M18

The Living Laboratory

Stevens Institute of Technology

2015 Environmental Protection Agency
Campus RainWorks Challenge

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Project Abstract

Stevens Institute of Technology is a 38-acre urban campus located on the east edge of Hoboken, NJ, bordered by the Hudson River. Flooding and combined sewer overflow is a primary concern for both Hoboken and campus. Campus contribution of annual runoff to the overburdened Hoboken urban water system exceeds 20 MG. Sustainable stormwater management practices are proposed to reduce runoff and stress on the system.
The RainWorks Team accepted the 2015 Environmental Protection Agency's (EPA) Campus Rainworks Challenge to create the first stormwater management plan for the Stevens' campus: "The Living Laboratory". The Team proposes 29 green infrastructure techniques, which have been applied to problem areas to reduce runoff, contaminant discharge and potable water usage. The Living Laboratory provides a practical example for urban campus green infrastructure and introduces classroom and community educational opportunities. The Team worked with Stevens Facilities and Events Management to ensure the proposed design is aligned with future growth of campus, can be maintained, is aesthetically pleasing and economically responsible.

The Living Laboratory was modeled using the EPA's Storm Water Management Model to quantify runoff volume and peak flow reduction. WinSLAMM (Source Loading and Management Model) was used to model pollutant loading. Model results indicate through implementation of the Living Laboratory, campus runoff will be reduced by 20% when modeled for the NJ water quality design storm. Primary pollutant reduction will be approximately 24%. Economic impact of The Living Laboratory will result in financial gains to the institution with a payback period of 23 years.

Figure 1: Campus Aerial View

Scope & Resources

The RainWorks Team (Team) members accepted the Environmental Protection Agency's (EPA) Campus RainWorks Challenge to create Stevens Institute of Technology's (Stevens) first Stormwater Management Master Plan: The Living Laboratory (Project or Living Laboratory). The Team undertook the challenge as their senior engineering design project, conducted from September to December 2015. The project will continue with the next phase during the spring 2016 semester, January to April. The Team hopes to create a culture in which green infrastructure (GI) is accepted and sought after to establish Stevens as a leader in urban campus GI implementation.

The Project is defined in five phases: initiation, planning, design, execution, and closing.

1. Initiation Phase (September 2015)

Establish the design team and advisors. Define the project purpose and scope. Raise awareness for a GI approach by researching existing water management problems at Stevens.

2. Planning Phase (October 2015)

Collect data. In previous years, Stevens students collected data on campus drainage delineation and soil infiltration. The Team used this data to o determine campus runoff using the EPA's Stormwater Management Model (SWMM). The Living Laboratory approach focuses on resilient and efficient designs that are aesthetically pleasing and cost-effective. Stakeholder engagement informed the Team of campus space usage. Integration of stakeholder engagement and education to assist in awareness and support of GI was essential for the planned implementation.

3. Design Phase (November 2015 - December 2015)

Modeling of the Stevens campus was performed using SWMM for both existing conditions and the proposed Living Laboratory. Model outputs were used to determine peak flow rate mitigation and runoff volume reduction. The Living Laboratory was also modeled using WinSLAMM (Source Loading and Management Model) to determine pollutant loading. The New Jersey Department of Environmental Protection's (NJDEP) Water Quality Design Storm (WQ storm), the National Stormwater Quality Database (NSQD), the National Urban Runoff Program (NURP), the National Climatic Data Center (NCDC), and the International Stormwater Best Management Practices (BMP) Database were all used in the modeling.

4. Execution Phase (January 2016 - August 2018)

Integrate The Living Laboratory into the proposed ten-year campus plan. At the end of this phase, the team aims to have all infrastructure implemented on campus and all planning concepts adopted by campus management. Through the Living Laboratory demonstration, the Team hopes additional installations will be proposed to expand the Living Laboratory.

5. Closing Phase (September 2018 - December 2022)

Utilize proposed GI as a hand on learning experience for classes, research, and the Hoboken community. Evaluate the long term effectiveness and sustainability for future improvements. The closing phase marks the end of the proposed ten-year campus plan at which point the campus will have completed its transformation into a "living laboratory" for education, research, and future influence of GI practices.

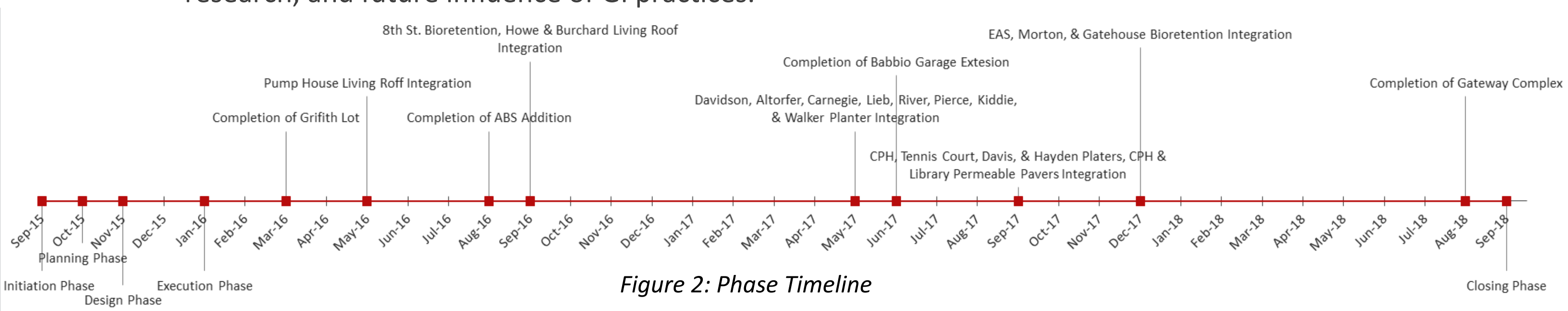

Figure 2: Phase Timeline

Background

Stevens is a 38-acre urban campus that houses 45 buildings and five main lawns. The total impervious area accounts for roughly 60% of campus, resulting in approximately 14 acres of permeable surfaces. The campus is located on a cliff edge with just over three acres exhibiting a 30-55% slope, the result of which is only 11 acres available for infiltration. In-situ soil testing yielded an infiltration rate of only 0.57in/hr.

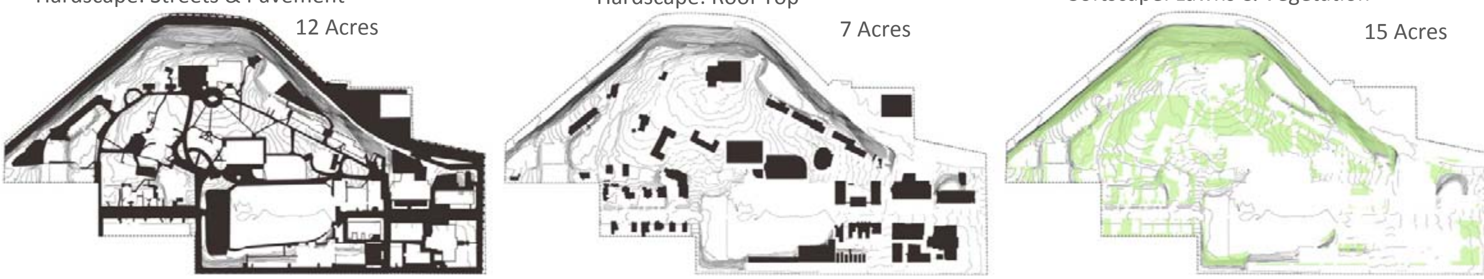

Figure 3: Campus Landscape Zones

From 1990 to 2015, as recorded at Newark Liberty International Airport, the average annual rainfall for the Hoboken area was 46-in, with an average of 121 days (annually) of measurable precipitation. (*"Climate Data Online"*) SWMM modeling performed by the Team indicates annual runoff from the Stevens' campus of approximately 18.27-in, or 20.6 MG. The annual precipitation rates, low infiltrating soils, and a buildup of impervious areas contribute to the severe runoff and frequent ponding the campus experiences.

Existing Campus Delineation

Stevens is currently delineated into eight major drainage areas, each designated by the topography and common drainage point. Table 1 and Figure 3 show the drainage areas and land characteristics.

Figure 4: Campus Drainage Areas

Table 1: Pervious and Imperviousness Acres

Drainage Areas	Pervious Acres	Impervious Acres	Total Acres
1	1.00	5.38	6.38
2	0.41	2.75	3.16
3	0.85	6.66	7.51
4	2.24	1.16	3.40
5&6	4.13	2.53	6.66
7	3.78	4.02	7.80
8	1.45	1.70	3.15

Existing Campus Drainage Investigation

The Team met with Stevens Facilities in order to present the Team's objectives, focus, and scope, as well as to obtain feedback to gain a better understanding of the perceived drainage problems on campus. Facilities provided drawings of campus infrastructure and the proposed ten-year campus plan and concepts.

The Team conducted campus site walks during rain events for further site analysis. Major runoff problems were noted in drainage areas 1, 3, 4, 5, and 6. Excessive ponding was noted in drainage areas 2 and 8. The Team also met with Stevens Events Management to receive input as to the placement of GI for maximum event benefit. The Team's investigation exposed six major problem areas; see Design Board 1: Figure 3, and Table 2.

Table 2: Campus Problem Area Identification

Problem Area	**Drainage Area**	**Problem Identification**	**Uses**
8th & Hudson St.	1 & 2	Facilities	Heavy pedestrian traffic
Morton, Kiddie, Pierce (MPK) Lawn	2	Events Management	Campus events ; Student recreational area
5th & River St.	2 & 3	Rainworks Team	Heavy pedestrian traffic; Nearby lawn for campus events
Babbio Patio	8	Students & Faculty	Heavy student traffic; Campus police parking
Sinatra Drive	3, 4, 5, & 6	Facilities	Heavy pedestrian traffic; Seasonal street fairs
Library Lawn	8	Facilities	Campus events; Student recreation area

When working with Facilities, the importance of considering the evolving nature of the Stevens' campus became apparent in designing The Living Laboratory. The addition of three new buildings, the redesign of a parking lot, and the loss of another were considered as near-term projects. While these improvements change the land use, there is no change in impervious coverage. All proposed campus expansions are not yet finalized, thus smaller and more frequent installations of GI are proposed. Smaller installations ensure the resiliency and integration of The Living Laboratory within the proposed ten-year campus plan.

Living Laboratory Strategy Development

Small storms frequently cause flooding and combined sewer overflows (CSO) in Hoboken. There are five combined sewer outfalls that discharge to the Hudson River. The Team used the WQ storm as representative of the frequently occurring storm in modeling. The WQ storm distributes 1.25-in of rain over a two hour period, which is represented in Fig. 5. Due to the extent of green space, and relatively low vehicle traffic, campus pollutant conditions do not measurably impact water quality and CSO discharge. Rather, the volume of runoff impacts pollutant loading into the Hudson River. The Team prioritized volume reduction to reduce CSO volume discharge. However, water quality was modeled for each proposed GI in order to show the additional benefits of the systems. Pollutant reduction in remaining discharge would assist Hoboken's municipal wastewater treatment plant prior to potential CSO. A decrease in pollutants in water captured will enable repurposing for irrigation.

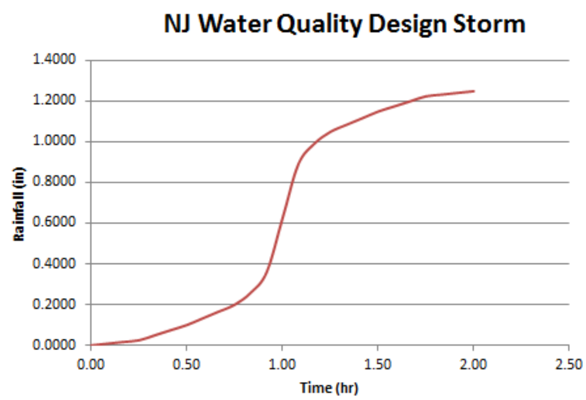

Figure 5: Water Quality Design Storm

Despite drainage, flooding, and runoff issues, there is presently no stormwater management strategy included within the proposed ten-year campus plan. The focus of the

Team was to include the entirety of campus in a stormwater master plan in order to minimize peak flow rates and runoff volume. The Team proposes the use of five different GI techniques to ensure the sustainability and resiliency of The Living Laboratory. Various applications provide facilities with flexibility in integration, as well as provide a wide range of learning and research opportunities. Proposed GI applications include: planters, bioretention cells, living roofs, permeable pavement, and cisterns. Compost amendment is proposed over the extent of existing campus softscape to increase the infiltration rates.

The Team's design focused on areas where runoff has the largest negative impact on campus life. Most problem areas were designed with more than one type of solution, varying in GI techniques. While each individual application assists in solving a particular problem area, the combination of applications generates a cohesive plan, creating a solution for the entire campus. All GI technologies provide an aesthetic appeal and enhance campus beauty. Table 3 provides specific examples of benefits to each of the problem areas.

Table 3: Problem Area GI Application

Problem Area	**Problem Description**	**GI Application**	**Benefit**
8th & Hudson St.	High impervious area increases runoff and causes local lawn flooding leading to unaesthetic landscape and hazardous walking conditions.	Planters Bioretention Cell	Reduce hazardous walking conditions
Morton, Kiddie, Pierce (MPK) Lawn	Popular event lawn ruined by low soil infiltration, roof runoff, and scour at downspouts.	Planters Living Roof	Eliminate large downspout scour holes Create hands-on learning experience Decrease lawn drainage to improve campus events
5th & River St.	High impervious area and roof runoff overflow inlets.	Bioretention Cell	Address bare soil spot Minimize ponding and runoff through busy campus thoroughfare
Babbio Patio	Runoff generated a sink hole at edge of cliff causing hazardous conditions.	Bioretention Cell Planters	Fix sinkhole Reduce risk of sinkhole recurrence
Sinatra Drive	Runoff freezes during winter months causing hazardous conditions.	Permeable Pavers Planters	Capture runoff from entire parking area Reduce runoff from steep slope Limit hazardous conditions
Library Lawn	Popular event lawn ruined by poor soil conditions.	Permeable Pavers	Creates permeable stage for campus events Covers bare soil spots

In addition to the campus improvements made by each system individually, the entire plan will function as a "living laboratory." Stevens, popularly known for its wide range of engineering programs, could use the proposed GI as teaching tools and research projects. The "Innovation University," will further benefit from implemented GI for continuous student research into sustainable uses of GI and benefits to surrounding area.

The Living Laboratory

Twenty-nine GI applications and compost amendment were proposed as part of the Living Laboratory. Twenty of the twenty-nine proposed GI applications directly alleviate stress at the six problem areas. However, all twenty-nine systems reduce runoff to an over-taxed urban CSO system. The proposed GI locations were identified by examining feasibility of implementation, maintenance, land availability, and impact to problem areas. See Design Board 2: Figure 1.

SWMM Modeling

The SWMM model was used to examine both existing conditions and the proposed ten-year campus plan. Topography and drainage areas were determined using land survey delineations, utility and infrastructure as-built drawings and site surveys. In-situ soil infiltration testing was used to calibrate a Horton infiltration model across campus. The WQ storm was used for precipitation input.

GI practices were created using the low impact development control editors and standard information within the New Jersey BMP Manual. Detailed design for GI systems was derived from municipal guidance from cities with advanced GI experience, including Philadelphia, PA; Portland, OR; and Seattle, WA. The use of GI was optimized by testing size and depth of differing GI techniques to achieve the maximum stormwater capture. Land availability most prominently governed GI type, design, and location. Campus has numerous areas ranging from 100-500 ft^2, each providing no significant stormwater mitigation benefit. The Living Laboratory will convert these areas into planters and bioretention cells, directing runoff into the GI practices. Bioretention cells optimize stormwater capture in larger lawn spaces. Elsewhere, proximity of smaller landscaped areas adjacent to structural foundations led to the proposal of planters. Planters focus on evapotranspiration (ET) and detention rather than infiltration. Permeable pavement was proposed for implementation on the Library Lawn to ensure the continuous utilization of an area frequently used for campus events and traveled extensively by pedestrians. The permeable pavement serves the dual purpose of managing stormwater while serving as a permanent stage for campus events. Limited parking on campus stipulated that the proposed design of a permeable paver parking lot would maximize parking spaces while allowing infiltration. Campus has close to seven acres of roof surfaces with opportunities to treat direct rainfall. Living roofs were proposed to assist in runoff mitigation prior to reaching ground level on three buildings resulting in 0.646 acres covered. Additionally, cisterns aid in roof runoff reduction by utilizing captured water for irrigation.

Compost amendment was an integral part of the Living Laboratory. Campus lawns are defined by urban soil composition. Heavy foot traffic has further compacted the soil to a degree of inhibiting grass growth and infiltration. Compost amendment was modeled as a 20% increase to the initial Horton infiltration rate and a 20% decrease to the decay constant. The final Horton infiltration capacity value was left unchanged in order to govern the final infiltration rate should a storm event persist.

WinSLAMM Modeling

WinSLAMM is the windows version of an urban stormwater quality model. Modeling is established via land use type, programing for residential, institutional, industrial, commercial, and freeway uses. Each land type is further defined by the source area (i.e. roofs, streets, landscaping areas, etc…). Drainage areas of campus were given their own land type; areas 1, 2, 3, and 8 were defined as institutional and areas 4, 5, 6, and 7 were defined as residential. Areas were divided according to building type. GI practices are assigned to source areas within each land use; modeled inputs for GI were adapted using the SWMM parameters.

WinSLAMM was the preferred method for modeling pollutant loading because the calculations are based on individual rain events. Individual rain events were deemed specifically important for pollutant loading as the most frequent rain events cause CSO problems for

Hoboken's stormwater system and for consistency with the NJDEP's regulatory approach for stormwater management design. Particulate concentrations within the model are a function of runoff depth, land use, and source area. Land use and source area are user defined according to campus subcatchment areas. Simulations were modeled using programmed files from NSQD and NURP.

Maintenance

Maintenance for all GI techniques is required to keep the systems working. Depending on the system, maintenance is needed weekly, monthly, semi-annually, and/or annually. Planter, bioretention, and living roof inspection are critical to the operation of the system to ensure it remains clear of debris. Debris will interrupt proper drainage flow, affecting the efficiency of the system. Cistern inspection is critical to the operation of the system to ensure the floor of the system remains clear of debris. Debris will provoke an odor and yellow tint, affecting the quality of the water. Permeable pavement inspection is critical to the operation of the system to ensure plants do not root into the pavement. Rooting into the pavement will decrease drainage, affecting the efficiency of the system. Existing stormwater infrastructure requires inlet maintenance and regrading around inlets to prevent unnecessary runoff to stressed areas. Campus inlets currently fill with organic debris reducing drainage capacity and tend to be bypassed by stormwater.

Expected Outcomes

The Living Laboratory is projected to successfully solve existing stormwater problems while adding the benefit of repurposing captured water for irrigation. The Living Laboratory reduces total campus runoff and peak flows, as shown in Figure 6.

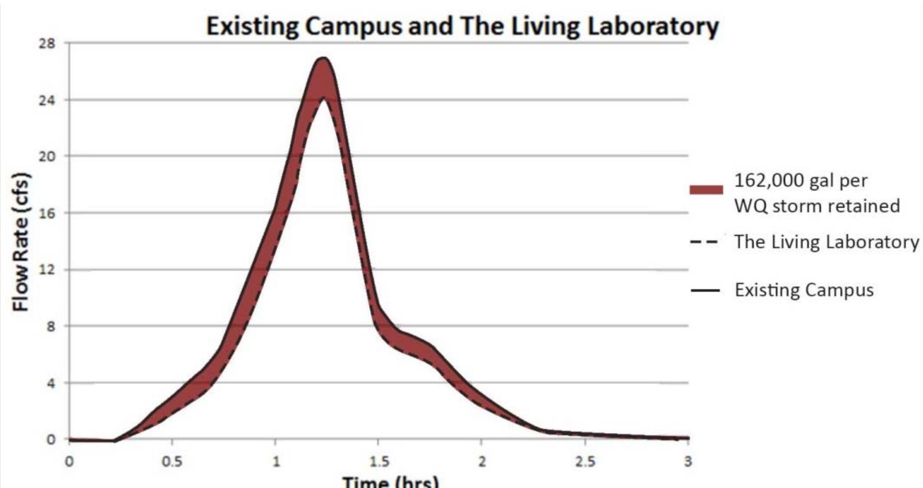

Figure 6: Existing Campus vs. Living Laboratory Hydrograph

The introduction of GI to the Stevens campus results in a 10.5% reduction (2.83 cfs) in peak flow of stormwater leaving the campus. The Living Laboratory will capture 0.162 MG during each WQ storm, a 20% reduction in runoff from the current conditions on campus.

Approximately 80% of campus is included in drainage areas, which house the designated problem areas. A breakdown of the level of mitigation achieved in these areas can be found in Table 4.

Table 4: Volume Reduction per Drainage Area

Drainage Area	Size (Acres)	Percent of Drainage Area Mitigated by GI (%)	Percent Reduction in Runoff Volume (%)	Volume Reduction (MG)
1	6.38	14	8.74	0.016
2	3.16	30	24.62	0.023
3	7.51	17	21.25	0.034
4	3.4	10	36.36	0.019
5&6	6.66	25	34.81	0.035
8	3.15	17	34.85	0.021
Total	30.26	19	23	0.147

The combination of proposed GI and compost amendment creates a cohesive aesthetic within the campus. The Living Laboratory alleviates ponding, significantly decreases runoff and demonstrates the successful implementation of GI within the urban environment in poor soil conditions. The compost amendment when modeled for the major lawns during the WQ storm shows a reduction of 61,000 gallons in runoff volume through infiltration. The amendment would promote grass growth and eliminate the existing turf replacement program resulting in savings. Table 5 shows the impact of all designed GIs grouped by technique, during modeling of the WQ storm, and continuous conditions.

Table 5: GI Retention Breakdown

GI Type	Number of Units	Volume Retained per WQS (gal)	Average Annual Retention (MG/yr)
Planters	15	18,513	0.432
Bioretention Cells	7	21,295	0.679
Cisterns	2	21,041	0.684
Permeable Pavers	2	18,735	0.645
Living Roofs	3	21,818	0.609
Total	29	101,400	3.049

The team analyzed the Living Laboratory's effectiveness over the simulated 25-yr period with the continuous model. Figure 7 shows the Living Laboratory's effect on runoff over long term conditions. The Living Laboratory reduced the number of days with runoff exceeding 0.25-in by approximately 200, over a 25 year period, while reducing the maximum runoff experienced by close to 0.5-in. The gap between the exceedance curves shows the Living Laboratory design effects frequent runoff events, and extreme runoff events.

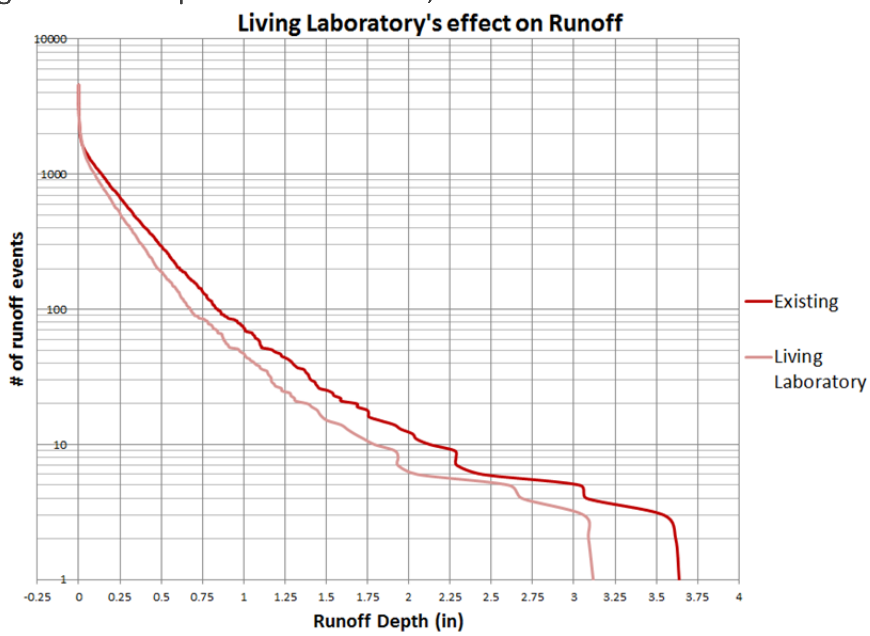

Figure 7: 25 Year Continuous Runoff Model

Under existing conditions, Stevens discharges 20.6 MG per year into the Hoboken CSS. The total volume reduction per year with the Living Laboratory is approximately 4.5 MG. This reduction includes compost amendment in the major lawns, which was recommended to increase infiltration, eliminate ponding and mitigate runoff to already stressed areas of the current drainage system.

Urban runoff is one of the greatest sources of water pollution. The Living Laboratory decreases runoff to the Hoboken CSS, and subsequently the Hudson River. The reduction in volume helps with mitigation of this problem and in turn, assists with pollutant loading. The Team addressed most typical pollutants experienced in stormwater systems and urban runoff. Specifically modeled were fecal coliform and E. coli as they are known discharge complications for the Hudson River. Nonpoint source pollution including oil, rubber, and heavy metals affect water quality of runoff, however these constituents were not modeled in order to keep the focus on site specific problems. All constituents that assist in bacteria growth at low dissolved oxygen conditions were included as well to assist in reduction of fecal coliform and E. coli.

Table 6: Living Laboratory Pollutant Reduction

Pollutant	**Percent Yield Reduction**
Particulate Solids	11%
Total Phosphorus	15%
Nitrate	8%
TKN	15%
Total COD	11%
Fecal Coliform Bacteria	3%
Filterable E Coli	6%

When the proposed Living Laboratory is phased into the proposed ten-year campus plan, the expected outcomes for runoff pollutant reduction will be significant as seen in Table 6. Percent yield reduction of pollutants were strictly monitored for the tributary areas of each GI. The highest percentage reduction is exhibited in phosphorus, total kjeldahl nitrogen (TKN), chemical oxygen demand (COD), and particulate solids. Phosphorus, TKN, and COD are all constituents that catalyze organic growth and bacteria formation. Remaining E. coli and fecal coliform growth will in turn be reduced due to limiting nutrient supply. The Team was able to achieve an 8% reduction in E. coli and 14% reduction in fecal coliform. The effectiveness of the GI in pollutant reduction was considered successful not only because of the moderate E. coli and fecal coliform reduction but also because of the high cofactoring nutrients and the particulate solids reduction. The percent pollutant reduction of particulate solids can be further broken down by GI practices as seen in Figure 8.

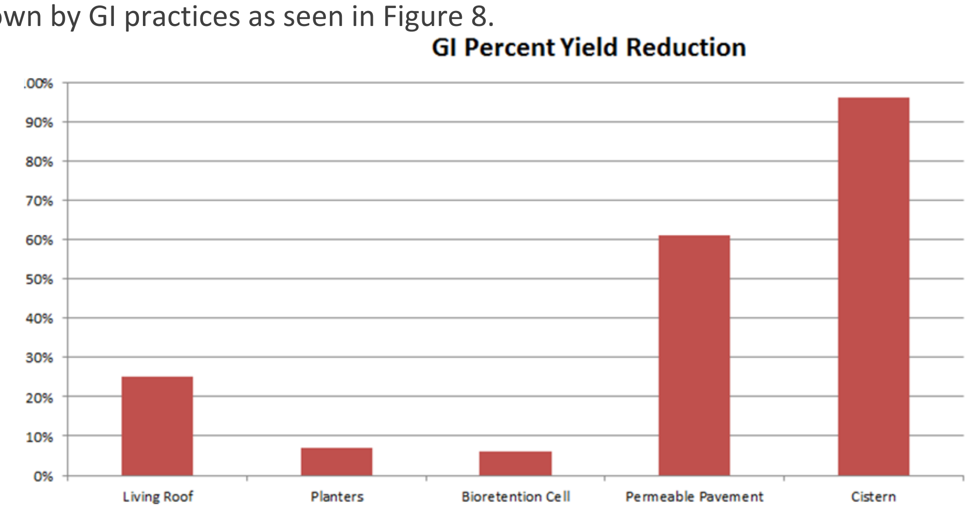

Figure 8: Pollutant Reduction per GI systems

The cisterns exhibit the highest amount of reduction as each unit captures nearly 100% of the water routed to them. Permeable pavers due to their high ability to store and reduce runoff assist in pollutant reduction with volume reduction. Living roofs only experience precipitation pollutant source loading thus experience a higher reduction. Planters and bioretention cells exhibit smaller reductions due to the high variety of tributary areas routed through each. All of these units experience a massive load in both volume of water and quantity of pollutants.

Cost

A cost-benefit analysis was completed on the project as a whole to assess feasibility and likelihood of implementation. Numbers pertaining to the cost of construction and cost of operations and maintenance (O&M) per square foot (bioretention, planters, permeable pavement, and living roofs) and per gallon (cisterns) were obtained from the Center for Neighborhood Technology's (CNT) Green Values® National Stormwater Management Calculator.

Table 7: GI 25 Year Lifespan Cost Analysis

GI Applications	**Cost**	
Planters	Minimum	$8,630
	Average	$155,904
	Maximum	$275,727
Bioretention	Minimum	$49,394
	Average	$59,350
	Maximum	$119,848
Cisterns	Minimum	$17,819
	Average	$93,475
	Maximum	$135,247
Permeable Pavement	Minimum	$102,692
	Average	$148,024
	Maximum	$328,428
Living Roof	Minimum	$258,667
	Average	$457,911
	Maximum	$1,177,284
Total	Minimum	$437,202
	Average	$914,663
	Maximum	$2,036,535

Table 7 provides a breakdown of the minimum, median and maximum cost estimations for each GI technique over the course of the 25 year lifespan. Cost of construction for the Living Laboratory project came to an average total of $685,507. Cost of O&M came to an average annual total of $9,166. Savings for campus was calculated per gallon saved by the Living Laboratory. Stevens's campus is charged 1.3 cents per gallon discharged into Hoboken's Stormwater Collection System. Table 8 depicts the total savings over the 25 year lifespan per GI.

Table 8: GI 25 Year Lifespan Savings Analysis

GI Application	Savings
Planters	$140,339
Bioretention	$220,534
Cisterns	$221,903
Permeable Pavement	$209,246
Living Roof	$197,610
Total	$989,634

The savings produced through water captured by the Living Laboratory came to an average annual total of $39,585. Over a 25 year period, Stevens will profit an average total of $74,968. Table 9 shows the costs, savings, and profits of the Living Laboratory over a 25 year period.

Table 9: Total Living Laboratory Cost Analysis

Living Laboratory	
25 Year Period	
Average Cost	$914,633
Savings	$989,632
Profit	$74,968

The Living Laboratory proposed is not only beneficial for stormwater and pollution reduction but also economically viable. The Living Laboratory plan cost analysis predicts that the plan will come ahead over the course of the 25 year lifespan by two years. Steven Facilities will benefit from the economic gains throughout those two years influencing future GI proposals, implementations, and the development of GI research programs. The GI systems are perceived as successful proposals for campus implementation as they provide aesthetic solutions to expressed problems. Facilities, Events Management, and campus users will benefit from lawn solutions enabling successful events, runoff volume reduction, and generate positive campus and community relations. The abundance of GI applications ensures that the Living Laboratory will transform Stevens into a leader of sustainable stormwater management.

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