Northeastern University

Recharging the City

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Site Selection: William E. Carter Field

Abstract

The Northeastern University Campus RainWorks Demonstration Project proposal improves upon Northeastern plans for the development of William E. Carter Field with the specific goal of leveraging stormwater management infrastructure to address local environmental issues, increase site resiliency, and improve the social and environmental context of the site's location in the City of Boston.

Facilities Division managers were immediately consulted in the planning phase of this project to discuss areas of campus in greatest need of stormwater management intervention. The team found enthusiastic support for developing a strategy to re-envision the drainage system at Carter Field – a 6.5-acre athletic field and park on Columbus Avenue just outside the Groundwater Conservation Overlay District with plans for renovation by the University. Our proposed design reinvigorates the currently neglected Southwest Corridor, a key pedestrian passage connecting Boston to its outlying neighborhoods, and establishes the site as a central community location within three Boston neighborhoods. With the Carter Field design, the team addresses three primary environmental issues in the City of Boston:

1. Combined Sewer Overflows and pollution of the Charles River
2. Groundwater level decreases and damaged building foundations
3. Sustainable water management education and outreach

The design represents a state-of-the-art proposal; blending innovative technologies, proven green infrastructure methods, and an educational community focus with the potential to achieve:

- A 70.99% Peak Flow Reduction and 72.52% Total Runoff Reduction in a 1- year storm
- A 61.47% Peak Flow Reduction and 27.43% Total Runoff Reduction in a 100-year storm
- 90% Total Suspended Solids (TSS) Reduction

Introduction

Environmental resource managers, engineers, landscape architects and developers are all familiar with the core problem of urban hydrology – increased runoff of precipitation from the expansion of impermeable areas due to intense development. The precipitation that falls upon these surfaces dissolves, suspends, and otherwise diffuses petroleum products and many potentially degrading substances into the surrounding water bodies through the subsurface drainage conduits engineers have, for centuries, relied upon to keep the urban environment dry, passable, and economically viable (1).

Urban runoff management has, until recently, ignored the biotic systems which these methods have dramatically impacted. The status-quo methods have also overlooked fundamental components of the hydrologic cycle itself. Decades of research conducted and compiled by the International Geosphere and Biosphere Program (IGBP), as well as many other scientists, have suggested that big-pipe drainage solutions are drying out the continents, contributing to the urban heat island effect, and may be a fundamental and overlooked driver of climate change (2,3).

In 2010, such practices caught up with the city in the form of a lawsuit brought forth by the Conservation Law Foundation and the Environmental Protection Agency (EPA)on the grounds that the city had failed to meet the stormwater runoff pollution standards of the Clean Water Act. In 2012, a consent decree was reached establishing an ongoing set of short-term and long-term stormwater management benchmarks for the city (4). The same year the consent decree was reached, the Water Infrastructure Finance Commission released a report on the status of the water infrastructure of the Commonwealth of Massachusetts. The report's findings estimated an $18 billion investment in stormwater infrastructure would be needed over the next 20 years in order to meet future federal stormwater regulations (5). In tandem with these local chronicles, the effects of climate change present an uncertain future with regards to the extremity of future weather events. The scientific implications of climate change have begun to trickle through the political sphere; leading to a discussion on increasing the city's resilience and adaptability to such events. It is in the spirit of these efforts to clean, revive, and conserve the tributaries and waterways of Boston, as well as to educate the public to these often neglected issues, that Northeastern University submits the following proposal.

Urban Context of the Carter Field Site

Site Description

The William E. Carter Field site is a 6.5 acre lot in the heart of the City of Boston. Surprisingly underutilized, the space features an under-maintained grass athletic field with concrete seating, five tennis courts, half a basketball court, one playground, an abandoned building foundation, and a series of small bench areas. The field is located on the north side of Columbus Avenue (MA-28), adjacent to a parking garage on the southwest side of the field with a footprint of just over one acre. Camden Street is a dead-end road to the northwest of the field that leads to the Massachusetts Avenue Massachusetts Bay Transportation Authority (MBTA) Orange Line station. A parking lot is situated to the northeast between the field and the Orange Line. The field is the largest undeveloped, unpaved surface in the immediate vicinity, and as such is an ideal location to implement low-impact development (LID) strategies to mitigate stormwater runoff.

Within the city, the site sits at the juncture of three Boston neighborhoods: The South End (east), The Back Bay (northwest), and Roxbury (southwest). Lengthwise the site is sandwiched between the MBTA Orange Line and the Southwest Corridor, a 4.7 mile pedestrian pathway that runs parallel to the MBTA. The site's immediate surroundings are composed of Northeastern buildings, MBTA infrastructure, and a combination of low-income and student housing. A small k-12 school also lies on the other side of Camden Street, a driving factor in our goal to make the experience of water intuitive and engaging throughout our site. This diverse location contributes to the site's usage by commuters, students, and local residents.

In a recent private-public partnership, Northeastern University was granted rights to develop the site as an athletic facility. The current design proposal by the University features two athletic fields, five tennis courts, and a youth playground. Our design proposal hopes to maintain the sites athletic function, restore the continuity of the southwest corridor, optimize value for all three of the bordering neighborhoods, and maximize site potential as a stormwater treatment, collection, and infiltration mechanism for the surrounding watershed.

An initial review of public drainage systems and previously submitted hydrogeologic information was performed. The information was made available by the Boston Water and Sewer Commission (BWSC) for the nearby Interdisciplinary Science & Engineering Complex (ISEC) building, which incorporated rain gardens and other groundwater-recharge infiltration systems. The team also sought consultation with the project engineer for the redevelopment effort, who graciously shared survey and design documents that enabled the team to ascertain the extent and capacity of the existing and currently proposed hydraulic design.

Southwest Corridor: Olmsted Legacy and Stormwater Management design in the City of Boston

The Southwest Corridor is in many ways an extension of the Emerald Necklace, a landmark park in the City of Boston designed by the famous Landscape Architect Frederik Law Olmsted. Weaving through the perimeter neighborhoods of the greater Boston area, the Emerald Necklace follows the snaking Muddy River to its eventual discharge into the greater Charles River and Boston Harbor. An important integration of urban stormwater management and landscape architecture, the functionality of the Emerald Necklace and its importance in flood control has historically been overlooked. Efforts of the recent Muddy River Restoration Project have attempted to revitalize the condition of the Muddy River back towards its original design: a natural flood management and water treatment utility (6).

As the team constructed the Campus RainWorks submission, we recognized the historical legacy of Olmsted. Given the unique similarities in the Emerald Necklace's integration of recreational urban space and stormwater management infrastructure, we hope to instill a similar sentiment in the conscious restoration of the Southwest Corridor on the Northeastern site. As a contemporary homage to the Olmsted legacy, our design strives to make legible the story of water treatment and bring the timely environmental issues of water sustainability to the experience of the Southwest Corridor.

The Urban Challenge

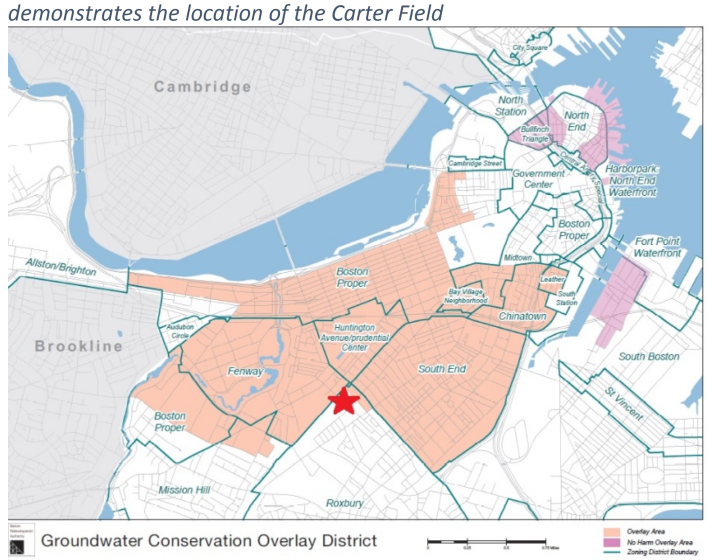
The Northeastern campus' urban character in many ways inhibits its ability to create the idealized natural stormwater conditions. Faced with the unique challenges and opportunities of a dense urban environment, the team sought to manipulate the overwhelming amount of impermeable surfaces and intensively programmed space in a demonstration project that would leverage these characteristics; in turn defining our decision to focus on water harvesting, infiltration, and education. Although many aspects did not make the final design, considerations of a number of green technologies included roof-top gardens, solar-panels, grey-water treatment facilities, and more. While green-roofs were omitted for financial reasons and the decision to focus our site on water harvesting, other considerations were omitted from this submission for either financial reasons or a lack of resources to fully investigate feasibility. That being said, the team strongly feels that the potential of the Carter Field site as a test-bed for alternative green infrastructure should not be overlooked, and we are confident that the proposals made here reflect the most feasible and effective means to reach our goals.

Local Environmental Issues

Boston Groundwater Trust (BGwT)

In 2005, The Boston Groundwater Trust was established to protect and conserve the wood-pile foundations of Boston's southwestern neighborhoods (including the recognizable brick row-buildings for which the city is known). In the 'fill' made neighborhoods of the Back Bay and South End areas, many old buildings are stabilized by 30-40 foot pilings which were driven through the man-made fill and organic silt layer into the clay layer. Urban development (sewers, subway lines, highway tunnels) of the Back Bay area has caused a "drawdown" effect, where underground aquifers' water levels drop, causing exposure of the wooden pilings to harmful microbes and decay. Once rotting has begun, the pilings must be replaced with steel and coated in concrete; the cost of which can exceed $400,000 for a multi-story row-building. As urban development grows, increasing impermeable surfaces have been engineered to direct precipitation through sewers and drains to off-site locations, largely contributing to the decrease in the groundwater table seen today(7).

Figure 1 Boston Conservation Overlay District - The red star demonstrates the location of the Carter Field



The Carter Field site is located directly next to the Boston Groundwater Conservation Overlay District (GCOD). Many newer campus buildings located in the GCOD have incorporated recharge components such as infiltration galleries in order to comply with a recharge mandate, and the Facilities Division is fully cognizant and proactive in dealing with this issue. A conscious goal of the site design is to mitigate the risk of foundational rot events from occurring in neighboring communities by infiltrating much of the Carter Field site into the surrounding watershed as advised by the Boston Groundwater Trust.

Stormwater Runoff Pollution and Combined Sewer Overflows in Boston

The greater Boston area has a history of combined sewer overflows (CSOs); and programs have sought to remedy the issue dating back before the 1980s. Since 1987, the city has taken great strides by reducing annual CSO levels 84% overall. However, as the results of the 2012 consent decree highlight, there is still much improvement to be made. While the metropolitan beaches of the Boston area have maintained an average safety score of 90% in 2014, a number of beaches remained under the 90% safety threshold. In fact, the lowest score for the 2008-2014 study periods was at Kings Beach in 2008 which had a score of 48%.

In cooperation with the BWSC, the team was able to trace the downstream drainage of the Carter Field site to discharges via two CSO outfalls in the Lower Charles River, and one CSO outfall in the Muddy River. In 2014, these three downstream CSO outfalls contributed 3.96 million gallons of CSO active outfalls, and thus likely polluted water, into the Lower Charles River (8).

Sustainable Water Management Education and Outreach

Northeastern University is home to multiple faculty-led sustainability initiatives directly related to urban stormwater management. Our team of advisors includes members of the Urban Coastal Sustainability Initiative as well as the Resilient Cities Laboratory. The integration of our distributed real-time control system allows for an exceptional collection capacity for data and provides valuable infrastructure through which both research and education are accessible and valuable. The theme of water and its journey is highly profiled throughout the design of our site, creating the potential to be an extraordinary example of a living educational experience.

Hydrologic Analysis

The proposed stormwater management system is designed to utilize the 6.5 acres of urban land to manage both on-site rainfall as well as rainfall on adjacent impermeable surfaces – the Columbus Parking Garage, Camden Street, and the northern half of Columbus Avenue. The goal is to detain and recharge rainfall from this engineered watershed to the maximum extent possible. Many of the proposed bioretention cells are designed so that they will not flood at all under normal conditions, and even fully retain some predicted extreme events (i.e. 100-year storm). As a result, the impermeable surfaces are fully recharged to groundwater for normal rainfall events, and runoff volumes are significantly (50% or greater) reduced in the extreme events. The proposed treatment train consists of oil-grit separators followed by vegetated swales to remove suspended solids prior to entry into the bioretention cells. After filtration through a bioretention soil mix, the stormwater is given credit by Massachusetts Department of Environmental Protection (MADEP) standards as having 90% TSS removal. Most of the runoff is then passed into a system of nine infiltration galleries sized to recharge the water in less than 72 hours after passage of the storm, while (depending on existing conditions) 40,000 gallons is directed to on-site cisterns. The hydrographs generated (via hydrologic analysis methods) for the design proposal demonstrate the success of the design under the assumed parameters described below. Excess flow to the infiltration galleries during extreme events is passed back to the drainage system via overflow pipes connecting to the existing drain.

Hydrologic analysis for both existing conditions and the proposed design were calculated via the proprietary hydrograph modeling software HydroCAD. For the analysis, total rainfall was determined by the 24-hour duration TP-40 totals rainfall predictions, and was distributed over the duration by the Type III SCS unit hydrograph curve. The time increment for each set of calculations was set at 0.01 hours, and refined by a factor of three, resulting in a time step of 12 seconds. The model was run to simulate the 1-, 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year storms. The limits were drawn to include the adjacent Columbus Avenue Garage, the north side of Columbus Avenue, the parking lot to the northwest of the field, and all of Camden Street. The model was run with hydrologic soil group C for all underlying soils, and a minimum infiltration rate of 0.6 inches per hour.

Engineering Methods

Hydrogeologic Considerations

The foundation of any hydrologic management effort is well beneath the visible surface, at the bottom of the groundwater table. An important point of concern is where the groundwater table lies. The engineering team focused significant research into developing an answer to this question. Unfortunately, the true properties of the aquifer underlying our site remain a mystery without results from field testing and the corresponding investment of time, money, and expertise. However, the Boston Groundwater Trust shared well boring logs for dozens of locations in the vicinity, providing useful clues. The Back Bay, as with much of Boston, is built on fill. Two well boring logs along Columbus Avenue demonstrate this fact clearly, and, when paired with the hydrologic analysis at ISEC, provide a conservative basis for our design assumptions. Coal, sand, and gravel are identified in the upper layers, and sandy fill intermixed with organics extends to a depth near twenty feet below grade until, around sea-level, an undetermined extent of marine clay is described.

In order to justify a base for modeling groundwater mounding consequences, we assume the marine clay layer acts as an impermeable lens on which the observed groundwater level slides along its gradient. According to the BGwT wells examined, the seasonal high groundwater table is slightly lower than an elevation of 8 feet.

An iterative groundwater mounding analysis was conducted based on the Hantush method (9). The size and number of galleries proposed are based on the most optimal geometric arrangement for evenly distributing the recharge over the full surface area of the site, within the constraints of surrounding foundations and, to the extent practicable, existing grade elevations. Based on these analyses, nine infiltration chambers are placed at a consistent invert elevation of ten feet, in two rows, and all are connected by 15” equalization pipes set at an invert of 10.6 feet.

Existing Hydrologic Conditions

Boston is often termed a “water-rich” environment, as is much of the northeastern United States. Rain gauge data collected at a BWSC pump station over the last ten years, less than a mile from the project site, was averaged and is summarized below.

Variability of Climatic Conditions

Climate change is a complex, difficult problem to understand. The feedback mechanisms involved in the process of modeling predicted climate change are not well understood. What is known is that we are adding energy to the climate system in the form of entrapped solar energy and higher sensible heat contributions, which is due both to GHG emission and interference with the global hydrological cycle, particularly in urban environments. The only sure way to prepare for more energetic weather patterns and events resulting from this excess energy is to build drainage systems that also retain water. The systems also need to return water to its place in the land, where it acts as a buffer to absorb energy in the latent heat of evaporation. This system has been designed to address climate change variability in this way.

Bioretention Cell Design

The MassDEP has issued a Stormwater Handbook to guide the design of LID and sustainable stormwater management practices. Bioretention is a technique that uses soils, plants, and microbes to treat stormwater before it is infiltrated and/or discharged, per the Stormwater Handbook. Bioretention cells were chosen as the primary best management practice (BMP) to be used at the Carter Field site. They can be used for two different purposes. They can be designed in order to exfiltrate and recharge into the groundwater while filtering stormwater, or they can be used solely as an organic filter which then discharges the stormwater to other BMPs, a discharge outlet, or into the municipal storm drain system. In both cases, bioretention areas remove pollutants from runoff such as total suspended solids (TSS), Nitrogen, Phosphorus, and various metals. Based on the existing conditions at Carter Field, several bioretention cells were to act as organic filters before discharging to the infiltration galleries.

Bioretention Cell Bottom Area Sizing

The Massachusetts Stormwater Handbook calls for bioretention cells to be sized at 5% to 7% of the area draining to it. This metric was considered along with the infiltrative capacity of the native soil. As previously mentioned, the native soil was determined to have an infiltration rate of 0.6 inches per hour, and the soils were specified as Hydrologic Soil Group C throughout the site. Volume 3 of the MA Stormwater Handbook requires a soil infiltration rate of at least 0.17 inches per hour at the site of infiltration.

Table 1: Bioretention Areas and Runoff Treatment

Bioretention Cells					Bioretention Ponds				
BRC	*Area (sf)*	Drainage Area (sf)	*Drainage Area (ac)*	***Percent Runoff Treated***	BRP	*Area (sf)*	Drainage Area (sf)	*Drainage Area (ac)*	***Percent Runoff Treated***
1	2015	18251.64	*0.419*	***83.88%***	*1*	*12710*	72266.04	*1.659*	***92.03%***
2	*2734*	18774.36	*0.431*	***89.55%***	*2*	*30964*	62160.12	*1.427*	***99.78%***
3	*3128*	12283.92	*0.282*	***97.11%***					
4	*5571*	15681.6	*0.360*	***99.02%***					
5	*6090*	37505.16	*0.861*	***94.31%***					
6	*1779*	12371.04	*0.284*	***88.81%***					

The rain garden bottom areas were determined using a design tool from the Low Impact Development Center website, which was developed under the US EPA Office of Water 104b(3) Program. The tool requires inputs such as the drainage area, drainage area NRCS Curve Number, storage depth above ground (ponding depth), infiltration porosity (voids ratio), soil depth, and bioretention area. Using these inputs, along with the probabilities and frequencies of different 24 hour precipitations in a year, a percent of total runoff treated is calculated (Table 1). Both the bioretention cells and ponds (larger ponding depth) were sized and placed using the LID tool, HydroCAD trial and error methods, and acknowledgement of the other proposed surface features at the site.

Stormwater Management Design Methods

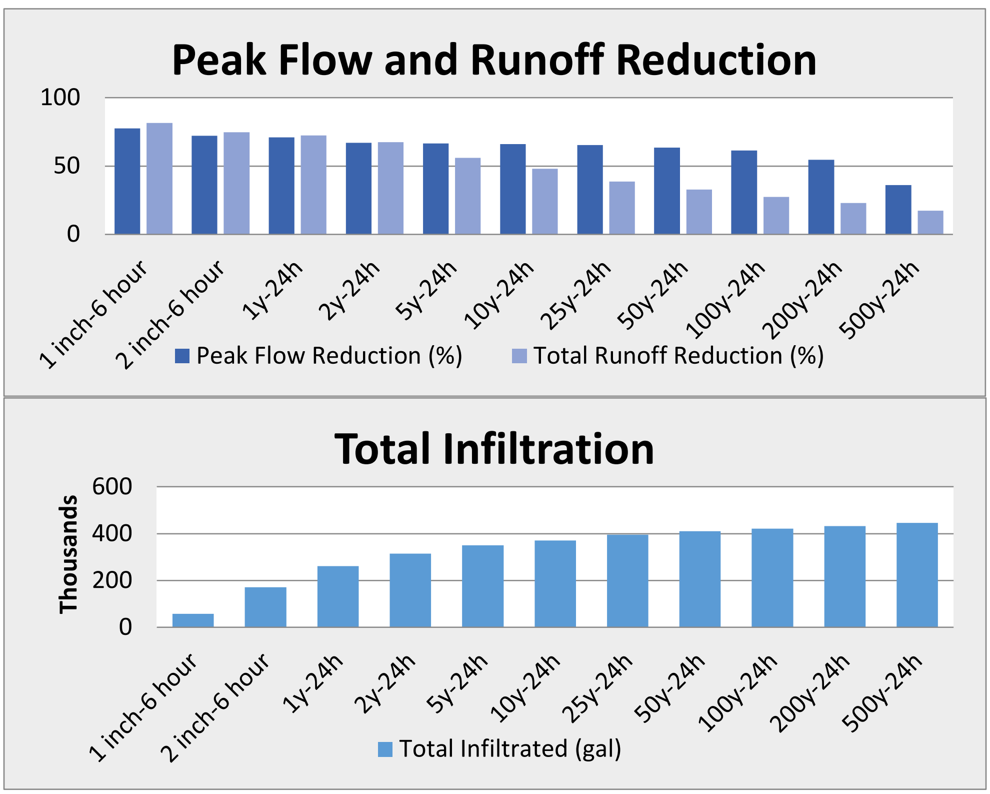
Several other BMPs are suggested in our design including oil-grit separators, vegetated filter strips, filtering bioretention cells and ponds, sediment forebays, porous pavement, wet-wells and infiltration galleries are designed in accordance with the MA Stormwater Handbook.

Table 2: TSS removal prior to infiltration galleries

Area Description	Best Management Practices	Total TSS Removed (80% Required)
Columbus Garage	OGS-G1 --> BRP-1 --> SF	*94%*
SW Columbus Ave.	OGS-1 --> BRC-1	*93%*
SSW Columbus Ave.	OGS-3 --> BRC-3	*93%*
Multipurpose Area	BRC-2	*90%*
S Columbus Ave.	OGS-4 --> BRC-4	*93%*
East Multipurpose Path	BRC-5	*90%*
SE Columbus Ave.	OGS-6 --> BRC-6	*93%*
Tennis Courts	BRP-2	*90%*
Camden St.	BRP-2	*90%*
Garage Alleys	PP	*80%*
Average		***90%***

The primary intention of using these structural practices is to settle as much of the TSS from the water before it enters the infiltration galleries, which may be clogged by excess grit and require more frequent maintenance. The total amount of TSS removed from stormwater runoff for difference treatment trains was determined based on the MA Stormwater Handbook's values before inflow into the infiltration galleries (Table 2). An average of 90% TSS removal (44% minimum recommended) was achieved over the whole site before runoff was discharged into the galleries. Abbreviations are used for oil grit separators (OGS), bioretention cells/ponds (BRC/P), sediment forebays (SF) and porous pavement (PP).

Figure 2



A complete hydraulic model of the existing and proposed conditions were developed and tested by the engineering team. These results were reviewed by Professor Onnis-Hayden, and pertinent values are reported in Figure 2.

Results

The resulting design meets or exceeds all requirements specified in the MADEP Stormwater Handbook. The bioretention cells are designed to remove 80-90% of TSS before delivering water to the infiltration galleries. Oil grit separators placed parallel to the road, beneath the sidewalk, remove 25% of TSS per unit in the treatment train and retain oil that could harm plants and soil infiltration rates in the bioretention cells. For a complete presentation of the treatment process and conveyance systems, including overflow systems to the existing drainage if needed, see the design boards.

Further Considerations

The assumptions stated above and cited in the appropriate figures suggest that this site could be utilized to great benefit in prevention of the site's contribution to downstream pollution, flooding and CSO events, as well as for groundwater recharge benefits for the GCOD. In order to proceed with further planning, field work must be conducted to determine the critical parameters used to define the site constraints. The field work includes a geotechnical analysis of the soils to confirm estimated infiltration rates and groundwater monitoring over a full season on the site to confirm water table levels pre-development, depth-to groundwater, and aquifer specific yield and transmissivity. If these assumptions prove to be correct, it is this team's opinion that the hydrologic design proposed would be of substantial benefit to the social and hydrologic environment of Northeastern's campus.

Investing in Stormwater Management – Benefits of our Design

Stormwater Fee

In September 2015, the BWSC announced they were seeking a consultant to conduct a feasibility study regarding the implementation of a stormwater fee. In anticipation of such a fee, the team constructed a model to estimate potential savings by averaging the costs of three similar credit/fee structures: Philadelphia, District of Columbia, and Seattle.

	Campus Design	Base
Avg Annual Fee*	$ 6,815.22	$6,773.88
Avg Annual Credit*	$ 3,168.54	$ -
Avg Annual Net Payment	$ 3,646.68	$6,773.88
All credit estimates calculated from best case scenario		

Our analysis calculated ~$3,127 in annual savings, a number that is expected to rise in the future as Stormwater fees are projected to increase across the United States (10).

Water Harvest and Smart System

The implementation of a distributed real-time controls (DRTC) system hopes to leverage the potential of the Carter Field site to decrease on-site flooding and optimize irrigation through the intelligent re-use of harvested water. The team consulted with OptiRTC, a local tech firm specializing in DRTC technology, and was able to confirm the feasibility of such a technology on site. The use of moisture sensors, temperature sensors (athletic field), real-time groundwater monitoring, National Oceanic and Atmospheric Administration weather forecasts, infiltration gallery volume sensors, and tank depth sensors could be leveraged to facilitate pre and post storm tank levels to optimize water harvesting during peak events and re-use practices during dry spells saving both money and resources for irrigation (10). This proven technology would allow the university to facilitate the collection of valuable performance data from the Carter Field site to demonstrate the potential of technologies and provide the infrastructure for continued research and testing of new technologies.

Runoff Pollutants

Based off of modeled runoff of a 1-inch rain event, our design would reduce TSSs by 96% (including infiltration galleries). From a valuation stand point, the natural filtration of both organic elements and other pollutants can be incredibly cost effective. The treatment of 1kg of Phosphorus in a waste-water treatment plant is on average $420, capital costs not included (11).

In the event of a combined sewer event, a NYDEP study estimated $1-2 dollars for every gallon of wastewater released into local waterways (10). With 111 gallons of untreated CSO volume entering the Boston tributaries in 2014, and an additional 532 gallons of treated volume, the remediation costs of such events can be extremely expensive, on top of additional ecological effects (8). The peak flow and total runoff reductions demonstrate our design's contribution towards limiting the potential for downstream CSOs and mitigation of the pollution in our local environment through on-site treatment.

Research Value

With its prestigious universities, $1.7 Billion water technology industry, and sector relevant institutions (MassCEC, NEWIN, etc.), the Commonwealth of Massachusetts is often described as a water technology cluster. The Carter Field site would provide R&D infrastructure to catalyze the growth of marketable technologies developed at the university, allowing Northeastern members to stake a claim in this rapidly growing sector (12). The site's sensor system allows the site to serve as a pilot testing facility for both demand technologies, as well as monitoring capacity for the effectiveness of BMP techniques on site.

Potential Sources of Third-Party Funding

In October, 2015 MassDEP announced its Intended Use Plan for the 2016 Clean Water State Revolving Fund (CWSRF). The department cited a total financial investment of approximately $380 million, at least 10% of which congress requires to be allocated towards "green infrastructure" projects in the Commonwealth. The plan also mentions a commitment to 12 new "green infrastructure" projects (13).

The Carter Field site is an ideal candidate for CWSRF funding because of its multiple environmental benefits to the Boston area, the application of research via the university, the educational design of the Carter Field site, and the sites development plan as a public-private partnership. In addition to the CWSRF, the team recognized a number of grants for further consideration and their potential value below.

Table 4: Potential Grants

Grant	Organization	Fund Amount
Five Star and Urban Waters Restoration Grant Program	National Fish and Wildlife Foundation	avg. $30,000
Hurricane Sandy Coastal Resiliency Competitive Grant Program	National Fish and Wildlife Foundation	avg. $2 Million
Community Impact Fund- Environmental	Nicholas B Ottaway Foundation	$3,000-20,000
Massachusetts Environmental Trust	Massachusetts EEA	Varies
319 Grant program	Environmental Protection Agency	Total $158.20 Million

Community Value

As a goal to expand the social value of our site, the design team specifically included observation decks for viewing the on-site BMPs and made a conscious effort to create space for both recreational and social events. Space between the tennis courts and field was designed to allow access via the emergency access road, allowing food trucks and local vendors to establish a comfortable location from which to sell their goods to the local community.

Cost Summary

Below combination of Water Environment Research Foundation: Whole Life Cost Model tools, RS Means, and 3rd party price quotes were used to estimate the expected capital and operation and maintenance costs for the Northeastern University design. The design team only calculated costs implicit to the design; excluding previously assumed costs associated with current Northeastern plans i.e. turf field, on-site impervious paving, tennis courts, etc.

Table 1 Cost Estimates

	Unit Cost	Installation Cost	O&M Avg Annual	O&M (50yrs)	Quantity	Total Capital Cost	Source
Bioretention Pond 1	$ 13,000.00	Included	$ 1,871.14	$ 93,557.00	1	$ 13,000.00	WERC
Bioretention Pond 2	$ 11,250.00	Included	$ 1,236.00	$ 61,800.00	1	$ 11,250.00	WERC
Oil/Grit Seperators	$ 23,000.00	$ 3,750.00			6	$ 160,500.00	RS Means
Rain Garden	$ 371,883.49	Included	$ 25,488.79	$ 1,274,439.69	1	$ 371,883.49	WERC
Cisterns	$ 50,200.00	$ 30,000.00			2	$ 160,400.00	WERC
Infitration galleries Pre-Cast	$ 1,000.00				16	$ 16,000.00	RS Means
Oil Grit Seperator Grading	$ 360.00	$ 1.22			6	$ 2,167.32	RS Means
Pipes from Pipes Summary	$ 59,086.00	Included			1	$ 59,086.00	RS Means
Permeable Paver-asphalt	$ 7,460.00	Included	$ 353.74	$ 17,687.00	1	$ 7,460.00	WERC
Boardwalk Planks	$ 10.17				4084	$ 41,534.28	Home Depot
Smart System	$ 15,000.00	Included			1	$ 15,000.00	OptiRTC
Butterfly Valves, Distributed Control 8"	$ 1,306.00	Included			4	$ 5,224.00	RS Means
Soil Moisture Sensor	$ 200.00	Included			15	$ 3,000.00	rainbird
Deep Sump Catch Basin (including Manhole Cover)	$ 2,835.00				7	$ 19,845.00	RS Means
Total			$ 54,438.47	$ 2,721,923.39		$ 886,478.48	

Conclusion

Ultimately, a collaborative decision was achieved with a focus on both the social landscaping and the stormwater management components of the redesign. Seeking out the site's full hydrologic potential (given known parameters), we also simultaneously provided a space for a variety of important recreational and social events and restored legibility to a neglected stretch of an alternative travel corridor into the heart of our city. The implications of stormwater management as a future concern for the City of Boston, given the unknown impacts of a changing climate, led the team towards a conscious effort to reflect the increase of even more intense weather events. This is reflected in our decision to model the site's management of 100-year and even 500-year storm events.

Additionally, the integration of technology allows for the monitoring and intelligent allocation of natural resources through on-site water infrastructure. This unique design not only maintains the integrity of the site as an athletic facility, but it also increases the productivity. Our proposal allows the site to generate value to the university, in the form of water harvest for irrigation, and embodies a deliberate recognition of the site as a valuable asset to one of the university's largest stakeholders: the Boston community. This constant collection of data will provide invaluable information to the University; in both its function as a research institution and its function as a facility. The increase of onsite biodiversity and flora throughout the rain gardens and bioretention ponds on-site demonstrates the previously illegible potential of the Carter Field Area.

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