Team M5
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Abstract

As a submission to the United States Environmental Protection Agency 2016 Campus RainWorks Challenge, a team of The City College of New York students in the Environmental Engineering, Advertising, and Landscape Architecture programs has designed a master plan for green infrastructure and stormwater management on the City College of New York (CCNY) Campus. Titled the "Castor Project" (CP), the design presents a climate-informed, optimized system for campus-wide stormwater management. The CP gives options to reduce stormwater runoff between 10% to 20% during a five-year 24-hour rain event, and increases permeable area from 8% to between 9-10%. The CP includes an educational component to teach college and high school students about stormwater and water conservation. This plan signifies a step forward in improving stormwater management for New York City, and campus sustainability for CCNY.

I. Introduction

Population growth and climate change are two major themes of civilization in the twenty-first century. Central to these themes is water. As populations — especially urban populations — grow, their demand for clean water increases. Additionally, climate change threatens to increase the frequency and severity of rain- and snowstorms in certain regions of the world. This storm intensification will increase the amount of stormwater generated per storm, threatening a host of problems that excess stormwater can cause.

While population growth and water issues may be most severe in areas of the developing world, the developed world is not immune. The United States must confront these phenomena too. As part of the US' response to these problems, the United States Environmental Protection Agency (USEPA) has posed the Campus RainWorks Challenge (CRWC). An annual challenge for the past four years, the CRWC is intended to involve university students in "reinventing [the US'] water infrastructure." The 2016 CRWC challenges teams of university students to design, propose, and present a plan that uses green infrastructure to reinvent their campus' water infrastructure, with a focus on stormwater management systems.

For much of the urban Northeast United States, including the greater New York City (NYC) area, both historical observations and General Circulation Models (GCM) generally show a trend towards warmer temperatures and more intense precipitation (NYSERDA 2011; Karl, et al. 2006). NYC is likely to experience more extreme rain- and snowstorms, both of which will create more stormwater for city infrastructure to handle. As NYC has predominantly combined sewer systems (CSS's), more stormwater per storm increases the risk of combined sewer overflows (CSO's). Thus, NYC needs to reduce the amount of stormwater that enters the city's CSS's.

This paper presents "Castor Project," (CP) a submission to the 2016 CRWC conceived and designed by an interdisciplinary team of university students at the City College of New York (CCNY). The primary goal of the CCNY CP is to use green infrastructure to reduce the amount of stormwater reaching CSS's via catch basins on CCNY's campus. Additional goals include educating and reaching out to both high school and university students about sustainability, green infrastructure and design, and other environmental issues and challenges.

II. Campus Description

The CCNY Campus is traditionally split into two sections: North and South Campus. For the CP, we chose to focus on North Campus, because it has significantly less permeable area and older buildings than South Campus, and because South Campus was recently renovated. From now on, we refer to North Campus as "the Campus." The Campus consists of buildings either side of 5-block stretch of the campus' main thoroughfare, Convent Ave. The main thoroughfare is closed to public vehicular traffic during weekdays, and is primarily served by pedestrians. South from the northern border of the Campus is a high elevation point on Convent, causing water to flow either North or South from there.

The Campus houses several neo-Gothic buildings built in the early 20th century; the North Academic Center (NAC); Steinman Hall (the engineering building); the Marshak Science Building; and the administration building. The Campus contains a marginal amount of greenspace – 8% of total area – mostly consisting of a grassy, terraced quadrangle located between the neo-Gothic buildings.

The United States Geological Survey (USGS) classifies roughly half the campus's soil as Urban land with slopes between 3 and 15 percent, and the other as Urban Land-Greenbelt complex with slopes of 3 to 8 percent. These soil types are considered totally impermeable, so the CP focuses on increasing surface permeability to promote infiltration, increasing evapotranspiration via new plants, and capturing water using storage tanks.

Image 1: A post-storm puddle of stormwater on Convent Avenue.

III. Project Overview

The design process of the CP consists of:

1. Climate-informed precipitation excess modelling and future simulations.
2. An integer programming optimization model to select most efficient design elements at lowest cost while meeting all design constraints.
3. The combination of (1) and (2) into a final design, with an added educational and outreach component.
4. A survey of the CCNY student-body, to measure student interest in the plan, and the willingness to pay for the proposed green infrastructure.

IV. Likely Government Support

Similar projects to the CP have been undertaken by the NYC municipal government. Two prominent examples are the city's Green Infrastructure (GI) Program and Stormwater Management Plan (SWMP).

The goal of the GI Program is for the NYC DEP and agency partners to "design, construct and maintain a variety of sustainable green infrastructure practices ... on city owned property such as streets, sidewalks, schools, and public housing."

The City's SWMP follows from a citywide MS4 permit that the New York State Department of Environmental Conservation (DEC) received under the Clean Water Act in 2015. According to the NYC DEP, the permit's intent is "to manage urban sources of stormwater runoff to protect and improve receiving body water quality." The CP incorporates elements of the SWMP into its education and outreach components.

The CP has similar goals as and fits into both governmental projects. Given that the CP is built within NYCDEP and NYC Department of Buildings (NYCDOB) standards; that our methodology is systematic and cost-efficient; and the innovative designs included in the project, the CP is likely to be supported by both the NYCDEP and CCNY.

V. The Castor Project

V.1 A Climate-Resilient Design

A successful plan for stormwater management infrastructure must be climate resilient: the plan should be able to operate despite changes in environmental conditions due to changing climate. So, a climate study was done to ensure the Castor Project's resilience to changing climate.

Historical observations from Central Park, the nearest weather station to CCNY (two miles away), show that the 5-year return period storm is 2.2 inches of rain in a day. However, the CP looks past the traditional framework of designing for historically observed rain events, and incorporates climate-informed simulations of future weather into its analysis.

Our team developed a climate-informed stochastic weather generator to identify future stormwater management needs. We started by using a two-state Hidden Markov Model (HMM) to identify trends in annual-scale precipitation. We then fit state-specific Generalized Linear Models (GLM) for precipitation occurrence and intensity. The GLMs were fit using observed climate/regional atmospheric predictors, so the weather-generators were climate-linked, allowing us to generate future extreme events. We then ran the weather-generator 1000 times to simulate new 5-year return period values and to identify the risk of failure for a variety of future scenarios. The climate model is schematized in **Figure 1**. Ultimately, the simulations led to an increase of 6% in design storm intensity (**Table 1**).

Figure 1: Schematic of the Climate-Informed Stochastic Simulator

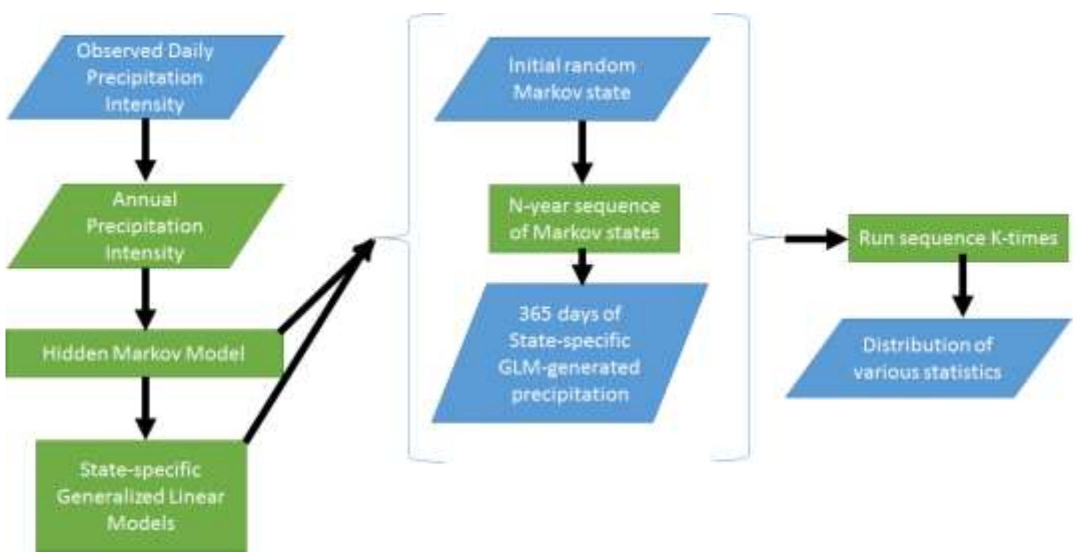


Table 1: Intensity of five-year design storm, historical vs. climate-informed.

	Observed Precipitation Intensity (in/day)	Simulated Future Precipitation Intensity (in/day)
Precipitation (in/day)	2.2	2.34
Effective Precipitation (in/day)	2.03	2.16

By considering these simulated 5-year return period events, the CP is resilient to future climate scenarios. **In addition to benefiting CCNY, this climate informed resiliency model sets the CP apart from other, previous Campus RainWorks entries.**

To calculate the total volume of runoff on campus during a rain event, we use the traditional National Resources Conservation Service (NRCS) Curve Number method to find runoff (Chow, 1988). The NRCS method approximates the initial abstraction of precipitation due to infiltration, pooling, and evapotranspiration, by using a ratio-method dependent on the land cover characteristics of a parcel of land. The remainder of the precipitation is deemed "effective," that is, turned into runoff.

The CP is designed using a modified version of the NRCS method, based on a 2006 study that found that urban watersheds had significantly lower abstraction ratios (Lim). We surveyed and classified the campus, finding a Composite Curve Number (CCN) of 96. This calculation gave the effective runoff values given in the previous table. Thus, we aim to control a percentage of the 2.03 inches of effective precipitation.

V.2 Optimizing Design Selection

The heart of the Castor Project is a systematic approach to implementing green infrastructure on CCNY's campus. The selection of green infrastructure elements and their locations was achieved via an integer programming optimization model. See **Table 2** for descriptions of the design elements considered. The model was designed to minimize the cost of the entire plan while meeting constraints on a minimum volumetric water reduction, a minimum permeable area increase, and other design goals.

To preserve ecological and aesthetic value, we did not consider designing individual bioswales. We instead calculated the design cost of a single bioswale, and then considered sections of bioswales along the main campus thoroughfare.

A basic element of the model is the desired amount of volumetric stormwater reduction on campus: 10, 15, or 20%. A fractional coefficient of total daily volume of flow during a 5-year daily rain event was set as a minimum capture constraint, and then cost-minimized for several volumetric runoffs. The model is designed to increase permeable area by at least 15%. A schematic of the model is shown in **Figure 2**. This chart essentially outlines the workflow of the entire design process.

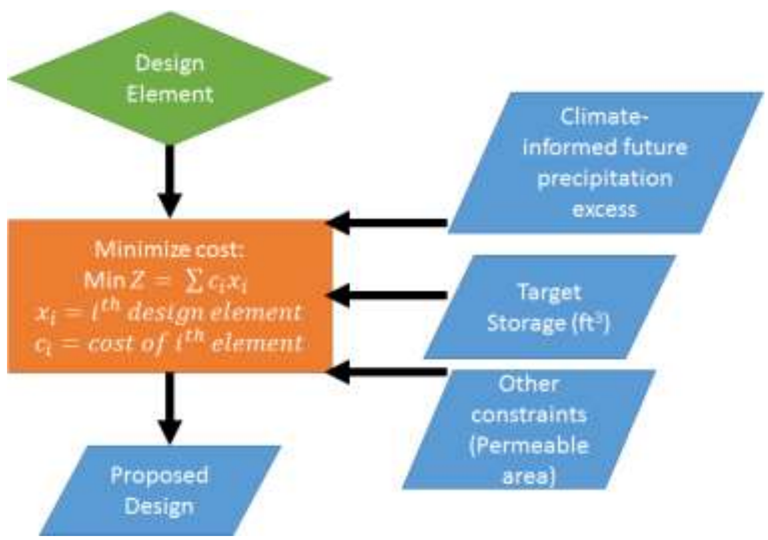


Figure 2: Schematic of the optimization model used to select design elements.

Table 2: List and description of design elements considered for implementation

<table>
<tr><th>Element</th><th>Description</th><th>Details</th><th>Location</th></tr>
<tr><td>Bioswales</td><td>10’x5’
Right of Way (ROW)
Type 3A
No connection to sewers
Unit cost: ~$2,600</td><td>Placed in groups, to maximize capture along the largest runoff corridor on campus, Convent Avenue.</td><td><table><tr><td>Convent Ave.</td></tr><tr><td>Upper (North)</td></tr><tr><td>Middle</td></tr><tr><td>Lower (South)</td></tr></table></td></tr>
<tr><td>Storage Tanks</td><td>Manufacturer: Highland Tank
Model: Aboveground Vertical HighDRO®
Storage capacity: 3,252 ft^3
Unit cost: ~$40,000</td><td>Fed by building scuppers & gutters.
Pump to remove built-up rainwater (to allow for irrigation use.)
Filtration system to preserve pump life.</td><td>Administration building
Marshak
Shepard Hall
Harris Hall</td></tr>
<tr><td>Marshak Greenroof</td><td>Can store up to 1” of precipitation
Maximum: 31500 ft2</td><td>Sedums and shallow rooted vegetation</td><td>Marshak</td></tr>
<tr><td>NAC Greenroof</td><td>Can store up to 2” of precipitation
Maximum: 8800 ft2</td><td>Sedums and shallow rooted vegetation</td><td>NAC roof</td></tr>
<tr><td>NAC Parking Lot Redesign</td><td>A 45,000ft2 sloped parking lot, with room for capture</td><td>Trees + Bioswales</td><td>NAC parking lot</td></tr>
<tr><td>NAC “Ramp” Redesign</td><td>Replace paved slope walkway with diverse planting</td><td>Seating available</td><td>NAC ramp</td></tr>
</table>

V.3 Final Design

The Castor Project presents three choices for implementation by CCNY. The choices are based on the desired reduction of total flow: 10% (mild), 15% (moderate), and 20% (severe). Note that each increase in severity includes the design elements from the previous scenario.

The mild scenario consists of two storage tanks and the redesign of the NAC ramp. This scenario meets the NYCDEP stormwater reduction requirements, and is thus sufficient to address stormwater needs on campus. The recommended course of action is to first implement the mild scenario, then re-evaluate precipitation patterns after five-years, and adjust implementation accordingly. The moderate scenario adds two more storage tanks and 3854 out of 4,988ft^2 of the NAC green roof. Finally, the severe scenario adds an additional 1,134ft^2 of the NAC green roof, and groups of bioswales on the upper and lower sections of Convent.

Table 3: Final Choice of Design Elements.

Plan Severity	Minimum Volumetric Runoff Reduction	Cost	Volume Stored (ft^3)	Design Elements	New Permeable Area (ft^2)
Mild	10%	$479,000	20,405	• Two Storage Tanks • NAC Ramp	15,444
Moderate	15%	$615, 810	27,552	• 10% Design Elements • Two Storage Tanks • Total NAC Green Roof: 3854 ft^2	19,298
Severe	20%	$1,036,139	37,203	• 10 + 15% Design Elements • Additional NAC Green Roof: 1,134 ft^2 • Lower Bioswales • Upper Bioswales	22,282

We summarize the basic benefits of each scenario in **Table 3**. A more thorough list of final design outcomes is presented in **Table 4**. The CP also has **offers several non-tangible benefits**, such as reduced costs from CSO penalties, improving campus sustainability, and restoring native species.

Table 4: Final design outcomes *for mild scenario.*

Metric	Value
Reduction in impervious (sq. ft.)	15444
Reduction in runoff depth from existing conditions (design storm)	5%
Reduction in potable water use for indoor uses (MGallons/yr); ($/yr)	0.75; $3700
Area of protected soils (sq. ft.)	22,282
Area of restored soils (sq. ft.)	22,282
Area of protected native plant communities (sq. ft.)	22,282
Area of restored native plant communities (sq. ft.)	22,282
Increase in canopy cover (10 years after installation) (% of site area)	8%
Increase in roof area shaded by vegetation (% of roof area)	20%
Increase in hardscape area (roads, sidewalks, parking lots, courtyards) shaded by vegetation (% of hardscape area)	2%
Carbon dioxide (CO2) sequestered by new trees (lb./year)	50000
Change in plant diversity	17 new native species

V.4 Outreach and Education

A key component of the CP is an education and public outreach program. We propose working with two on-campus high schools (the High School for Math, Science and Engineering & the A. Philip Randolph Campus High School) to design and conduct educational workshops for students to learn about urban stormwater management, green infrastructure, and water conservation. Through these workshops students will learn how to conserve water, care for their natural environment, and become ecologically and environmentally engaged and concerned citizens in the 21st century.

We also recognize the need to show the value of the natural ecological systems present on the CCNY campus. We have identified the presence of a creek running underneath and across part of the campus. The plan calls for highlighting the presence of this creek by placing signage and planting native species along the historical streambed. Additionally, the CP calls for the unique native species on campus to be labelled with species name, brief description of natural history, ecological value, and botanical interest.

Through these measures, the CP will not only improve the stormwater management infrastructure of and add green infrastructure to CCNY's campus, but will also benefit the community surrounding and inhabiting the campus.

V.5 Student Support and Engagement

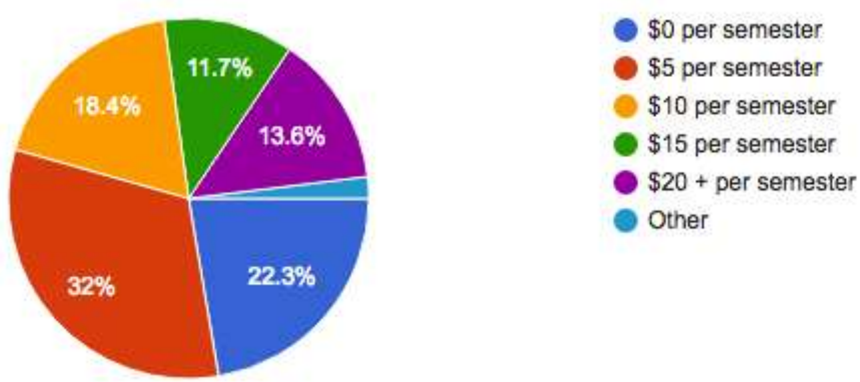
The choice to implement the Castor Project will be made by a mixture of governmental bodies both within and outside of CCNY. Within the school, administrative and student governments will determine CCNY's choice. To effectively gauge student support, the design team surveyed students on campus for their knowledge of Campus water supply and stormwater management, their willingness-to-pay for upgrades, and their support for student-led initiatives.

The highlight of the results is that the majority (≥75%) of 103 total respondents:

1) Believe that CCNY should implement sustainable water usage on campus.
2) Think that student run, on-campus environmental initiatives are effective.
3) Would be willing to pay to help fund sustainable water usage on campus.

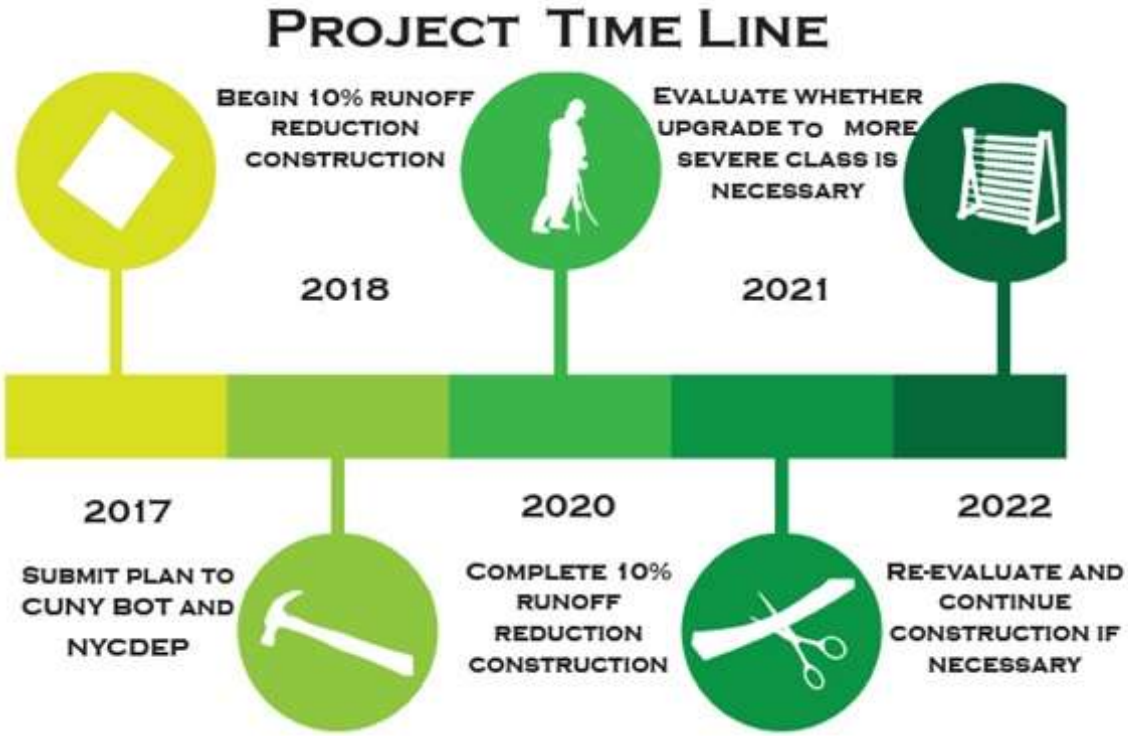
Based on these responses, it is likely that the CCNY student body would support and fund the CP. We also found that while the majority (60-80%) of students were familiar with green roofs, low-flow toilets, and sewage overflows, 65% of students were unfamiliar with greywater systems which could be implemented to reduce potable water usage. This result, coupled with 7 out of 10 students not knowing about CCNY's water supply, suggested that we should incorporate information about the New York City water supply and its management; water conservation; and the maintenance of clean waterways into the educational component of the CP.

Figure 3: How much are students willing to pay for sustainable infrastructure?



VI. Implementation Timeline

The CP is set to be implemented over the initial course of the SWMP and to continue after the completion of the SWMP. We begin with a formal review of the CP by various city agencies including the City University of New York Board of Trustees and the NYCDEP, and go onto a timeline for design implementation and reevaluation.



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EFFECTIVE RAINFALL CALCULATION

Calculations for an effective rainfall by the NRCS method are done as follows:

We define P as observed precipitation, P_e as effective precipitation, CN as the Curve Number, $S_{.20}$ as potential maximum soil moisture retention after runoff begins (20% model), $S_{.05}$ as the 5% approximation S given by the 2006 Lim study, AMC as the antecedent moisture class, and I_a as the initial abstraction. The AMC is the antecedent moisture class dependent on the cumulative sum of the preceding five day's precipitation, with 3 possible values, AMC II being "normal", as shown in Chow's, 1988 text, where P_5 is the antecedent five-day precipitation total. The CN is then modified by the AMC during that time-step, as shown in equations below where CN(II) is the "normal" curve number.

$$AMC = \begin{cases} I & for \quad P_5 < 0.5 \\ II & for \quad 0.5 \le P_5 \le 1.1 \\ III & for \quad 1.1 < P_5 \end{cases} \tag{1}$$

$$CN = \begin{cases} \frac{4.2CN(II)}{10-0.058CN(II)} & for \quad AMC\ I \\ CN(II) & for \quad AMC\ II \\ \frac{23CN(II)}{10+0.13CN(II)} & for \quad AMC\ III \end{cases} \tag{2}$$

We then find S_{20} as a function of CN, given by (3), taking the appropriate CN value.

$$S_{.20} = \frac{1000}{CN} - 10 \tag{3}$$

We then convert S_{20} to S_5 using a power relationship between the two.

$$S_{.05} = 1.33 * S_{0.20}^{1.15} \tag{4}$$

The initial abstraction is taken as a fraction of S. We use the 5% value posited by Lim et al.

$$I_a = 0.05 * S_{.05} \tag{5}$$

We then conclude by finding P_e using **(6)**.

$$P_e = \begin{cases} 0 & for\ P \le I_a \\ \frac{(P - .05S_{.05})^2}{P+0.95S_{.05}} & for\ P > I_a \end{cases} \tag{6}$$