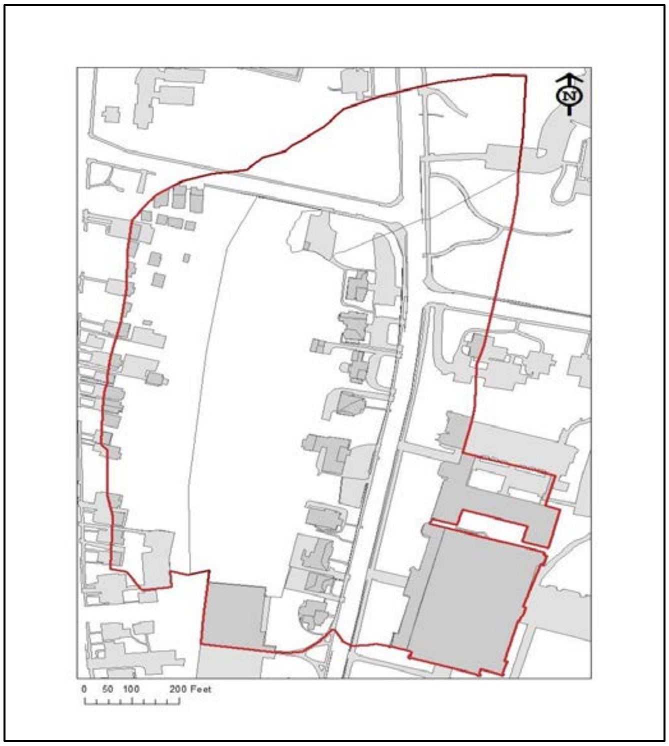


Figure 3: Modified Yale Swale Watershed.

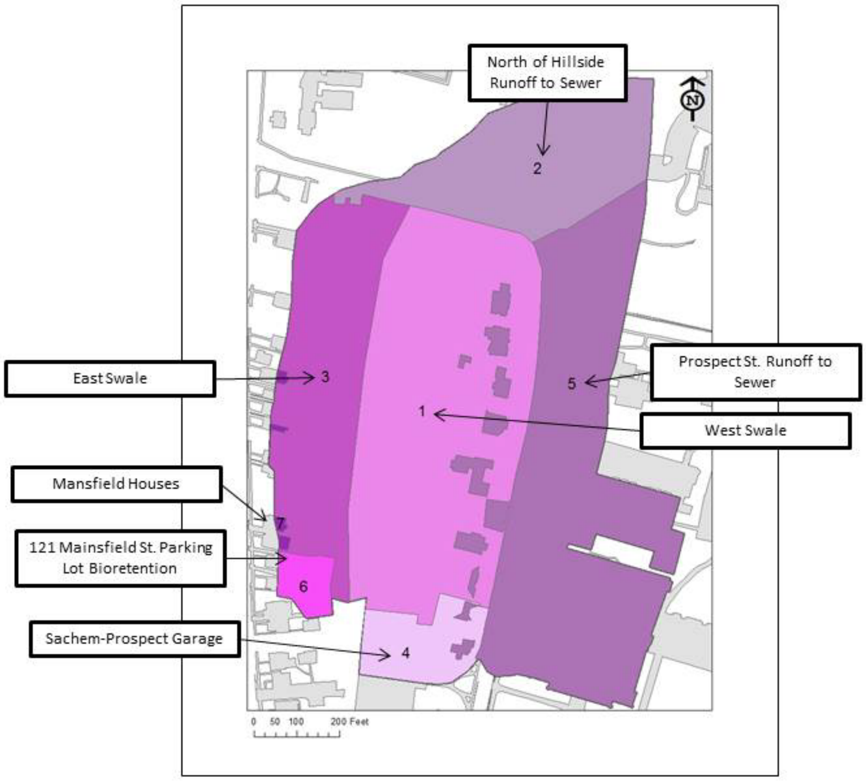


Figure 4: Subcatchment Delineation

3.2.2 Land use cover, soils, and curve number

With the subcatchments delineated, the surface types found in each subcatchment were identified and the area of each surface type was calculated. The surfaces included both impervious (driveways, house walkways, parking lots, roads, rooftops, and sidewalks) and pervious (trees and lawns) areas. Shapefiles from the Yale Swale database were used to identify each of these surface types and calculate areas, as is shown in **Figure 5.**

Table 1 summarizes each subcatchment's area including its respective land cover and drainage. Areas that drain to the sewer, such as the buildings on Mansfield and Prospect St., were included as part of the swale watershed because of the potential redirection of flows into the Swale as part of a green infrastructure project.

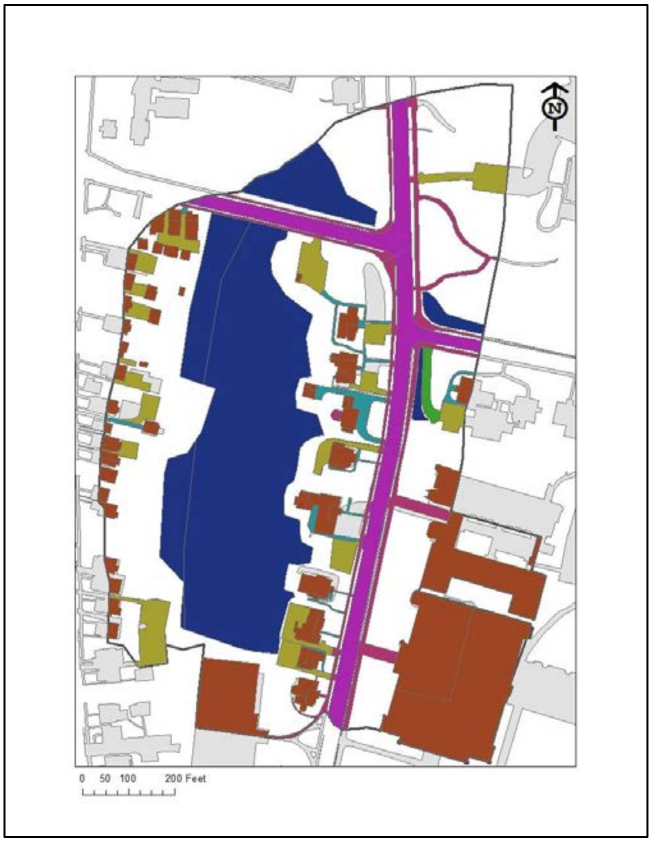


Figure 5: Types of Surfaces within the Swale Watershed

TABLE 1: SUBCATCHMENT AREAS BY LAND COVER (ACRES)

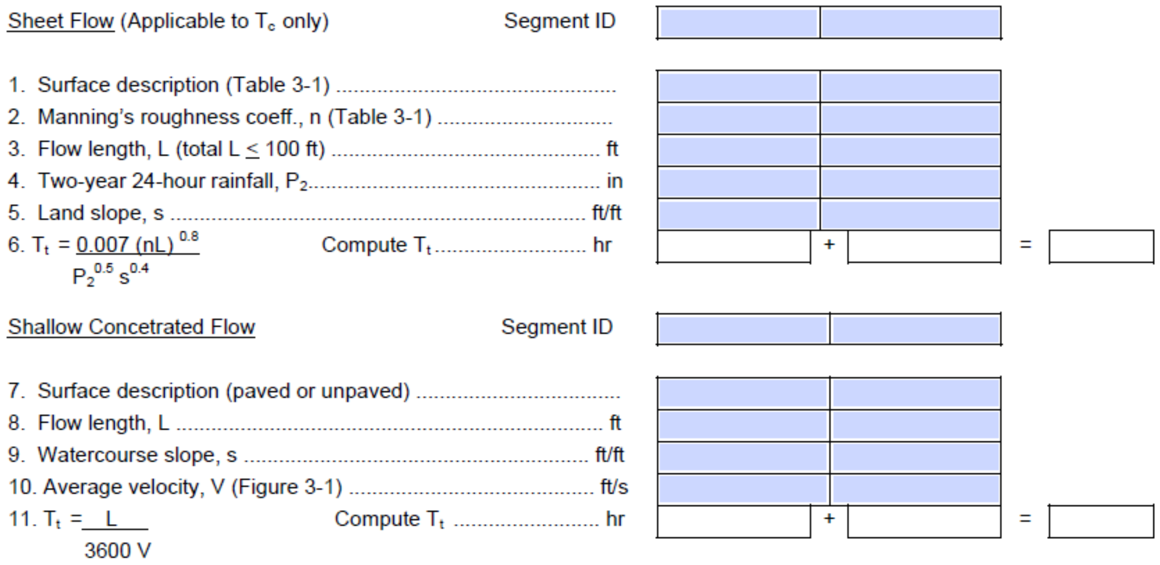
Subcatchment Number	Total Area	Impervious Area						Total Impervious	Pervious		Total Pervious	Drainage
		Driveway	House Walk	Parking	Road	Roof	Sidewalk		Trees	Lawn		
1	7.3393	0.0000	0.2355	0.3815	0.0000	0.0946	0.0136	0.7253	4.2241	2.3900	6.6140	Swale
2	3.4803	0.0000	0.0035	0.1455	0.5788	0.0266	0.2601	1.0145	0.5149	1.9508	2.4657	Sewer
3	3.8017	0.0000	0.0162	0.3161	00.0000	0.3648	0.0002	0.6973	0.8460	2.2584	3.1043	Swale
4	1.0000	0.0000	0.0081	0.0717	0.0000	0.5140	0.0206	0.6144	0.0000	0.3856	0.3856	Swale
5	7.7042	0.0756	0.0265	0.1461	0.9052	3.0073	0.5923	4.7528	0.1505	2.8009	2.9514	Sewer
6	0.3728	0.0000	0.0000	0.1968	0.0000	0.0359	0.0000	0.2327	0.0000	0.1401	0.1401	Sewer
7	0.0656	0.0000	0.0000	0.0000	0.0000	0.0654	0.0000	0.0654	0.0000	0.0002	0.0002	Sewer

Soil cover data was obtained from the United States Department of Agriculture's (USDA) Web Soil Survey. Using this data, curve numbers for each land use cover within the subcatchments were calculated using a lookup table in HydroCAD.

3.2.3 Time of Concentration

To define the time for stormwater to move through each subcatchment, the time of concentration (TOC) was defined and used as an input to the model. The urbanized subcatchments - subcatchment numbers 3, 4, 5, 6, and 7 - have high levels of impervious areas and drain quickly to sewer outlets. Under recommendation from Nicole Homes, these areas were given a TOC of 5 minutes. For the remaining 2 subcatchments, subcatchment number 1 and 2, which are the east and west portions of the Swale's wetland, TOC was calculated using average velocity, longest flow path, type of flow, slope, surface description, and Manning's roughness within each subcatchment.

Average velocity data was obtained from the USDA's TR-55 manual, Figure 3.1. Longest flow path was calculated using ArcGIS. A digital elevation model (DEM) was imported into ArcGIS from the University of Connecticut's Center for Land Use Education and Research website. The 10-foot DEM was used to draw 3-foot contours. Using these contours, both the longest flow path and slope were calculated. The first 50 feet of the path was assumed to be sheet flow and the remaining length was assumed to be shallow concentrated flow. The Manning's roughness number was obtained from Table 2 in the TR-55 manual. Worksheet 3 from the TR-55 manual was used to calculate the TOC (see **Figure 6**).



Sheet Flow (Applicable to T_c only) Segment ID

1. Surface description (Table 3-1) ....
2. Manning's roughness coeff., n (Table 3-1) ....
3. Flow length, L (total L $\leq$ 100 ft) .... ft
4. Two-year 24-hour rainfall, P_2... in
5. Land slope, s .... ft/ft
6. $T_t = \frac{0.007\ (nL)^{0.8}}{P_2^{0.5}\ s^{0.4}}$ Compute T_t........................ hr + =

Shallow Concetrated Flow Segment ID

7. Surface description (paved or unpaved) ....
8. Flow length, L .... ft
9. Watercourse slope, s .... ft/ft
10. Average velocity, V (Figure 3-1) .... ft/s
11. $T_t = \frac{L}{3600\ V}$ Compute T_t .... hr + =

Figure 6: TOC Equation

Table 2 below summarizes the TOC values for subcatchments 1 and 2.

TABLE 2: INPUTS AND TOC VALUES FOR SUBCATCHMENTS 1 AND 2

Subcatchment 1							
	Slope	Surface Desc.	Mannings roughness	Flow length (ft)	2yr, 24hr rainfall (inches)	Average velocity (ft/s)	Tt (min)
Sheet	0.06	Grass/woods	0.15	50	3.5		3.46739867
Shallow conc.	0.07212056	unpaved		929		3	5.16111111
							8.62850979

Subcatchment 2							
	Slope	Surface Desc.	Mannings roughness	Flow length (ft)	2yr, 24hr rainfall (inches)	Average velocity (ft/s)	Tt (min)
Sheet	0.08	Grass/woods	0.15	50	3.5		3.0904967
Shallow conc.	0.03125	unpaved		896		3	4.97777778
							8.06827448

3.2.4 Rainfall

In New Haven, the Greater New Haven Water Pollution Control Authority controls stormwater permit approval for all construction projects. For their permits, projects must retain the 2-yr, 6-hr storm event. Because of being restricted to the rainfall events already input into HydroCAD, we could not model the 6-hour storm and chose instead to use the 2-yr, 24-hour storm design storm. This storm event is used as the design storm for all buildings seeking the stormwater quantity reduction credits for LEED buildings (USGBC 2014). We used this storm to model the baseline and proposed conditions model.

3.3 Green Infrastructure Opportunities Identification

With the baseline model developed, on Wednesday, March 5th 2014, Nicole Holmes from Nitsch Engineering, Professor Gaboury Benoit from Yale, and Colleen Murphy-Dunning from the Hixon Center for Urban Ecology joined us for a site walk of the Swale watershed to identify potential green infrastructure opportunities. Ideas included opportunities to use green infrastructure to either: a) reduce stormwater volumes entering the New Haven sewer system; or b) improve the quality of the stormwater already flowing into the Swale. The green infrastructure opportunities were catalogued to provide Yale Facilities with a comprehensive list of green infrastructure projects for the Swale watershed.

A model to quantify the impact of each of these opportunities was created using HydroCAD using the same methodology to model the existing watershed (described above). New subcatchments were created in ArcGIS based on where green infrastructure opportunities existed. For example, one of the opportunities included disconnecting downspouts on the houses along Prospect St. To estimate the potential runoff that could be captured, the estimated roof area that could be disconnected from the sewers and redirected was delineated from the original baseline conditions subcatchment and defined as a new subcatchment. **Figure 7** shows the additional subcatchment delineation in ArcGIS, while **Table 3** summarizes the areas of each different surface type.

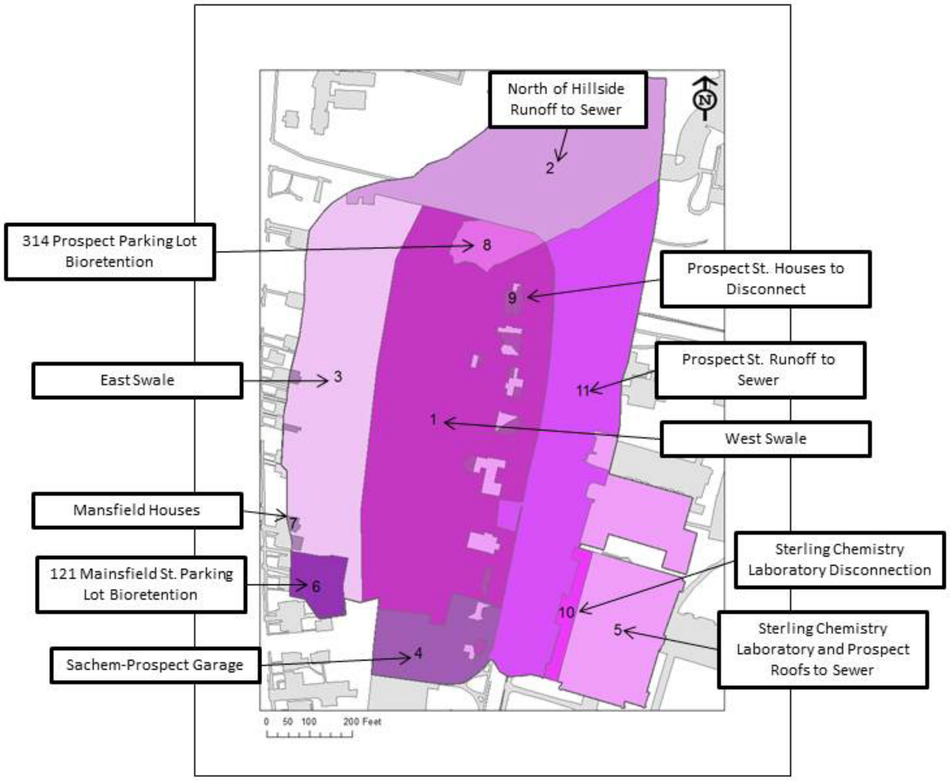


Figure 7: Additional Subcatchment Delineation.

TABLE 3: SUBCATCHMENT AREAS AND SURFACE INPUTS FOR THE PROPOSED CONDITIONS MODEL

Subcatchment Number	Total Area	Impervious Area						Total Impervious	Pervious		Total Pervious	Drainage
		Driveway	House Walk	Parking	Road	Roof	Sidewalk		Trees	Lawn		
1	6.9628	0.0000	0.2354	0.2576	0.0000	0.0904	0.0136	0.5971	4.2248	2.1409	6.3657	Swale
2	3.4803	0.0000	0.0035	0.1455	0.5788	0.0266	0.2602	1.0146	0.5149	1.9508	2.4657	Sewer
3	3.8017	0.0000	0.0162	0.3161	0.0000	0.3647	0.0002	0.6973	0.8458	2.2585	3.1044	Swale
4	1.0000	0.0000	0.0081	0.0717	0.0000	0.5140	0.0206	0.6144	0.0000	0.3856	0.3856	Swale
5	2.5253	0.0000	0.0000	0.0000	0.0000	2.2155	0.0000	2.2155	0.0000	0.3098	0.3098	Sewer
6	0.3728	0.0000	0.0000	0.1968	0.0000	0.0359	0.0000	0.2327	0.0000	0.1401	0.1401	Sewer
7	0.0656	0.0000	0.0000	0.0000	0.0000	0.0654	0.0000	0.0654	0.0000	0.0002	0.0002	Sewer
8	0.3758	0.0000	0.0000	0.1240	0.0000	0.0041	0.0000	0.1281	0.0000	0.2477	0.2477	Swale
9	0.1280	0.0000	0.0000	0.0000	0.0000	0.1280	0.0000	0.1280	0.0000	0.0000	0.0000	Swale
10	0.6304	0.0000	0.0000	0.0000	0.0000	0.09527*	0.0000	0.0000	0.0000	0.0040	0.0040	Swale
11	4.4238	0.0755	0.0267	0.1460	0.9051	0.0381	0.5923	1.7838	0.1505	2.4895	2.6400	Sewer

3.4 Feasibility Scan

The information from the modeling and green infrastructure cataloguing activities was used to present the potential projects to the Office of Facilities and identify a feasible project that could be moved forward. The following section provides an overview of how each opportunity's feasibility was assessed.

3.4.1 Goal Development for Feasibility Assessment

A feasibility scan was conducted for all identified green infrastructure opportunities to determine which projects would be most suitable for implementation in the Swale watershed. Seven suitability goals were developed with assistance from Yale Facilities, Nicole Holmes from Nitsch Engineering, and

Professor Gaboury Benoit from the Yale School of Forestry. The goals include: a preference for downspout disconnection; combined sewer overflow reduction potential; stormwater reduction potential to the separate storm sewer system; protection of future residential colleges on Prospect St.; water quality improvement potential; potential for research and/or outreach; and cost. Each suitability goal is described in greater detail below:

1) Downspout disconnection project preference.

In addition to the strategy to create a green infrastructure pilot program, the Sustainable Stormwater Management Plan also outlined a strategy to prioritize disconnecting downspouts on campus. Because many of the roof drains at Yale are directly connected to New Haven's combined sewer system, connected downspouts pose the risk for CSOs even when storm sewers have been separated (Yale, 2013). In accordance with the plan, downspout disconnection projects will be prioritized whenever possible.

2) Combined Sewer Overflow Reduction

The Office of Facilities views reducing the campus's contribution to CSOs in New Haven as a priority. Potential green infrastructure opportunities that alleviate pressure on the City of New Haven's combined sewer system will be prioritized whenever possible.

3) Stormwater Reductions to the Separate Storm Sewer System

Beyond CSO mitigation opportunities, potential green infrastructure opportunities that alleviate pressure on the City of New Haven's separate storm sewer system will be prioritized whenever possible. Nonpoint source pollutants collected by the separated sewer system contribute to poor water quality by rapidly flushing stormwater into New Haven's rivers and the Long Island Sound without allowing for water to be naturally filtered by soil and vegetation.

4) The Protection of Future Residential Colleges on Prospect St.

Prospect St. stormwater flows downhill from Hillside Place to Sachem St. This stormwater is directed towards the new Yale residential colleges being constructed on the corner of Sachem St. and Prospect St. While flooding within this area is not currently an issue, there may be an opportunity to reduce potential flood risk through capturing Prospect St. runoff. Proactive stormwater management that reduces volumes of water adjacent to the new Yale residential college should be prioritized whenever possible.

5) Water Quality Improvements

Stormwater running off the parking lots within the Yale Swale watershed and the Sachem Prospect parking is assumed to carry pollutants that currently enter the Swale wetland and can have negative environmental impacts. Opportunities to improve water quality through filtration should be prioritized whenever possible.

6) Research, Education, and Monitoring

In accordance with Yale's goals of creating a campus that functions as a living laboratory, opportunities that that allow for increasing the scientific research, education, and monitoring will be prioritized whenever possible.

7) Low Cost

Estimates of the cost of each green infrastructure opportunity were included as a means of assessing its feasibility. Low cost was considered to be less than $20,000; medium cost was considered to be $20,000 - $50,000; and high cost was considered to be greater than $50,000. Green infrastructure opportunities with a lower cost were prioritized whenever possible.

3.4.2 Feasibility Assessment with Yale's Office of Facilities

We met with Julie Paquette from Yale's Office of Facilities on April 16th, 2014, to present the identified green infrastructure opportunities and the initial feasibility assessment. We discussed each green infrastructure opportunity in detail and indicated how it achieved the various specified goals. With initial feedback, we met with both Julie and Nicole on April 23rd to finalize the selection of a green infrastructure project that we could move forward into a conceptual level design.

After each identified green infrastructure opportunity received both a feasibility scan and input from Yale Facilities, we developed a conceptual level design for the green infrastructure opportunity that met the highest number of suitability goals and was also determined to be realistic for implementation in the near term from Yale Facilities. This conceptual level design included information related to the following: 1) site plans and conceptual green infrastructure design; 2) approximate stormwater volume capacity for identified design storm events; 3) description of the materials involved in the green infrastructure opportunity; and 4) approximate cost of the green infrastructure opportunity.

4.0 Project Results

The following sections detail the results from each aspect of our project.

4.1 Green Infrastructure Opportunities

Seven potential green infrastructure opportunities were identified in the Yale Swale Watershed. They include:

- Disconnecting downspouts on the Prospect St. houses with redirection to rain gardens, if necessary;
- Disconnecting the external downspouts of the Sterling Chemistry Laboratory with redirection to rain gardens;
- Capturing St. runoff from Prospect St. with the use of bioswales in the right-of-way;
- Capturing St. runoff from Hillside Place with the use of bioswales in the right-of-way or redirecting the runoff into the Swale watershed via the stream within Marsh Gardens;
- Redirecting the runoff from 314 Prospect St. parking lot through bioretention before it enters the Swale watershed;

- Redirecting the runoff from 121 Mansfield St. parking lot through bioretention before it enters the Swale watershed;
- Planting salt-tolerant species at the Prospect - Sachem Garage's outlet to potentially reduce the amount of salt entering the Swale.

Each of these opportunities is shown in **Figure 8** below and described in greater detail in Appendix A.

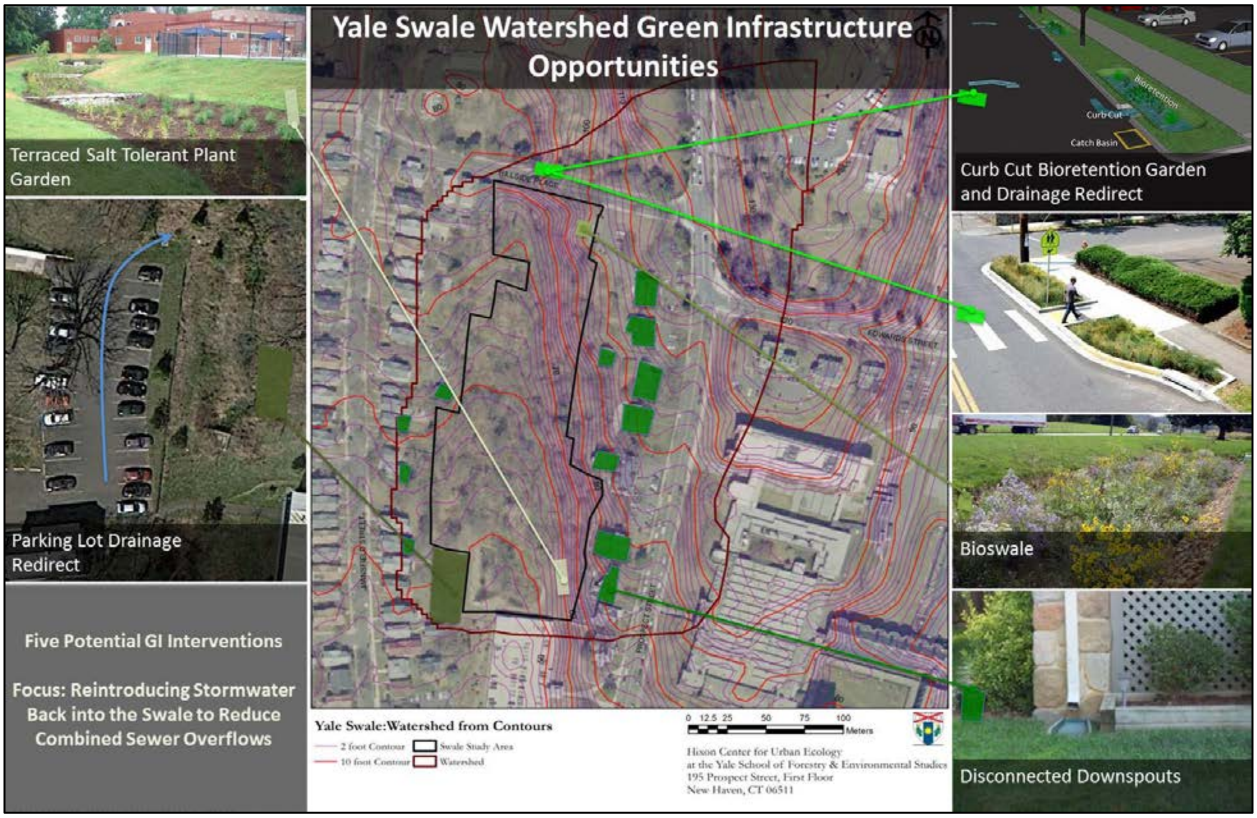


Figure 8: Green Infrastructure Opportunities in the Swale Watershed.

Each potential green infrastructure opportunity was modeled in HydroCAD to determine stormwater volume reductions to the New Haven sewer system. **Table 4** lists the potential stormwater volume reductions for each green infrastructure opportunity during the two year, 24 hour storm event (3.5 inches):

Table 4: Estimated volume reductions from Green Infrastructure Impacts

Green Infrastructure Opportunity	Potential Stormwater Volume Reduction
Prospect Houses Downspout Disconnection	11,300 gallons redirected from the sanitary sewer system
Sterling Chemistry Laboratory External Downspout Disconnection	8,400 gallons redirected from the sanitary sewer system
Prospect St. Right-of-Way Bioswales	16,200 gallons redirected from the storm sewer system
Hillside Place Right-of-Way Bioswales	9,700 gallons redirected from the storm sewer system
314 Prospect St. Parking Lot Bioretention	0 gallons - stormwater runoff flows into the Swale.
121 Mansfield St. Parking Lot Bioretention	0 gallons - stormwater runoff flows into the Swale.
Salt-Tolerant Plantings at the Prospect - Sachem Garage Outlet	0 gallons - stormwater runoff flows into the Swale.

4.2 Feasibility Assessment Results

Using the goals identified previous, each green infrastructure opportunity was evaluated according to whether or not it could achieve each goal. **Table5** below shows the results of the feasibility scan. Feasibility points were allocated in the following way: a) one point was given for every 5,000 gallons reduced to the New Haven sewer system; b) one point was given for each goal that the identified green infrastructure opportunity was fulfilled; and c) three points were given for low cost opportunities, two points for medium cost opportunities, and one point was given for high cost opportunities.

TABLE 5: RESULTS OF FEASIBILITY SCAN WITH TOTAL SUITABILITY POINTS

Green Infrastructure Opportunities	Potential Volume Reduced to Sewer*	Facilities'/Green Infrastructure Goals							Total Points
		Downspout Disconnection	CSO Reduction	Reduction to Separate Storm Sewer	Protect Future Residential Colleges on Prospect	Potential Water Quality Improvements in Yale Swale	Opportunity for Research/ Education	Cost	
Prospect Street Houses	11,300 gallons	🟥	🟥				🟥	Low (<$20,000)	**8.3**
Sterling Chemistry Laboratory	8,400 gallons	🟥	🟥				🟥	Low (<$20,000)	**7.7**
Prospect Street Runoff	16,200** gallons			🟥	🟥		🟥	High (>$50,000)	**7.24**
Hillside Place Runoff	9,700** gallons			🟥			🟥	High (>$50,000)	**4.94**
314 Prospect Street Parking Lot	0 - Already flows to Swale					🟥	🟥	Low (<$20,000)	**5**
121 Mansfield Street Parking Lot	0 - Already flows to Swale					🟥	🟥	Medium ($20,000 - $50,000)	**4**
Prospect Sachem Garage Outlet	0 - Already flows to Swale					🟥	🟥	Low (<$20,000)	**5**

*2yr, 24 hour storm = 3.5 inches
**Estimated assuming green infrastructure manages 10% of runoff from impervious area

The Prospect St. downspout disconnections and Sterling Chemistry Laboratory downspout disconnections scored the highest in the feasibility ranking, with 8.3 and 7.7 points, respectively. If combined into one project, 19,700 gallons could potentially be reduced to the New Haven Sewer System. Both of these projects would fulfill goals stated in the Yale Sustainable Stormwater Management Plan, and the ongoing renovation of the Sterling Chemistry Laboratory provides an opportunity to incorporate downspout disconnections into the scope of work of that project. Additionally, both projects reduce stormwater volumes into New Haven combined sewer system. The Sterling Chemistry Laboratory project has the additional benefit of being combined with other projects that Yale Facilities is currently working on.

From discussions with Facilities, the other green infrastructure projects offer great opportunities, but have complexities that require additional consideration before the can be moved forward. The right-of-way bioswales along Hillside Place and Prospect St. have a higher estimated cost and require coordination with the City of New Haven to move them forward. The 314 Prospect St. and 121 Mansfield St. bioretention projects and the salt-tolerant plantings at the Prospect - Sachem garage outlet require data collection first to understand the baseline water quality.

4.3 Prospect St. Rain Garden Concept

After determining that the Prospect St. and Sterling Chemistry Laboratory downspout disconnections were the green infrastructure opportunities that were considered to be the most feasible for implementation, we created initial concepts for three houses with potential downspouts that could be disconnected on the Prospect St. houses. Appendix B includes the sizing needed for rain gardens of each of the potential downspouts along Prospect St. The appendix also includes potential ideas for locations of rain gardens at the three houses.

5.0 Pilot Program Next Steps

The work this semester is part of the initial steps toward developing a comprehensive understanding of how green infrastructure can perform at reducing the amount of stormwater running off Yale's campus. The work was intended to move the Yale Office of Facilities toward identifying a project that would be possible to monitor and track its performance. Additional work is still needed to move this pilot program toward gathering the necessary knowledge to help Facilities. The following section includes recommendations for the next phases of starting the pilot program.

5.1 Design and Construction of the Green Infrastructure Project

With the completion of this initial phase of identifying a potential project to move into design, we hope that Yale's Office of Facilities will move forward with full design of rain gardens along Prospect St. for both the houses and Sterling Chemistry Laboratory.

5.2 Monitoring Plan of the Green Infrastructure Project

In conjunction with the development of the design, a monitoring plan for the project should be develop. This plan should include the instrumentation necessary to monitor the projects, what data should be gathered and how often data should be gathered, and how that data will be used to understand the performance of the disconnection. If possible, both site-scale and well as watershed-scale monitoring recommendations should be made.

6.0 References

Spatari, Sabrina; Ziwen Yu, and Franco Montalto. 2010. “Life cycle implications of urban green infrastructure” Environmental Pollution. Volume 159, Issue 8-9:2174-2179

Dietz, Michael and John Clausen. 2007. “Stormwater runoff and export changes with development in a traditional and low impact subdivision”. Environmental Management. Volume 87, Issue 4: 560-566.

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Yale University. 2013. “Sustainable Stormwater Management Plan”.

Appendix A
Green Infrastructure Catalogue for the Yale Swale Watershed

Prospect Street Downspout Disconnection

Description of GI: Disconnected downspouts redirect water into rain gardens and pervious areas rather than sewer systems and the street. Nine houses along Prospect Street between Hillside Place and Sachem Street have downspouts that could be disconnected. These downspouts are considered ‘priorities one and two’ by Yale Office of Facilities and could either be disconnected and diverted directly into the Swale or disconnected and captured by an adjacent rain garden.

Proposal: Disconnect Priority 1 and 2 downspouts directly into the Swale or into adjacent rain gardens.

Goal Achievement: Downspout disconnection project preference; combined sewer overflow reduction; opportunities for research, education, and monitoring.

Stormwater Volume Reduction to New Haven Sewer: 11,300 gallons.

Estimated Cost: $16,400 (assuming $10 per sq ft)

Rain Garden.

Sterling Chemistry Laboratory External Downspout Disconnection

Description of GI: Disconnected downspouts redirect water into rain gardens and pervious areas rather than sewer systems and the street. The Sterling Chemistry Laboratory (SCL) has 1,925 square feet of roof drainage serviced by external downspouts that could be disconnected from entering the New Haven combined sewer. Although a majority of the building's drainage is plumbed through the building and exits the building relatively deep (approximately 10 feet), the external downspouts facing Prospect Street present an opportunity to manage stormwater by disconnecting and diverting them to two rain gardens located in the front of the building. As construction is currently underway on the renovation of SCL, the opportunity exists to add targeted downspout disconnections and rain gardens within the scope of the current project.

Proposal: Disconnect external downspouts facing Prospect Street into adjacent rain gardens.

Goal Achievement: Downspout disconnection project preference; combined sewer overflow reduction; opportunities for research, education, and monitoring.

Stormwater Volume Reduction to New Haven Sewer: 8,400 gallons.

Estimated Cost: $17,500 (assuming $10 per sq ft)

Disconnected Downspout.

Capture Runoff with Right-of-Way Bioswales along Prospect Street

Description of GI: Bioswales could be located along Prospect Street between Hillside Place and Sachem Street. Bioswales are stormwater runoff conveyance systems that absorb low flows and infiltrate and filter water through engineered soils and native plant species. Enhanced tree pits are similar to bioswales, but also contain native tree species that provide added habitat for wildlife and shading for pedestrians. These bioswales and enhanced tree pits would capture 10% of the stormwater runoff flowing down Prospect Street and help alleviate pressure on New Haven's overburdened sewer system.

Proposal: Install 4-6 curb cut bioswales along the west side of Prospect Street between Hillside Place and Sachem Street.

Goal Achievement: Reduction to separate storm sewer; protect future residential colleges on Prospect Street; opportunities for research, education, and monitoring.

Stormwater Volume Reduction to New Haven Sewer: 16,200 gallons.

Estimated Cost: $40,000 – $60,000 ($10,000 per bioswale based on New York City Parks estimates)

Right-of-Way Bioswale.

Capture Runoff with Right-of-Way Bioswales along Hillside Place and/or Redirect Runoff into Marsh Gardens

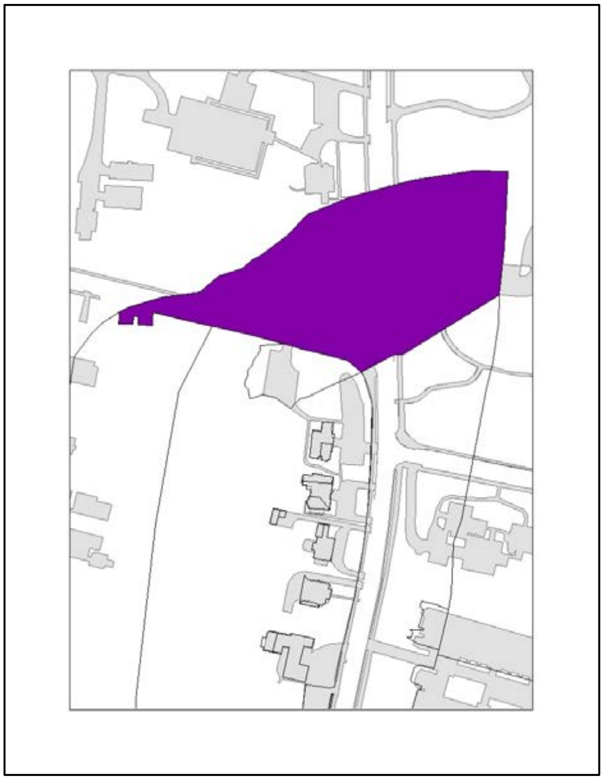
Description of GI: Bioswales could be installed on Hillside Place adjacent to the Swale watershed's northern boundary. In addition to slowing water velocities and improving water quality, bioswales located on the northern side of Hillside Place could contain stormwater diversion pipes underneath the sidewalk that would redirect flows to the pond located adjacent to the Marsh Botanical Gardens. This water would enter the pond and flow through the culvert below Hillside Place before making its way into the Swale.

Proposal: Install 2 right-of-way bioswales along the north side of Hillside Place adjacent to the Marsh Botanical Gardens. Include one stormwater diversion pipe underneath the sidewalk draining from one of the bioswales.

Goal Achievement: Reduction to separate storm sewer; opportunities for research, education, and monitoring.

Stormwater Volume Reduction to New Haven Sewer: 9,700 gallons.

Estimated Cost: $25,000 ($10,000 per bioswale based on New York City Parks estimates and $5,000 for stormwater diversion)



Right-of-Way Bioswale.

Bioretention Installation at the 314 Prospect Street Parking Lot

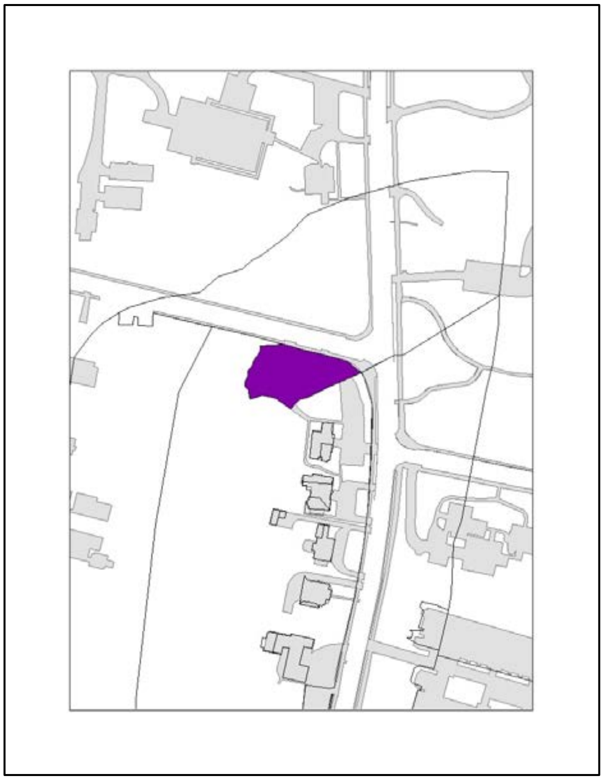
Description of GI: A large bioretention area could be installed adjacent to the 314 Prospect Street Parking Lot that would improve the water quality flowing into the Swale from the area. A large, flat open space is available that would require no grading and capture much of the water exiting the parking lot.

Proposal: Install a bioretention area adjacent to the 314 Prospect Street Parking Lot .

Goal Achievement: Potential water quality improvements to Swale; opportunities for research, education, and monitoring.

Stormwater Volume Reduction to New Haven Sewer: 0 gallons – water already flows into the Swale.

Estimated Cost: $5,000



Bioretention.

Bioswale Installation and Flow Redirect at the 121 Mansfield Street Parking Lot

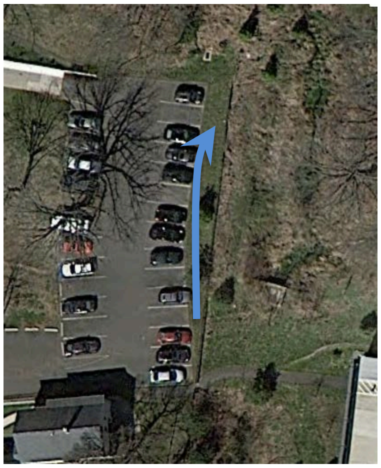
Description of GI: A terraced bioswale could be installed adjacent to the 121 Mansfield Street Parking Lot that would capture stormwater flowing across the parking lot and redirect it away from the current outlet structure back into the Swale. This new terraced bioswale would begin adjacent to the current parking lot outlet and drain to the north in order to hydrologically connect the parking lot to the Swale. This opportunity would require some grading to ensure water flows into the bioswale.

Proposal: Install a terraced bioswale adjacent to the 121 Mansfield Street Parking Lot and regrade portions of the parking lot to redirect flow away from the current outlet.

Goal Achievement: Potential water quality improvements to Swale; opportunities for research, education, and monitoring.

Stormwater Volume Reduction to New Haven Sewer: 0 gallons – water already flows into the Swale.

Estimated Cost: $20,000 ($10,000 for terraced bioswale and $10,000 for site grading)



Parking Lot Redirect.

Salt-Tolerant Plantings at the Prospect-Sachem Garage Outlet

Description of GI: Terraced salt-tolerant plantings could be installed adjacent to the Sachem Garage Outlet. These plantings would help reduce the amount of salt entering the Swale from the Sachem Parking Lot through filtration and plant uptake. All plantings would be in accordance with Cornell's Woody Shrubs for Stormwater Retention Practices guide and would be terraced to accommodate the outlet's slope.

Proposal: Install salt-tolerant plants at the outlet for stormwater runoff from the Prospect-Sachem Garage

Goal Achievement: Potential water quality improvements to Swale; opportunities for research, education, and monitoring.

Stormwater Volume Reduction to New Haven Sewer: 0 gallons – water already flows into the Swale.

Estimated Cost: $1,000 for plants

Terraced Salt-Tolerant Plantings.

Appendix B
Recommendations for Disconnecting the Downspouts along Prospect St.

Introduction

The recommended green infrastructure project for the pilot program is to disconnect the downspouts of the houses along Prospect St. and the external downspouts of the Sterling Chemistry Laboratory. If necessary, it is recommended to implement rain gardens to capture and manage the runoff from these newly disconnected downspouts. With limited time in the semester, we were only able to begin considering the possible concepts for rain gardens needed for Prospect St. houses. This appendix serves to document the work completed for this semester as a means to help in future stages of this program development.

Drainage Area Sizing

All of the downspouts located on the west side of Prospect St. between Hillside Place and Sachem Street, and all of the external downspouts facing Prospect St. on the Sterling Chemistry Laboratory were inventoried as part of our assessment of the potential downspouts to disconnect. Using the downspout disconnection survey completed this year, we identified the downspouts that had been labeled as Priority 1 and Priority 2 disconnections as the most feasible to be disconnected in this work (Yale, 2014). Priority 1 downspouts had been identified as those downspouts that could easily be disconnected and may require a rain garden to manage stormwater (depending on the available area adjacent to the downspout). Priority 2 downspouts had been identified as those that were adjacent to impervious area and may require additional design considerations for their disconnections.

These Priority 1 and 2 downspouts were then associated with their respective roof drainages to determine volumes of water that each would drain during a specified rainfall event. We determined approximate roof drainages for each downspout by cross-referencing ArcGIS data with oblique aerial photographs taken from Google Earth in order to show roof contours (see **Figures 1-3**).

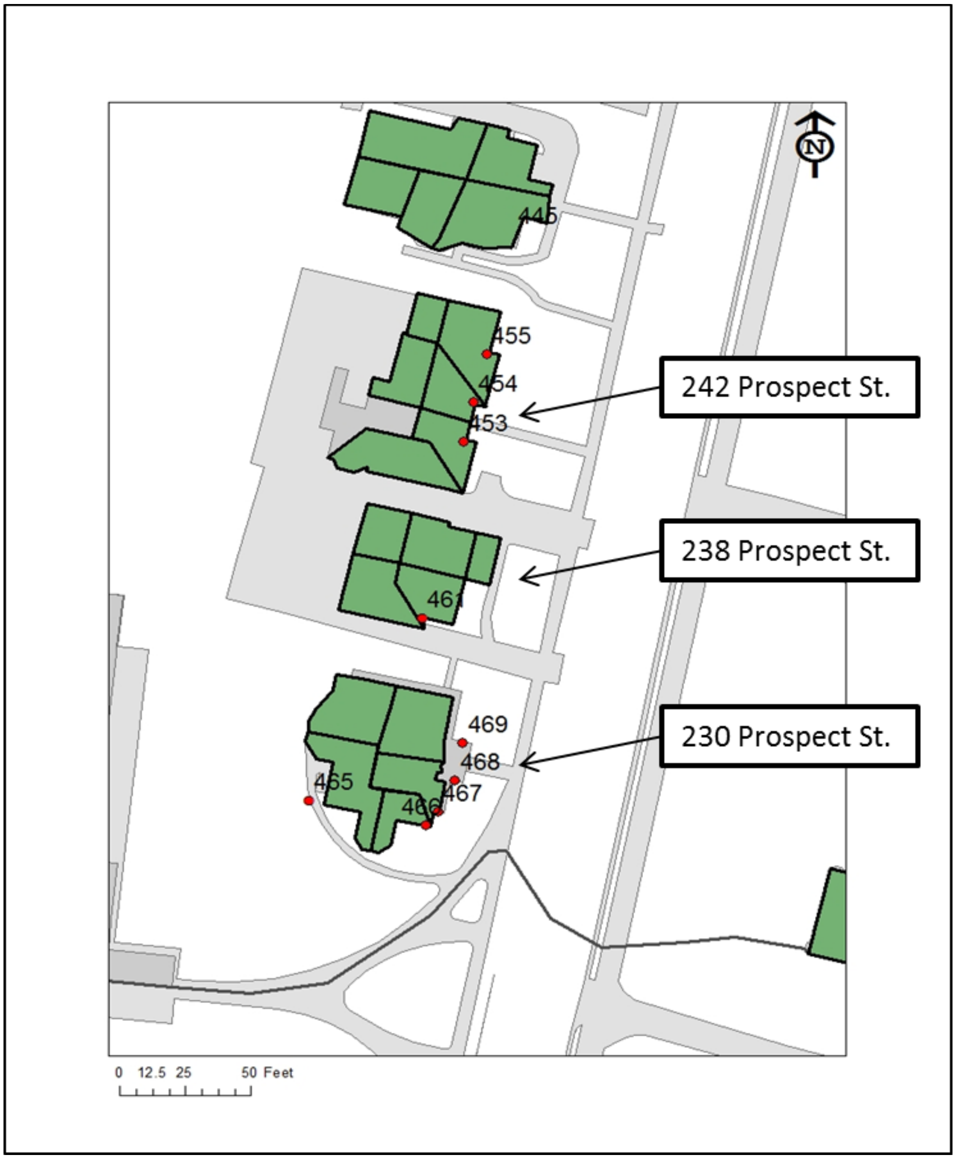


Figure 1: Priority 1 and 2 Downspouts for 230, 238, and 242 Prospect St.

Figure 1: Priority 1 and 2 Downspouts for 276, 282, and 300 Prospect St.

Figure 3: Priority 1 and 2 Downspouts for 310 and 314 Prospect St.

Once roof drainages were determined, approximate rain garden sizes were calculated using the guidelines established by the University of Connecticut's NEMO Program (UCONN, 2014). For our calculations, we assumed that each rain garden would have a depth of six inches and would be designed for a one inch rainfall event. After this information was obtained, we conducted a site walk along Prospect St. to determine if areas adjacent to identified downspouts would be able to accommodate appropriately sized rain gardens. We also contacted Julie Paquette from Yale Facilities to check if any of the properties located along Prospect St. would not be suitable candidates for downspout disconnections due to homeowner concerns. She informed us that the property located on 300 Prospect St. should not be considered for our Prospect St. downspout analysis.

We identified eight houses along Prospect St. with 23 potential downspout disconnections and associated rain gardens, and 11 potential downspout disconnections in front of the Sterling Chemistry Laboratory. Results of this survey are shown in **Table 1.**

Table 1: Downspout drainage areas and potential rain garden sizing for a 1-inch design storm

Downspout Number	Address	Priority	Estimated Drainage Area (sqft)	Rain Garden Depth (inches)	Rain Garden Area (sqft)	Rain Garden Length and Width, if a square (ft)
466	230 Prospect	1	295.7	6	49	7
467, 468			421.6	6	70	8
453	242 Prospect		410	6	68	8
454			388	6	65	8
455			615	6	103	10
439	276 Prospect		838	6	140	12
434	282 Prospect		524	6	87	9
433			218	6	36	6
419	300 Prospect		159	6	27	5
420			173	6	29	5
413, 412	310 Prospect		560	6	93	10
409			443	6	74	9
408			448	6	75	9
406	314 Prospect		259	6	43	7
407			602	6	100	10
465	230 Prospect	2	700	6	117	11
461	238 Prospect		435	6	73	9
436	282 Prospect		270	6	45	7
435			307	6	51	7
425	300 Prospect		417	6	70	8
405	314 Prospect		117	6	20	4
404			596	6	99	10
403			445	6	74	9
399			311	6	52	7

Concept Designs

Site walks indicated that the properties located on 230, 238, 310, and 314 Prospect St. had sufficient available space for rain gardens and would be most suitable to develop a conceptual level design. The properties located at 230 Prospect St. and 238 Prospect St. contains 11 total downspouts. Of these 11 downspouts, three would be suitable candidates for disconnection into adjacent rain gardens. Because of the ample open space surrounding these properties, these rain gardens could be sized for a ten year, 24 hour rain event instead of a one inch event. Approximately 2,117 square feet of roof drainage would be accommodated by 1,763 square feet of adjacent rain gardens. The rain garden located to the southwest of the 230 Prospect St. property would contain a drainage feature that would divert flows under the adjacent pedestrian path. The rain garden located between the two properties would be terraced to prevent erosion with a series of stone check-dams. **Figure 5** provides an overview of the site, roof drainage areas, and potential rain gardens.

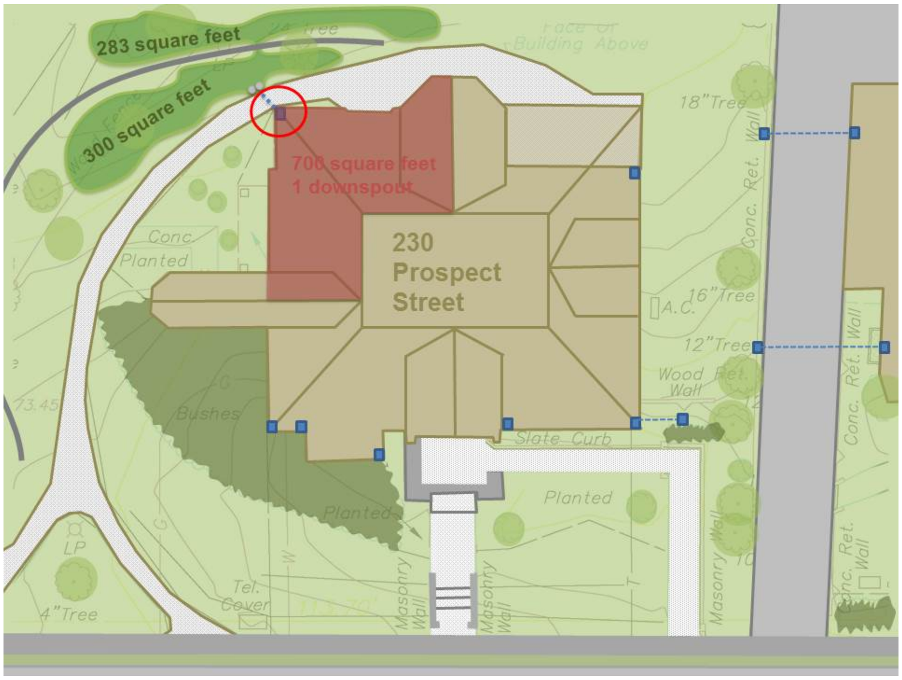


Figure 2: Potential Sizing for Downspout Number 465

The properties located at 310 and 314 Prospect St. contain 20 total downspouts. Of these 20 downspouts, 13 would be suitable candidates for disconnection into adjacent rain gardens. Similar to the properties located at 230 and 238 Prospect St., the ample space adjacent to these properties would allow for rain gardens sized for a ten year, 24 hour rainfall event. Approximately 3,600 square feet of drainage would be captured by 3,000 square feet of rain gardens. The rain garden located to the west of the 314 Prospect St. property would contain a drainage feature under the pedestrian sidewalk that feeds into a terraced design adjacent to the site's steps. The rain garden beginning in the south of the 310 Prospect St. property would flow through a series of stone check dams that would slow water velocities and prevent erosion. **Figure 6** provides an overview of the site, roof drainage areas, and potential rain gardens.

Figure 3: Potential Rain Garden Sizing for

Plant List

As part of the Sage Hall Rain Garden development efforts, a plant list was developed based on recommendations for University of Connecticut's rain garden design guide. **Table 2** provides a list of all of the suitable plants that could be utilized for potential rain gardens.

References

University of Connecticut (UCONN), 2014. "CT NEMO Program". *Available at:* http://nemo.uconn.edu/

Yale University. 2013. "Yale University Strategic Stormwater Management Plan". *Available at:* http://www.facilities.yale.edu/publications/MN045850.Stormwater.WEB.lmr.pdf

Yale University. 2014. "Yale University Downspout Disconnection Survey". ArcGIS Data Collected by the Yale Office of Facilities. Received on March 15th, 2014

Table 1: Table of Potential Plants for the Rain Gardens

	Name	Scientific Name	Height	Width	Bloom Time	Native	On List	Location in Rain Garden	Notes
Small Shrub	Sweet Fern	Comptonia peregrina	2-5	4-8	Spring	Y	Y	Any	Showy green foliage, grows well in average, medium well-drained soils
	Sweet Pepperbush	Clethra alnifolia	2-4	3-5	Late Summer	Y	Y	Any	Fragrant blooms
	Black chokeberry	Aronia melanocarpa	2-3	4-5	Spring	Y		Any	Attracts birds
	Smooth Hydrangea	Hydrangea arborescens	3-5	3-5	Summer	Y		Any	
	Common Buttonbush	Cephalanthus occidentalis	2-6	4-8	Summer	Y	Y	Best in bottom	Blooms all summer
Large Shrub	Bayberry	Myrica pensylvanica	4-5	5-7	n/a	Y	Y	Any	Tolerates salt and salt spray
	Silky Dogwood	Cornus amomum	6-10	6-10	Late spring	Y	Y	Any	Blue fruits; wildlife benefit
	Gray Dogwood	Cornus racemosa	6-10	0	Early summer	y	Y	Any	Blue fruits; wildlife benefit
	Redosier Dogwood	Cornus sericea	6-10	7-9	Early summer	Y	Y	Any	Red stems attractive in winter
	Witchhazel	Hamamelis virginiana	6-10	6-10	Fall	Y		Any	
	Winterberry Holly	Ilex verticillata	6-10	6-10	n/a	Y	Y	Best in bottom	Bright red berries in fall persisting into winter
	Red Chokeberry	Photinia pyrifolia	6-10	3-5	Spring	Y		Any	Red fruit
	Red Chokeberry	Aronia arbutifolia	6-10	3-5	Late spring	Y		Any	Red fruits; wildlife benefit
	Inkberry Holly	Ilex glabra	6-8	8-10	n/a	Y	Y	Best in bottom	Evergreen
	Swamp Azalea	Rhododendron viscosum	6-8	3-8	Spring	Y		Any	Fragrant blooms
	Spicebush	Lindera benzoin	>10	6-12	Early spring	Y		Best in bottom	Aromatic leaves and stems
	Elderberry	Sambucus canadensis	5-12	5-12	Mid summer	Y		Any	Edible berries for wildlife; jelly; wine
Grasses/ Herbaceous	Bluejoint	Calamagrostis canadensis	4-5	0	Late spring	Y		Best in bottom	None
	Broom sedge	Carex scoparia	2-3	0	n/a	Y		Any	None
	Tussock sedge	Carex stricta	<2	1.5-2	n/a	Y		Any	None
	Riverbank wildrye	Elymus riparius	4-5	0	n/a	Y		Best in bottom	None
	Virginia wildrye	Elymus virginicus	2-3	0	n/a	Y		Best in bottom	None
	Switchgrass	Panicum virgatum	3-7	2-3	n/a	Y	Y	Any	Tolerates salt; has good fall and winter color
	Swamp milkweed	Asclepias incarnata	4-5	1-2	Fall	Y	Y	Best in bottom	None
	Butterfly milkweed	Asclepias tuberosa	2-6	2	Summer	Y	Y	Best in siope or upland	Attracts butterflies
	Astilbe	Astilbe sp.	1-3	0	Early summer	Y		Best in slope	None
	Coastal plain joe pye weed	Eupatoriadelphus dubius	2-6	2-3	Mid summer	Y		Best in bottom	None
	Spotted trumpetweed	Eupatoriadelphus maculatus	2-6	0	Mid summer	Y		Best in bottom	None
	Boneset	Eupatorium perfoliatum	2-6	3-4	Mid-late summer	Y		Best in bottom	None
	Joe pye weed	Eupatorium purpureum	2-6	3	Mid summer	Y	Y	Best in bottom	None
	Rose mallow	Hibiscus moscheutos	3-8	3-5	Mid summer	Y		Best in bottom	None

	Slender blueflag	Iris prismatica	0	0	n/a	Y		Best in bottom	None
	Blue flag	Iris versicolor	2-3	1-2	Early summer	Y	Y	Best in bottom	None
	Turk's cap lily	Lilium superbum	0	0	n/a	Y		Any	None
	Great blue lobelia	Lobelia siphilitica	1-2	2-3	n/a	Y	Y	Best in bottom	None
	Orange coneflower	Rudbeckia fulgida 'Goldstrum'	2-6	1.5-2	Mid-late summer	Y	Y	Any	Attracts butterflies and other insects
	Green headed coneflower	Rudbeckia laciniata	6-8	0	Late summer	Y		Best in bottom	None
	New England Aster	Symphyotrichum novae-angliae	2-6	4	Late summer/Early fall	Y	Y	Any	None
	New York Ironweed	Vernonia noveboracensis	2-6	2-6	Late summer	Y		Any	None
	Purple coneflower	Echinacea purpurea (L.) Moench	1-2	0	Early summer	Y	Y	Any	None
	Tickseed sunflower	Bidens aristosa	3-4	0	Late summer	Y		Any	None