Team PreciPITTation: Addressing Our Urban Campus Stormwater Needs

The University of Pittsburgh
Team Registration Number: M35

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Abstract:

The University of Pittsburgh Oakland Campus (Pitt) offers a diverse urban terrain ideal for the planning and implementation of sustainable stormwater management practices. Without such planning our campus will continue to face increasing precipitation events, a worsening of the region's combined sewer overflow problem (CSO), and stagnation in reaching campus sustainability goals set forth by the 2018 Pitt Sustainability Plan [15]. Our team extensively considered a multitude of University planning documents such as the 2019 Pitt Institutional Master Plan draft (IMP) [11]. This COVID-19 pandemic has shown us as a country we need more quality outdoor areas and greenspace as people have flocked to these locations as a means of relief. In order to promote and complete goals like impervious to pervious diversion, increases in urban canopy, increased water conservation, reduction in campus contribution to CSOs, and many others we've identified key campus solutions. These solutions include an initial phase of demonstration Gray water storage retrofits designed to catch rainfall from rooftops providing the benefit of a pervious surface, but also introducing water reuse to water-dependent buildings. Further, we established standardized tree pit specs. with stormwater built into the design allowing for consistency in design and stormwater capture across campus. Finally, we took an in-depth look at three particular sites with unique campus features making large scale conversions to Green Infrastructure (GI) or Low Impact Development (LID) while exemplifying campus themes and aspirations represented in the IMP. Working in tandem with Pitt Facilities Management, the Office of Sustainability and a number of other campus organizations

we are certain our proposed GI and LID solutions can serve to inspire a regional effort to mobilize in order to fight our region's current water issues.

1. Background

The University of Pittsburgh, Oakland campus, was established in 1787 just outside the City of Pittsburgh, Pennsylvania (**Figure 1**). This 145-acre urban campus traverses' diverse topography, geology, and within an extensive network of city sewer system with over 4,100-miles of subterranean pipes [2]. Water is a central motif and resource to our region, as the city itself is located at the confluence of three large rivers: the Allegheny, Monongahela, and Ohio. These rivers are essential to the entire Allegheny County area as 90% of residents pull drinking water from the city's three rivers [1]. However, like many older urban centers around the country, Pittsburgh's water infrastructure is over a century old and deteriorated, unable to meet current and projected needs as climate change alters our region's precipitation patterns. Most urgent is our need for updated stormwater management. Currently, nearly two-thirds of Allegheny County's municipalities have their sewage and stormwater flows treated by the Allegheny County Sanitary Authority (ALCOSAN) and its 59-acre treatment plant [7]. Additionally, Pittsburgh is dominated by a combined sewer system responsible for transporting stormwater and wastewater to the ALCOSAN treatment facility. The sewer capacity is reached at around 0.1 inches of rain [14]. With the average Pittsburgh rainfall event depositing 0.25 inches, the system's limitations are a large source of nutrients, pathogens, and contaminants which are extensively linked to health risks and fish kills downstream. The system discharges over 9 billion gallons of sewer overflow per year into the surrounding rivers as Combined Sewer Overflow (CSOs) and the estimated cost to refit the Pittsburgh system to prevent such discharge is between $2 and $3.6 billion [21]. In response to noncompliance under the Clean Water Act, the Environmental Protection Agency (EPA) in 2008 declared a consent decree for the city to solve its sewage overflow issues [3].

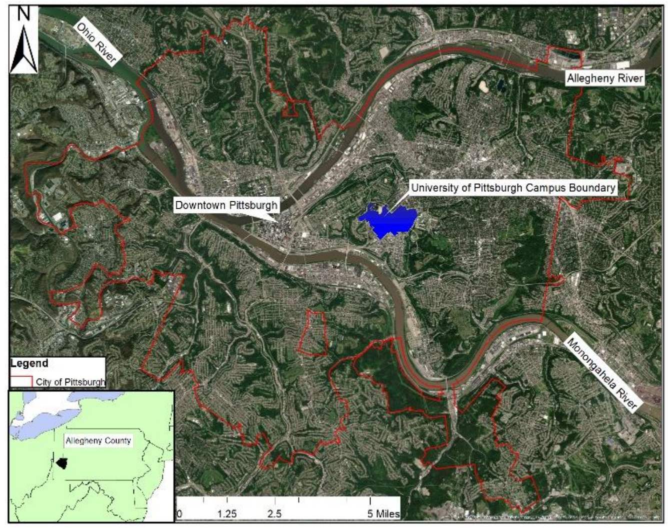

Figure 1: *Inset map of the Oakland campus as it resides in the City of Pittsburgh which resides in Allegheny County represented in black within the Pennsylvania State Boundary.*

2. Introduction

The University of Pittsburgh resides just east of the downtown Pittsburgh area. Surrounded on all sides by diverse topography, businesses, and residential areas, this world-renowned research institution offers a unique landscape laboratory for its students. However, in such a diverse area the effects of climate change and aging infrastructure are prominent with precipitation events exceeding past averages further overloading campus infrastructure (**Figure 2**). In fact, in 2020 alone, the average City of Pittsburgh household paid an average of $3,579.00 in flood damage repair [12]. With future projections in the region of increased precipitation intensity, we can expect rising costs and damage. The goal of this project is to employ a suite of Green Infrastructure (GI) and Low Impact Development (LID) projects including standardized stormwater tree pits across campus, increased canopy for rainfall interception and slope stabilization, and stormwater capture focused bioswale, rain garden, and gray water systems to reduce CSOs and increase water conservation. This master plan adaptation incorporates the targets of the Pitt Sustainability Plan [15], 2019 Pitt Institutional Master Plan Draft (IMP) [11], ALCOSAN Clean Water Plan [6], and PWSA Green First Plan [17] proposals, and ensured the IMP was at the heart of our adaptations to the plan while conserving the themes and goals the University set forth. The following goals and themes are central to our proposed effort:

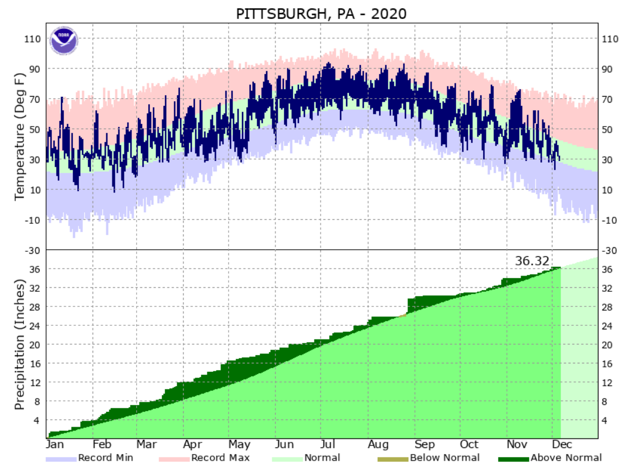

***Figure 2**: National Weather Service Climate Graph of Pittsburgh temperature and precipitation for 2020. This further emphasizes above normal precipitation events becomming the new norm.*

- Work with the City to ensure clean, healthy drinking water for all in our community.
- Adhere to Pitt's Sustainable Landscape Guidelines in all new landscape designs [8].
- Reduce Campus impervious surfaces by 20% by 2030 from the 2017 baseline.
- Divert 25% of stormwater from remaining impervious surfaces to rain gardens, bioswales, or rainwater harvesting tanks by 2030.
- Increase tree canopy by 50% and replace 15% of lawn area with native and adapted plants by 2030 from the 2017 baseline.
- Strive towards a water neutral campus, with a 3% reduction in water use.
- Embrace the District goals of 50% reduction below the district average in water use intensity (consumption per square foot) by 2030 and establish design standards and operational practices to achieve them.

In addition to these planning documents, we considered general campus attitudes towards sustainability at Pitt to incorporate as many themes in our adaptations as possible. After reviewing the results of the 2020 Pitt Sustainability Literacy and Culture Survey (**Figure 3**) we learned that Faculty, Students, Staff, and others part of the Pitt community were most interested in enabling and promoting sustainable behavior, integrating sustainability into student/residential life, and encouraging projects that benefit our communities. To center these ideas and address campus needs our team developed three focal themes: (**1**) Reduce campus contribution to CSOs (**2**) Centralize stormwater runoff and pollution capture (**3**) Establish greenspace and increase campus connectivity.

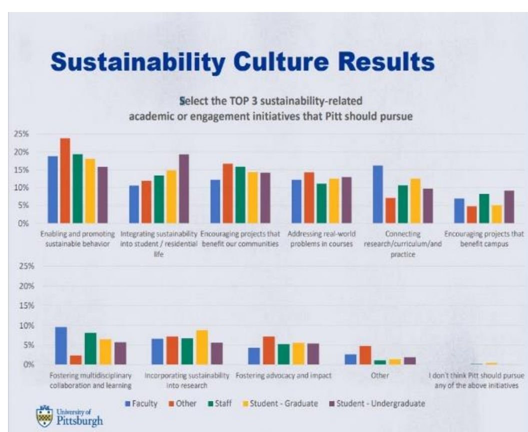

***Figure 3:** Snippet from the Sustainability Culture Survey Results providing our team with an understanding of faculty, other, staff, and students top 3 desired Sustainability*

Lastly, our team worked closely with the Pitt Facilities Management department to analyze campus utility data, allowing access to visualize the subterranean network of sewer inflows and outflows. Further collaboration with the Office of Sustainability, Mascaro Center for Sustainable Innovation, Campus Tree Advisory Committee, Campus Pollinator Habitat Advisory Committee, and other campus laboratories focused on urban interactions ensured a vested interest and comprehensive approach to our campus master plan adaptations.

3. Site Conditions and Challenges

Our campus is a uniquely urban and fragmented setting. Covering over 145 acres of University-owned buildings and landscape, the campus also directly influences the environment around it, i.e., the Educational/Medical Institution District or EMI District [11]. This area is significantly influenced by our campus and represents about 380 additional acres that Pitt is responsible for considering during the master planning process under Zoning Code 905.03.C. Our adaptations take the EMI district into consideration and benefit the entire basin area by diverting and capturing stormwater.

3.1.1 Classifying Sewersheds and CSOs

Within the IMP's environmental study area boundary, there are four designated sewersheds that considerably overlap the university: M-19, M-19A, M-19B (form the Soho Run sewershed), and M-29 (Junction Hollow sewershed). All are served by combined sewer systems, classified as priority sewersheds, and are connected to outfalls along the Monongahela's north bank. As only M-19A and M-29 occupy a significant portion of campus and contain nearly all of our proposed GI, they are our main target for reduced runoff contributions. By reducing the volume of campus-derived runoff entering these sewersheds, the University of Pittsburgh can contribute to the mitigation of CSOs into the Monongahela (**Figure 4**) Present-day M-19A and M-29 runoff contributions are quantified below in Table 1. To determine the effectiveness of our proposed GI in mitigating CSOs, existing and post GI-installation runoff contributions are needed for comparison. The environmental study area is used to determine campus-derived contributions to these sewersheds as its boundaries reflect the general extent of campus. Furthermore, all of our prosed GI lie within its boundaries.

Figure 4: *Display of Sewersheds significantly overlapping the University of Pittsburgh. Overlapping sewersheds are all combined and have outfalls along. the Monongahela River.*

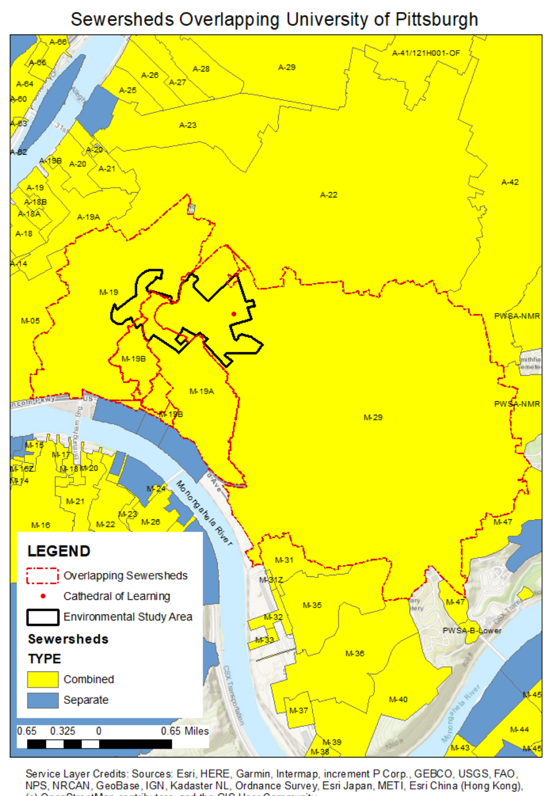

Table 1. Existing characteristics of M-19A and M-29 CSO contributions. MG = million gallons.
Note. Data are from PWSA (2020)[16] and Stormwater[19].

Sewershed	Typical Year Overflow Volume (MG)	Number of Typical Year Events	Typical Year Discharge Duration (hours)	Average Impervious Area Annual Runoff (MG/Impervious Acre)	Average Pervious Annual Runoff (MG/Pervious Acre)	Area (Acres)
M-19A	83.5	57	296	0.85	0.007774	249.56
M-29	402.0	54	467	0.7	0.00265	2377.83

The environmental study area covers 177.4 acres, which excludes public streets [11]. Including public streets, it covers 356 acres. Campus-owned land within M-19A consists of approximately 35.0 impervious acres and 14.6 pervious acres. Within M-29, campus-owned land consists of approximately 52.9 impervious acres 45.3 pervious acres. **Figure 5** displays existing impervious and pervious coverage within the sewersheds (bordered in pink). Using the average annual runoffs per impervious and pervious acre provided by the PWSA for the two sewersheds, a rough estimate of their typical annual runoff can be made:

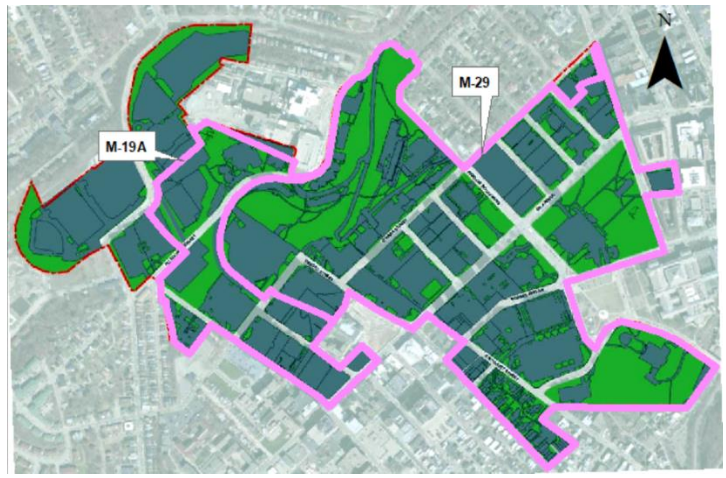

***Figure 5**: Impervious and pervious areas within M-19A and M-29 sewersheds that overlap campus.*

M-19A (0.85 MG/Impervious Acre × 35.0 acres) + (0.007774 MG/Pervious Acre × 14.6 acres) = 29.9 MG/year

M-29 (0.7 MG/Impervious Acre × 52.9 acres) + (0.00265 MG/Pervious Acre × 45.3 acres) = 37.2 MG/year

In summation, existing campus-derived runoff contributions to the M-19A and M-29 sewersheds are approximately 67.1 MG/year. According to the PWSA, M-19A receives an annual wet weather volume of 318.2 MG and M-29 receives 1426.3 MG. Therefore, the University of Pittsburgh campus currently contributes 9.4% of M-19A's annual runoff volume and 2.6% of M-29's[15]. In accordance with the EPA's CSO control policy, the PWSA has set the goal of capturing 85% of sewage and stormwater within CSSs. Currently, M-19A captures 73.7% and M-29 captures 71.8%. Therefore, the goal of our project is to increase the capture-capacity of campus-derived runoff within the sewersheds M-19A and M-29 in order to contribute to an approach of 85% capture.

3.1.2 Pre-existing Runoff Conditions for Zones of Grounded GI Implementation

The size, urban complexity, and location of campus within M-19A and M-29 make it difficult to assess runoff contributions (figure #). Also, the zones of the proposed GI are relatively small, varied in size, and isolated from each other. However, there are a few assumptions that can be made to simplify the estimation of runoff derived from our three zones of grounded GI that will still allow their post-implementation effectiveness to be compared to current conditions.

First, the Hillside zone is bounded by a boundary of M-29 and is on top of a hill (**Figure 6**); therefore, its maximum potential runoff is equal to directly received precipitation. Second, the Towers zone and proposed GI occupy an elevated surface; therefore, its maximum potential runoff is equal to directly received precipitation. Third, the Sutherland Drive zone is positioned on the divide of the M-19A and M-29 sewersheds. Any potential runoff is assumed as originating from the portion of the sewersheds at equal or higher elevations of the zone. Lastly, all areas are assumed impervious in order to determine maximum potential runoff.

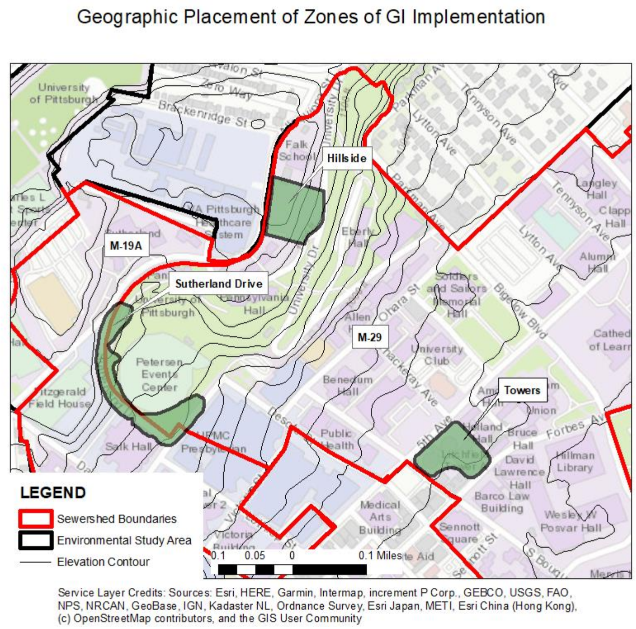

Figure 6*: Geographic position of grounded zones of GI infrastructure where runoff contributions must be considered from outside their area.*

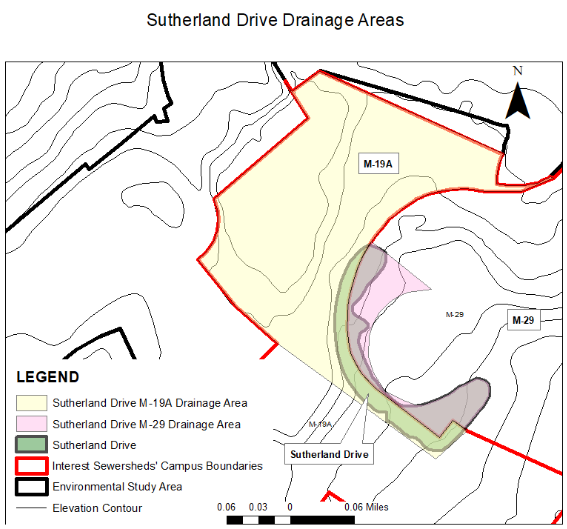

Figure 7*: Drainage areas outside the Sutherland Drive zone with potential to contribute runoff into it must be considered in assessing its potential inputs.*

Thus, runoff from outside drainage areas must only be accounted for in the Sutherland Drive zone. Its drainage areas within M-19A and M-29 are shown in **Figure 7**. The drainage areas are derived as portions of M-19A and M-29 at equal or higher elevations of the Sutherland zone and within any definitive boundaries. The M-19A drainage area is approximately 26 acres, and the M-29 is approximately 4 acres. The sum of the two drainage areas is 30 acres. The Hillside and Towers zones measure 3.4 and 2.9 acres, respectively. Using the areas of the Hillside and Towers zones, as well as those of the Sutherland zone, as an estimation of each zones' maximum potential runoff can be made using average annual precipitation:

Hillside 38.19 in/yr x (2.13x10^7 in^2) = 8.13 x 10^8 in^3/yr = 3,520,000 gallons/yr

Towers 38.19 in/yr x (1.82x10^7 in^2) = 6.95 x 10^8 in^3/yr = 3,000,000 gallons/yr

Sutherland 38.19 in/yr x (1.88x10^8 in^2) = 7.18 x 10^9 in^3/yr = 31,100,000 gallons/yr

Table 2. Maximum potential runoff attributed to the three zones of grounded GI.

Zone	Maximum Potential Runoff (MG/yr)
Hillside	3.52
Towers	3.00
Sutherland Drive	31.1
Total	**37.6**

3.2 Geology and Topography

The Pittsburgh area is well known for its historical reliance on mineral resources like coal, oil, natural gas, and its extensive steel industry [10]. Part of the Appalachian Plateau Province, Pittsburgh resides on top of mostly sedimentary strata consisting of sandstone, shale, mudstone, and coal. Additionally, Pitt is located in hilly terrain, with almost 400 feet of elevation change between the highest and lowest points on campus [11]. Taking all these factors into consideration the Pitt IMP identifies an Environmental Study Area and superimposes such variables like a steep slope classification, landslide risk area, and undermined areas [11]. When considering adaptations and site design these variables are accounted for and campuswide efforts to stabilize slopes and reduce the risk of landslides were centralized.

3.3 The Urban Landscape and Connectivity

Figure 8: IMP Snapshot of the North-South Braid representing a campswide initiative to increase connectivity.

As an urban campus, Pitt has two main "braids", North-South (**Figure 8**) and East-West, that link residential and student services as well as synergies among teaching, research, and innovation. The IMP heavily emphasizes connectivity throughout campus and our team worked to strengthen such pathways by incorporating our adaptations to the campus "greenribbon". The greenribbon[9] connects students with local greenspaces, most notably Schenley Park. Thus, it is central to our project to prioritize such connections and was the foundation of our planning process. The three main areas outlined in the Adaptive solutions section address the challenges identified above and provide unique solutions that can be applied throughout campus.

4. Adaptive Solutions

Pilot studies of the Pittsburgh and greater Allegheny County area suggest the best approach to stormwater mitigation is a combined "Green and Gray" strategy [20]. This practice unites cost-effectiveness and incorporates the triple bottom line benefits of green infrastructure. To maintain consistency with regional efforts justifications for GI decisions, this project also combines green and gray infrastructure. Additionally, our team utilized the initial broad study on Best Management Practice GI included in the Pitt IMP on future development areas. Guided by these two criteria we specified a general campuswide implementation of GI and LID that can be developed within the IMP 10-year and 25-year framework. These general campuswide implementations are outlined below:

4.1 Campuswide Implementation

According to the Pitt IMP 63% or 112 acres, of our campus is impervious, leaving only 37% or 65.4 acres pervious within the environmental study area [11]. With increasing urbanization, it is progressively more difficult to convert land from impervious to pervious. In order to combat this problem our team proposes an array of gray water storage tanks across campus retrofitted to capture stormwater for use in campus facilities. By doing so we are combatting the trend towards more impervious surface and providing important rainwater capture. The following outlined in Table 3 below are examples of such retrofits and represent their extensive capability to reduce the stormwater flow of an average Pittsburgh rainfall event of 0.25 inches.

Table 3. Estimation of average annual rainfall capture via demonstration Gray water storage tank retrofits.

Site	Area (Acres)	Average Annual Rainfall (in)	Potential Annual Captured Rainfall (acre-in)	Potential Gallons Captured Annually
Peterson Event Center	5.78	38.19	221	6,001,097
Benedum Hall	1.08	38.19	41.2	1,118,757
Sutherland Hall	1.21	38.19	46.2	1,254,528
Trees Hall	5.16	38.19	197	5,349,394
Hillman Library	2.51	38.19	95.8	2,601,381
Litchfield Towers	0.67	38.19	25.6	695,150
Total:	16.41	38.19	627	17,020,307

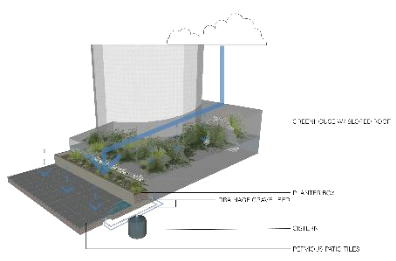

Figure 9: Site rendering of Towers Green Atrium stormwater runoff capture via cistern for reuse in high water use buildings.

These demonstration gray water storage retrofits represent a first phase of proposed adaptations (**Figure 9**). Furthermore, downspout disconnects have the lowest cost per-square footage of drainage area at a base case of $0.20 per sq. ft. [20]. Additionally, these initial retrofits would reduce total campus CSOs by roughly 25% in an ideal scenario that would capture all rainfall. This rough estimation achieves the Pitt Sustainability Plan's goal of "diverting 25% of stormwater from remaining impervious surfaces to rain gardens, bioswales, or rainwater harvesting tanks by 2030." and with plans to push for more campus adaptations during 10-year and 25-year IMP development periods diversion rates will only increase.

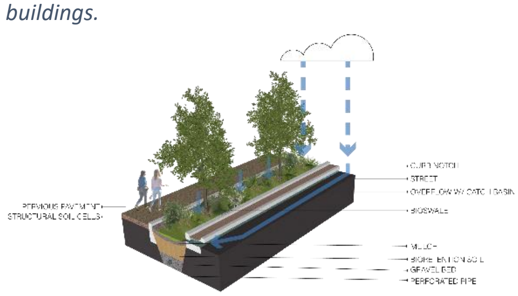

Figure 10: Site rendering of a potential Stormwater tree pit standard to be used throughout campus.

To further build on-site stormwater infrastructure integrations, we propose to set a campuswide standardization for tree pit specs (**Figure 10**). The 2018 Pitt Sustainability Plan emphasizes a University goal to "increase our urban canopy by 50% from the 2017 baseline." The IMP goes into further detail assessing the feasibility of this goal, concluding that a 50% increase is not possible due to our campus land usage and planned future development. However, we can still increase our urban canopy between 4% - 15% depending on campus development plans. To address this opportunity, we coupled stormwater mitigation with the multiple bottom-line value of urban canopy. Our proposal is to standardize stormwater tree pit specs and deploy them wherever new street tree plantings occur on campus throughout the 10-year and 25-year development period. These standardizations include structural cell systems or open-air pit depending on site locations and area available. For constricted sidewalk spaces a structural cell system will be designed allowing for a suspended pavement that promotes root growth and ultimately larger trees. For larger areas with more sidewalk space, a more open and connected tree pit system can be engineered. These systems will include in-cuts for stormwater runoff and structural soils will be used for additional stormwater retention based on site parameters. Special considerations should be made for our lower campus area near the William Pitt Union as a small aquifer is present and significant lateral flow through these engineered soils could reduce overall system strength [9] and geotextile support and underdrainage. Finally, to ensure the longevity of these stormwater tree pits, sites should include small fencing or barrier to the soil area as soil compaction can reduce infiltration efficiency significantly. This effort will move the University away from incongruent contractor-based decisions for tree pit specs and provide consistency throughout new campus developments. After working with the Pitt Tree Advisory Committee and their chairman, Dave Klimchock senior project manager for Facilities Management, we developed a vested interest from the University in employing these strategies, promoting carbon sequestration, runoff capture, temperature mitigation, and many other ecosystem services reaching some 40 large IMP development projects over the next 25 years.

To conclude our general campuswide GI and LID adaptations our team further built on the IMP’s green infrastructure Best Management Practices (BMPs) decisions for new campus projects. In doing so we took the outline drafted in the IMP displaying potential for new GI and LID BMPs and established a best fit analysis based on site topography, geology, location on campus, and cost-effectiveness. These include rain gardens, bioswales, and areas for stormwater trees (**Figure 11**). The above-mentioned projects would take place over the outlined 10-year and 25-year IMP timelines respective to their project's classification. In cooperation with the Universities Pollinator Habitat Advisory committee and chair, Andy Moran Senior manager of Grounds, all of our plantings uphold the Sustainable Landscape Guidelines and further will provide pollinator habitat space. Additionally, these projects will further the committee's goal for a new 100% pollinator supporting habitat on campus each year till 2025 and build our reputation as a certified Bee Campus USA by the Xerces Society. Finally, our site adaptations will further decrease impervious spaces on campus and divert stormwater away from the sewershed helping to achieve Pitt Sustainability Plan stormwater goals.

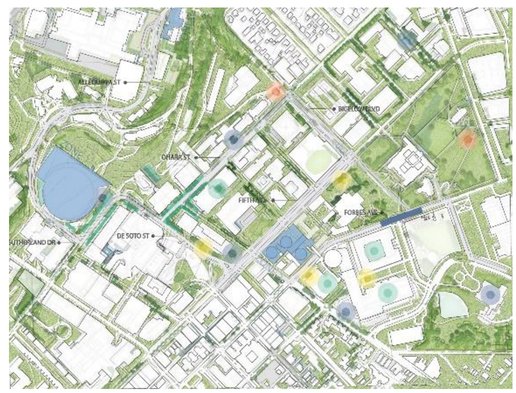

Figure 11*: Campus Masterplan adaptations red - rain garden, Black - Bioswale, Green - Green roof, and Yellow - Pervious Surface.*

4.2 Sutherland Drive Connectivity Conversion

A crucial aspect of our campus is facility accessibility. The Sutherland Drive area is just to the left of the Peterson Event Center (Pete) which serves as a major gym and sporting complex. This road could also serve to further connect the North-South Braid to upper campus which is home to our other large campus recreation facility Trees Hall and several dormitories. This street is largely used for campus personnel

Figure 12: *Sutherland Drive Connectivity Conversion, visulaizing proposed GI and LID adaptations and increasing the green ribbon and student walkways.*

parking and storage. The IMP outlines a plan to convert this street to pedestrian-only and limit vehicle travel to campus employees and event shuttles. Given this plan, our team proposes significant changes in impervious space by converting the road to pervious pavement. The regional GI siting and cost-effectiveness map tool also indicates that this change has especially positive value nearing a reduction in inflow by almost 1 million gallons per year and costing an estimated $13 per gallon of water captured [20]. Furthermore, as seen in **Figure 12** we converted the front right corner of the Pete landscape into a rain garden and established stormwater tree pits that will extend all the way up the drive to drain the road cut to the rain garden. Due to the more intense slope in this area, our goal was to capture as much stormwater as possible and store it preventing discharge downslope. In order to prevent oversaturation of this area, we propose connecting the GI to a cistern inside the Pete for the facility to potentially filter and use. Thus, stormwater flow is still being captured via the connected stormwater tree pits and pollinator rain garden on both sides but is limiting infiltration that could potentially affect the integrity of the substrate and downslope building basements. Finally, due to our campus canopy initiatives and the unique sloped topography of this area of campus we propose a small tree planting of about ten additional Native trees on the back corner of the site next to the fieldhouse. These trees would provide slope stability, further carbon sequestration, and capture additional stormwater that would otherwise have fallen on the slope.

4.3 Upper Hillside Development

Figure 13*: Site rendering of the proposed Upper Hillside Development. Most notably displaying the preserved basketball courts and recreational area on top of the garage's green roof. And exposed cisterns and terraced wall planters offer educational opportunities.*

The Upper Hillside Development (**Figure 13**) is another unique site in the IMP and represents a great compromise between gray development and sustainability. This 9.2-acre lot currently resides in between the Falk Laboratory School (K-8th grade) and the Fraternity housing complex. The IMP labels it as site 4a and lists it as most likely becoming a large campus parking garage, which is needed due to garage demolitions set to take place in the next few years. So, our team decided to integrate sustainable practices into a stereotypically gray and drab construction project. We worked to reserve themes from the site pre-construction and include them in the overall post-site design. These themes included the basketball court, Falk School outdoor spaces and laboratory, and new outdoor spaces for students and community members to enjoy. We propose constructing a large-scale green roof on the top of the parking garage, including the relocation of the basketball courts to the roof and the addition of park-style seating and landscaping. This will replace trees lost within and surrounding the planned parking structure. Further, we plan to incorporate a slight slope allowing for excess water to flow towards the side of the parking garage facing the Falk School, filling w planters blocking the school children's view of the parking structure. Eventually, excess water would be captured in large exposed gray water tanks to distribute water on campus and serve as educational features. Bioswales would also be incorporated near the upper and lower entrances and along the sides of the garage with the purpose of capturing and retaining stormwater. These adaptations would take a gray facility and turn it into non-CSO contributing pervious surface and provide the community and students with fantastic educational and recreational opportunities by conserving the environment of the upper hillside.

4.4 Towers Plaza Green Atrium Project

***Figure 14**: Towers Plaza Green Atrium proposed site rendering. Sloped glass roofing, edible gardens, gray water storage and tree pits will transform this historic residence hall into a sustainable beacon.*

The Litchfield Towers site is a unique area that combines historic Pitt with modern housing and campus dining facilities. Currently, Towers A, B, and C can house nearly 2,000 predominantly first-year students. Our design adaptations accentuate the open gathering space by heading the IMP and developing a glass atrium around the terrace area. This atrium will feature a heightened greenhouse-inspired space with opportunities to work with campus clubs like Pitt Plant2Plate and the hydroponics club to produce food for the dining hall below (**Figure 14**). We further include gray water adaptations to the three tower residence halls which can capture significant amounts of stormwater and be cleaned for usage in bathroom facilities. Additionally, the previous terrace used to drain into the sewer contributing to CSOs, but in our adaptation, the permeable terrace and runoff from the sloped glass atrium roof flow into planters and bioswales located in the front and side of the plaza. Finally, we incorporated a large strip of stormwater tree pits that would further reduce stormwater runoff, sequester CO_2, scrub harmful pollutants from the nearby roadway, and provide other aesthetic and cooling benefits to the students on the terrace space. These proposed adaptations provide significant benefits to the campus, in terms of ecosystem services, and to students as local produce can be grown right in the residence hall area and students can interact in a more open therapeutic environment central to our campus.

5. Reductions in Runoff Contributions from Zones after GI Implementation

To determine the potential effectiveness of proposed GI, estimates of maximum potential annual runoff after installation are needed. The considered maximum annual volume of runoff from all areas of proposed GI (zones and greywater retrofits) prior to their implementation excludes Trees Hall as it is not considerably within M-19A or M-29. This volume sums to 48.6 MG. To estimate post-implementation runoff reductions, various empirically-derived annual effective retention rates were used for the different GI.

Table 4. Estimation of maximum potential annual runoff capture within M-19A and M-29 after implementation of overlapping GI. *Note. Data are from Center for Neighborhood Technology* [4] *and Szota et al (2018)* [5].

Site/GI & LID	Area (sq-ft)	Effective Retention Rate	100% Capture-Effective Area (sq-ft)	Maximum Potential Annual Rainfall Capture (cubic-ft)	Maximum Potential Annual Rainfall Capture (MG)
General Gray Water Retrofits					
Peterson Event Center	251,776.8	5%	12589	40064.4925	0.299703237
Benedum Hall	47,044.8	5%	2352.2	7485.8765	0.055998249
Sutherland Hall	52,707.6	5%	2635.4	8387.1605	0.062740322
Hillman Library	109,336	5%	5466.8	17398.091	0.130146768
Litchfield Towers	29,185.2	5%	1459.3	4644.22225	0.034741197
Total:					0.583329773
Sutherland Dr. Connectivity Conversion					
Permeable pavement	121,968	50%	60984	194081.58	1.451831141
Stormwater Tree Pits	60,374.16	18%	10867	34584.2275	0.258708005
Rain Garden	20,124.72	60%	12074.832	38428.15284	0.287462566
Total:					1.998001712
Upper Hillside Development					
Green roof	280,526.40	60%	168316	535665.67	4.007057758
Bioswale	80,150.40	60%	48090.24	153047.1888	1.144872557
Gray water retrofits	40,075.20	5%	2003.8	6377.0935	0.047703975
Total:					5.19963429
Towers Plaza Green Atrium Project					
Stormwater Tree Pits	15,681	18%	2822.6	8982.9245	0.067196946
Permeable pavement	20,908.80	50%	10454.4	33271.128	0.248885338
Total:					0.316082285
Cumulative Total:					**8.09704806**

Table 4 calculates that the maximum runoff reduction potential of all proposed GI is 8.10 MG/yr. With these particular GI systems, the maximum potential reduction in annual campus runoff contributions to M-19A and M-29 reduces from 67.1 MG to 59.0 MG, which is a percent change of -12.1%. The sum of GI footprints has the potential to capture 16.7% of their maximum annual received runoff. Thus, effectively, 21.5 acres of proposed GI are capable of initiating a 12.1% decrease of the maximum annual runoff potential of campus. This serves as an indicator of the high potential for runoff capture on-campus within a relatively small area. For example, the roofs of Towers and the Peterson Events Center do not presently have any existing GI, occupy an area of 10.0 acres, and in a typical year receive 10.4 MG of precipitation. With a 5% green roof effective retention rate, 0.52 MG of runoff can be reduced from entering the M-29 sewershed. The PWSA provides the ratio of volume overflow reduced per volume inflow reduced in the M-29 sewershed as 0.85[17].

$$0.85 \times 0.52 \text{ MG/yr} = 0.44 \text{ MG/yr inflow to M-29 reduced}$$

Thus, as the M-29 outfall typically discharges 402.0 MG in annual CSO, the Pittsburgh campus can use an area that occupies 0.02% of the M-29 sewershed to reduce annual CSO overflow volumes by 0.11%. Therefore, the implementation of GI on campus is capable of producing disproportionally beneficial effects in the local CSOs issues.

6. Campus and Community Engagement

Campus and Community Engagement is a crucial factor both in Pitt's IMP process and in our project. Before starting our design phase, we analyzed the results from the 2020 Campus Sustainability Literacy and Culture Survey and incorporated the findings into our foundational thinking. These results included enabling and promoting sustainable behavior, integrating sustainability into student/residential life, and encouraging projects that benefit our communities. Additionally, our master plan adaptations would follow the same public commentary scheme currently present in the IMP drafting process. We find it extraordinarily valuable to hear those voices from members of our community and hope to facilitate feedback and dialogue by hosting workshops bimonthly. Moreover, developing a relationship between the campus and its students is a massive focus of our project. We took the time to communicate with the Campus Tree Advisory and Pollinator Habitat Advisory Committees to provide opportunities to students to conduct research, participate in unique urban ecology labs, inventory campus trees, and even help build habitat to support our pollinator-friendly rain gardens. In conjunction with the Oakland Planning and Development Corporation (OPDC) and The Office of Pitt Serves, we would like to offer more stormwater-related volunteer opportunities for Pitt Make a Difference Day (PMADD) and MLK Day of Service.

7. Construction and IMP Coordination

In order to maintain consistency with the 2019 Final Draft of the Pitt IMP, our team focused on staying within the 10-year and 25-year development framework. Because of this broad scope, we approached GI and LID implementation by adapting three specific sites and applying GI and LID that would be generally applicable to the entire campus and be developed throughout the IMP timeline. However, as indicated by the IMP 10-year development sites have the capacity to make significant changes to our landscape in a brief amount of time. Due to the global movement to combat climate change and adapt our region's water infrastructure we feel it is necessary to move the Sutherland Drive Connectivity Conversion, Upper Hillside Development, and Towers Plaza Green Atrium Project forward to be completed by the end of the 10-year period. In addition, the first phase of gray water retrofits should also be completed during this decade and specific site GI selections should be filtered throughout the 10-year and 25-year time frame to continue advancing progress.

8. Adaptation Costs and Funding Opportunities

Table 5. Estimated site costs based on 3RWW regional averages
Note. Data from RainWays[17]

Site/GI & LID	Average Regional Cost	Area (sq-ft)	Estimated Construction Cost ($)
General Campus Gray water retrofits:	0.3 ($/sq ft)	-	-
Peterson Event Center		251,776.8	75,533
Benedum Hall		47,044.8	14,113.20
Sutherland Hall		52,707.6	15,812.30
Trees Hall		224,770	67,431
Hillman Library		109,336	32,800
Litchfield Towers		29,185.2	8755.60
Total:			$214,445.1
Sutherland Dr.	-	201,247.2	-
Connectivity Conversion	-		-
Permeable pavement	14.5 ($/sq ft)	121,968	1,768,536
Stormwater Tree Pits	8.11 ($/sq ft)	60,374.16	489,634.40
Rain Garden	26.2 ($/sq ft)	20,124.72	527,267.70
Total:			$2,785,438.10
Upper Hillside Development	-	400,752	-
Green roof	28.1 ($/sq ft)	280,526.40	7,882,791.84
Bioswale	26.2 ($/sq ft)	80,150.40	2,099,940.48
Gray water retrofits	0.3 ($/sq ft)	40,075.20	12,022.56
Total:			$9,994,754.88
Towers Plaza Green Atrium Project	-	52,272	-
Gray water retro fit (Already considered above)	-	-	-
Stormwater Tree Pits	8.11 ($/sq ft)	15,681	127,177.78
Porous Paver	9.34 ($/sq ft)	20,908.80	195,288.20
Large tree and vegetation planters x20	~$300 per planter	-	6,000
Total:			$328,465.98
Sum of Project Totals:			**$13,323,104.06**

Over the 10-year period of first phase demonstration gray water retrofits and site-specific adaptations, we can expect to pay an estimated $1,332,310.41 on construction costs per year. In addition, the 3 Rivers Wet Weather Green Solutions page provides a number of construction companies capable of doing this work [18].

9. Maintenance and Management

Table 6. Estimated maintenance based on 3RWW regional BMPs
Note. Data from RainWays[20]

GI/LID Type:	Maintenance:	Frequency:	Notes:
Gray Water Storage/ Downspout Disconnect	**Inlet inspection**	2-12/year	Inspect periodically for clogging (failure to drain). Remove any accumulated leaves, organic materials, and sediment as soon as practical if an inspection reveals clogging.
	Miscellaneous upkeep	Periodically	Infiltration areas should be routinely checked to ensure that they are free of debris and trash. Receiving areas should be inspected for signs of channelized flow and signs of compaction.
Bioswale	**Pruning**	1-2 times/yr	Nutrients in runoff often cause bioswale vegetation to flourish.
	Mowing	2-12 times/yr	Frequency depends on location and desired aesthetic appeal.
	Mulching	1-2 times/yr	Recommend maintaining 1"–3" uniform mulch layer.
	Mulch removal	1 time/2–3 years	Mulch accumulation reduces available water storage volume. Removal of mulch also increases the surface infiltration rate of fill soil.
	Watering	1 time/2–3 days for first 1–2 months; Sporadically after establishment	
	Fertilization	1 time initially	One time spot fertilization for first-year vegetation.
	Remove and replace dead plants	1 time/year	Within the first year, 10% of plants can die. Survival rates increase with time.
	Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the bioswale is as designed. Remove any accumulated sediment.
	Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet and remove any accumulated mulch or sediment.
	Miscellaneous upkeep	12 times/year	Tasks include trash collection, plant health, spot weeding, removing invasive species, and removing mulch from the overflow device.
Green Roofs	**Watering**	1st year, periodically, after 1st year occasionally	May require additional watering during an exceptionally dry period.
	Weeding	1st year, periodically, after 1st year occasionally	This can involve gardening and irrigation.
	Fertilization	After 1st year, lightly fertilize once a year	This can involve gardening and irrigation.
		Once a year	

	Inspection		Green roofs are less prone to leaking than conventional roofs. In most cases, detecting and fixing a leak under a green roof is no more difficult than doing the same for a conventional roof.
Permeable Pavement	**Inlet Inspection**	Once after first rain of the season then monthly during the rainy season	Check for sediment accumulation to ensure that flow onto the permeable pavement is not restricted. Remove any accumulated sediment. Stabilize any exposed soil.
	Vacuum street sweeper	Twice a year as needed	Pavement should be swept within a vacuum power street sweeper at least twice per year or as needed to maintain infiltration rates.
	Mowing (for grass filled pavers)	2–12 times per year	Pavers filled with turf require mowing. Frequency depends upon location and desired aesthetic appeal.
	Replace fill materials	4 times per year	Fill materials will need to be replaced after each sweeping and as needed to keep voids with the paver surface.
	Watering (for grass filled pavers)	1 time every 2–3 days for fires 1–2 months; sporadically after establishment	If drought conditions exist, watering after the initial year may be required.
	Fertilization	4 times per year or as needed for aesthetics	One time spot fertilization for “first-year” vegetation.
	Miscellaneous upkeep	4 times per year or as needed for aesthetics	Tasks include trash collection, sweeping, and spot weeding.
Rain Garden	**Pruning**	1-2 times/yr	Nutrients in runoff often cause bioretention vegetation to flourish.
	Mowing	2-12 times/yr	Frequency depends on location and desired aesthetic appeal.
			Between 1"–3" of mulch depth is ideal.
	Mulching	1-2 times/yr	Mulch accumulation reduces available water storage volume.
	Mulch removal	1 time/2–3 years	Removal of mulch also increases the surface infiltration rate of fill soil.
	Watering	1 time/2–3 days for first 1–2 months; Sporadically after establishment	If drought conditions exist, watering after the initial year might be required.
	Fertilization	1 time initially	One time spot fertilization for first-year vegetation.
	Remove and replace dead plants	1 time/year	Within the first year, 10 percent of plants may die. Survival rates increase with time.
	Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the bioretention is as designed. Remove any accumulated sediment.
	Outlet inspection	Once after first rain of the season, then monthly	Check for erosion at the outlet and remove any accumulated mulch or sediment.

		during the rainy season	
	Miscellaneous upkeep	12 times/year	Tasks include trash collection, plant health, spot weeding, removing invasive species, and removing mulch from the overflow device.
Stormwater Tree Pit	**Inlet inspection**	Twice annually	Check for sediment accumulation and erosion within the swale.
	Mowing	2–12 times/year	Frequency depends on location and desired aesthetic appeal.
	Watering	1 time per 2–3 days for first 1–2 months; sporadically after establishment	If drought conditions exist, watering after the initial year may be required.
	Fertilization	1 time initially	One time spot fertilization for "first-year" vegetation.
	Remove and replace dead plants	1 time/year	Within the first year, 10 percent of plants may die. Survival rates increase with time.
	Check dams	One prior to the wet season and monthly during the wet season	Check for sediment accumulation and erosion around or underneath the dam materials.
	Miscellaneous upkeep		Tasks include trash collection and spot weeding.

We can also expect to include budgeting for new monitoring equipment and potential new staff members to take on extra work, but this will be decided by Facilities. Funding for this project can come from a multitude of local, state, and national sources. Locally, both **PWSA** and **ALCOSAN** have large grant opportunities through their **GROW** and **Green First Plans** respectively. State-wide we have the opportunity to apply for a **Growing a Greener Watershed Grant** via the **PA Department of Environmental Protection** and Nationwide opportunities like **FEMA's Building Resilient Infrastructure and Communities (BRIC) Grant** whose application is currently open until January 21st. All of these opportunities offer thousands to millions of dollars in grant money and can easily subsidize costs that the University can't pick up.

10. Conclusion

Given the significant implications of increasing precipitation for aging and undersized infrastructure, it is essential for the University of Pittsburgh to implement GI and LID systems over the coming 10-year and 25-year period based on models like our project. Our proposal envisions a resilient urban campus making substantial strides to lead our region in its fight to reduce combined sewer overflow pollution. Additionally, our proposal makes significant strides in laying out a defined pathway to completing goals outlined in the Pitt Sustainability Plan. These goals include diverting 25% of stormwater into bioswales, rain gardens, and stormwater storage tanks. Proposed adaptations further reduce impervious areas and when we couldn't change the landscape, we captured the runoff instead. Our team utilizes a cost-effective approach backed by regional studies to deploy continuous upgrades to campus infrastructure ensuring continuity and long-term benefits. Standardized tree pit specs that include stormwater storage, promote, and physically increase campus canopy will provide CO_2 sequestration, reductions in CSO contribution, help mitigate the urban heat island effect, and more. Our proposal provides students with increased connectivity and access to campus facilities and greenspace. Lastly, our proposal embodies the Pitt campus IMP central goals in that we prioritize student health, safety, accessibility, and offer ample opportunities for community members and students to become invested in their campus. Our team addresses Pitt's urban campus stormwater needs and transforms them into our strengths, adapting our proposal would mean Pitt realizes its position as a regional leader in sustainability.

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