GICO Inc.

58 University Ave Kingston, ON K7L 3N9
April 23, 2025

David Gerrish
Nathan Splinter
Liam Dreany
Facilities | Queen's University
355 King St. W. Kingston, ON K7L 3N6

Dear Mr. Gerrish, Mr. Splinter, and Mr. Dreany,

Please find attached our final report for the Queen's Climate Resilient Campus project. The report details our proposed solution to address the flooding experienced during heavy rainfall events across the Queen's campus. Our progress includes the development of a thorough problem definition, two detailed designs, and a cost-analysis. The report will also consider the potential impacts of constructing the designs and discuss our decision-making process. The conceptual designs selected address both the current flooding problem spots as well as aid the water management around future builds on campus.

We kindly ask for written acknowledgment that you have received the attached draft report. If you have any questions about our final solution, please email our project manager, Christopher Ridolfi, at christopher.ridolfi@queensu.ca.

Sincerely,

Christopher Ridolfi, Ossaid Khan, Grace McAuley, and Ivan Bogomolsky

GICO Inc.

FINAL REPORT:

CLIMATE RESILIENT CAMPUS – MANAGING STORM SURGES, WATER RETENTION AND BIODIVERSITY ACROSS CAMPUS

Prepared For

Queen's Facilities

By

Christopher Ridolfi
Ossaid Khan
Grace McAuley
Ivan Bogomolsky

GICO Inc.

April 23, 2025

Statement of Originality

Our signatures below attests that this submission is our original work. Following professional engineering practice, we bear the burden of proof for original work. We have read the Policy on Academic Integrity posted on the Civil Engineering departmental website (www.civil.queensu.ca/undergraduate) and confirm that this work is in accordance with the Policy.

Name	Signature	Date
Christopher Ridolfi		April 23, 2025
Ossaid Khan		April 23, 2025
Grace McAuley		April 23, 2025
Ivan Bogomolsky		April 23, 2025

Executive Summary

Queen's University Facilities has tasked GICO Inc. with developing a stormwater diversion plan to address flooding experienced during heavy rainfall events. This report will present GICO Inc.'s final draft on the diversion plan, which includes defining the problem, developing and analyzing conceptual designs, selecting two improvement methods, and conducting a complete analysis for their implementation. The main areas of focus for these solutions include: Sutherland Hall, Mackintosh-Corry Hall, Humphrey Hall, and Beamish Munro Hall.

Some of Queen's buildings have been previously analyzed by Facilities staff and consulting engineering companies. The analysis was focused on buildings previously affected by flooding. Improvements have been made however flooding has persisted. GICO Inc. will focus on improving rainfall management around Sutherland Hall as well as suggest an improvement method that can be applied to future builds on campus.

The final stormwater diversion plan consists of two designs to improve rainwater management on the Queen's campus. Designs were evaluated using a quantitative evaluation matrix, based on their constructability, environmental impact, cost, construction duration, accessibility, and aesthetic. The engineering analysis conducted showed that permeable interlocking concrete pavers and blue-green roof systems are the best approaches in terms of the selected criteria. Permeable interlocking concrete pavers can be applied to the current Sutherland building, to filter and direct stormwater into the existing storm sewer system. Blue-green roofs can be implemented in future construction projects to collect and discharge stormwater from the building's rooftop into the drainage system.

An initial estimate determined it would cost approximately $4777 to install interlocking concrete pavers, and $578,402 for a singular blue-green roof system on the roof of Beamish Munro Hall. The construction process is estimated to take 16 and 20 days for the pavers and blue-green roof respectively, with the majority of these timelines dedicated to site preparation.

As next steps, GICO recommends a monitoring and maintenance plan be established for both systems, outlining regular inspections, cleaning, and repairs to ensure long-term effectiveness.

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1 Introduction

This report will present GICO Inc.'s final draft for the Climate Resilient Campus project, developed in collaboration with Queen's Facilities. The project's goal is to address flooding events on the Queen's campus, that are worsening as a result of climate change. Over the course of 7 months, GICO has developed and evaluated several conceptual designs to mitigate excess stormwater, conducted a cost analysis, and formulated design drawings. Two of the conceptual designs were selected for implementation, with one suited for existing buildings and flooding locations, and the other designed for future builds on campus.

2 Problem Definition

Queen's University is located in Kingston, ON, along the shore of Lake Ontario. Over the last 20 years, the university has seen an increase in flooding events across campus, triggered by an increase in severe and sudden rainfall events. GICO was retained by Queen's Facilities to develop an improved stormwater diversion plan, focusing on the campus's low-lying areas that are most susceptible to flooding. These areas include: Sutherland Hall, Mackintosh-Corry Hall, Humphrey Hall and Beamish Munro Hall.

Flooding has affected many buildings across the Queen's campus and resulted in moderate water damage, as pictured below in Figure 1 and Figure 2.

Figure 1: Flooding in Beamish Munroe Hall in 2018 (Davis 2018)

Figure 2: Water Damage to Sutherland Hall in 2019 (Queens Facilities 2024)

Catch basins and drains are located across campus, especially in low-lying areas, to help mitigate excess rainwater. These catch basins and drains can become clogged or overwhelmed during intense storms, leading to the experienced flooding.

2.1 Background Information

The following background information was utilized in the design of stormwater mitigation measures.

2.1.1 Flooding History

From 2017 to 2022, major rainfall events affecting the Queen's campus were surveyed by Queen's Facilities. The survey is summarized below in Table 1 and identifies the buildings impacted by flood damage for each rainfall period.

Table 1: A summary of the major rainfall events affecting Queen's University over a 5-year period

Date	Cumulative Rainfall (mm)	Peak 1 hr (mm)	Buildings with Flood Damage
Jun 01, 2022	58	28	None
Oct 16, 2021	21	8	Sutherland, Humphrey, MacCorry, Beamish
Oct 31, 2019	71	17	Sutherland, Summerhill, & Nicol
Aug 15, 2018	26	9.3	Beamish, MacCorry
Jul 24, 2017	102	38	Ontario, Law, Fleming J., Summerhill

2.1.2 Previous Analysis

Facilities staff and consulting engineering companies have previously evaluated some of the flooding locations on campus. Documentation provided to GICO Inc. by Queen's Facilities indicated the evaluation was focused on three main buildings: Humphrey Hall, Sutherland Hall, and Mackintosh-Corry Hall (MacCorry Hall).

The flooding of Humphrey Hall was investigated in 2017 by Queen's Facilities, with the recommendation of installing a new check valve to prevent stormwater from flowing backward up the floor drain. This recommendation has been fulfilled; however, Humphrey Hall did experience further flooding as recent as 2021.

In 2021, J.L. Richards was retained to perform stormwater improvements at Sutherland and MacCorry Hall through a localized approach. With the project scope nearing completion, a major storm flooded the basement of Sutherland Hall, as well as other campus buildings. Following the company's investigation of the event, Queen's reviewed the preliminary findings and recommendations and requested a proposal for additional watershed modelling and improvement options. J.L. Richards provided the requested information, and Queen's University accepted the proposal. Some of the low points of interest at Sutherland Hall are pictured below in Figure 3 and Figure 4.

Figure 3: Sutherland Hall Low Point (Queens Facilities 2024)

Figure 4: Sutherland Hall Low Point (Queens Facilities 2024)

2.1.3 Environmental Impacts

The increased rainfall intensity experienced in the Kingston area can be attributed to climate change. Global temperatures are rising as a result of greenhouse gas emissions, in turn affecting earth's hydrological cycle. The rising temperatures increase the air's capacity for water vapour, leading to more intense rainfall events ("Extreme Precipitation and Climate Change" n.d.). As greenhouse gas emissions continue, climate change is expected to worsen. Kingston's rainfall intensity for a one hour storm is expected to increase to up to 52 mm/hr by the year 2080, a 22% increase from a reference period of 1976-2005 ("Climate Change in the City of Kingston" 2021). The maximum rainfall in a 5-

day period is also anticipated to reach up to 75 mm (“Climate Change in the City of Kingston” 2021). With rainfall intensity expected to rise, flooding events on Queen's campus are likely to worsen, increasing the risk of environmental effects.

Without proper mitigation, ponding water can erode the campus's green space, leading to landscape deterioration. Additionally, rainwater that is carried as overland flow can collect a wide range of pollutants settled on the surface. These pollutants may stem from car emissions, grass fertilizers, road materials, and animal waste (The Ripple Effect 2024). Polluted overland flow can make its way to larger water bodies, eventually affecting drinking water sources and aquatic life.

2.1.4 Social Impacts

The impact of flooding on Queen's infrastructure and environment has a number of social impacts for students and faculty.

2.1.4.1 Health and Safety Risk

The damage caused by flooding events can lead to health and safety concerns for students and staff. Health and safety concerns of flooding include, slipping hazards, power outages, mold, electrical shock, and falling debris. The flood damage must be addressed in a timely manner to reduce health and safety risks, putting further stress on Queen's Facilities staff.

2.1.4.2 Education

The damage caused by flooding may require the closure of certain buildings, disrupting scheduled classes/exams and displacing students. Disrupted classes may require relocation or be held online—an alteration that can cause added stress for students, potentially affecting their education.

2.1.4.3 Ethical Issues

Buildings or classrooms affected by flood damage may disproportionately affect certain students or programs, causing their relocation. Building accessibility may also be affected, if specific entrances or ramps are flooded.

2.1.4.4 Standard of Care

Queen's University has a duty of care to students and faculty, requiring them to maintain an environment safe from foreseeable risks. In the event of flooding on campus, the standard of care is that Queen's Facilities must address potential damage within a reasonable time frame, to prevent the harm of students and staff. Implementing stormwater mitigation measures will help maintain the standard of care, and reduce the stress placed on Queen’s Facilities’ employees.

2.2 Scope of Work

The scope of GICO Inc.'s work on the Climate Resilient Campus project includes the following elements:

- Assess the current topography of the campus and identify key locations at risk of flooding during high rainfall events.
- Develop improvement options to divert stormwater away from low-lying areas and manage the high volumes of water.
- Consider the use of water and naturalized spaces that can act as water retention areas.
- Design an improved stormwater diversion plan for the campus. The design should consider land use, environmental benefits, and cost.
- Provide detailed design recommendations for the stormwater diversion plan, with a final cost estimation.
- Conduct a mid-term and final presentation, updating facilities staff and faculty on the project's progress and final design.

All recommendations made by GICO Inc. must also follow Queen's Building Standards for the use of contractors.

2.3 Constraints

The Climate Resilient Campus project must adhere to several key constraints to ensure that proposed solutions are practical, sustainable, and effective. These constraints have been carefully considered throughout the project development process.

2.3.1 Timing

The 8-month timeline requires efficient planning and execution to meet all deliverables. Designs must be implemented within the outlined schedules, prioritizing solutions with shorter construction durations to minimize delays.

2.3.2 Budget Limitations

The project operates within the financial constraints set by Queen’s University. Solutions must balance affordability with effectiveness, ensuring materials, designs, and construction methods are cost-efficient while still delivering the desired outcomes.

2.3.3 Regulatory Compliance

All designs must align with local, provincial, and university-specific regulations, including the Ontario Water Resources Act and Queen’s Building Standards. These standards shape the technical and environmental aspects of the project, which ensure compliance throughout the design and implementation phases.

2.3.4 Environmental Impact

Sustainability is a core consideration, with solutions designed to minimize harm to the environment and biodiversity. Features such as permeable pavers and green roofs reduce runoff, improve stormwater quality, and support ecological balance on campus.

2.3.5 Pedestrian Impact

The safety and accessibility of students, staff, and faculty must remain a priority. Designs are evaluated for their effect on pedestrian areas, ensuring construction minimizes disruption and final implementations improve campus usability without compromising accessibility.

2.3.6 Aesthetics

The visual appeal of proposed solutions is vital to maintaining the campus's aesthetic integrity. Features like bioswales and green roofs are designed to integrate seamlessly with the existing environment, enhancing the campus's overall appearance.

2.3.7 Stormwater Management

Effective stormwater management is the objective of this project. Solutions must address current flooding issues while accommodating projected increases in rainfall intensity due to climate change. Proposed designs focus on water retention, diversion, and pollutant reduction.

2.3.8 Maintenance

Long-term functionality depends on practical maintenance protocols. Solutions such as permeable pavers and blue-green roofs are designed with ease of maintenance in mind, ensuring they remain effective without imposing excessive demands on facility staff.

2.3.9 Construction Complexity

Construction activities must align with university schedules and minimize disruptions to campus operations. Simple, efficient construction methods are prioritized to reduce the complexity and duration of implementation while ensuring safety and quality.

2.4 Stakeholders

The stakeholders for the Climate Resilient Campus project are described below in Table 2.

Table 2: A summary of the project's stakeholders and their corresponding interests

Stakeholders		Project Interests
Primary	Queen's University Facilities	Facilities require a stormwater diversion plan to improve campus flooding events and reduce building/property damage.
	Queen's University Internal Facility Staff	Internal facility staff is responsible for performing maintenance and will be directly affected by improvement methods
	Queen's University Students & Faculty	Students & faculty will be affected by any stormwater diversion infrastructure as well as the construction process.
Secondary	City of Kingston – Utilities Kingston	The stormwater management system serving the Kingston area is owned and operated by the City of Kingston. The city holds approval authority for all modifications to the stormwater management system.
	The Ministry of Environment	Stormwater management practices are outlined in the "Stormwater Management Planning and Design Manual" created by the Ministry of the Environment. *Ontario Water Resources Act* shall also be consulted throughout the project.
	Cataraqui Region Conservation Authority (CRCA)	Cataraqui Conservation works in partnership with municipalities and government agencies to monitor and protect natural resources within the Cataraqui watershed. The CRCA has a collection of guidelines for stormwater management that may be applicable to the project.
Tertiary	Local Community	The local community may be impacted by changes to Lake Ontario.

2.5 Background Research

Preliminary research identified several rainwater management systems that were considered throughout the conceptual design phase. These rainwater management systems are summarized below:

2.5.1 Blue Roof Systems

Blue roof systems are constructed over flat roof buildings, in which stormwater is collected and detained slowly over time with the use of different water flow restricting devices (Hill 2018). Blue roof systems control the attenuation of heavy rainfall and control the rate at which the stormwater is discharged to the roof and collected by the roof's existing drainage system (Blue Roofs 2023). This allows the discharge, direct runoff, and infiltration rate to all be significantly reduced. Blue roof systems can be constructed in various ways. The system that will be closely analyzed for the Queen's campus will be permeable plastic trays that have ballast material on them. This system allows excess stormwater to be collected naturally by evaporating the collected water and having one of the flow water restrictive devices hold the stormwater and slowly release it back into the roof. This can potentially combat the various building halls that are susceptible to floods occurring in the basement.

Figure 5: Example of Blue-Roof System ("Unlocking Stormwater Solutions: A Northwestern University Case Study on Blue and Green Roofs" 2023)

2.5.2 Green Roof Systems

Green roof systems are similar to blue roof systems as they are also constructed on flat-roof buildings. However, green roof systems have plants and vegetation acting as a bed on the roof's surface. One method of combatting stormwater flooding and excess infiltration is the concept of evapotranspiration, in which plants collect water from their leaves and then evaporate into the air. Green roof systems use the concept of evapotranspiration by collecting stormwater from the area of plants and soil contents, absorbing stormwater and hence reducing its discharge, infiltration, and direct runoff rate into the building (Hill 2018). The stormwater then gradually gets released, helping the existing roof drainage to not be susceptible to failing.

Figure 6: Example of a Green Roof ("All About Green Roofs" 2022)

2.5.3 Rainwater Harvesting

Rainwater harvesting is a strategy to collect stormwater from paved surfaces, such as from the top of a roof, and collect it for non-potable use, such as irrigation, or practices that do not involve the usage of treated water (i.e. for human consumption). One potential idea is to install multiple storage tanks from buildings that are identified as key flooding locations and to use that stormwater for different uses around campus, such as irrigation of existing campus vegetation. This will help combat localized flooding in the land and low areas. This can benefit Queen's Facilities as collecting rainwater can minimize the usage of municipal treated water, which is a monetary utility paid by Queen's University.

2.5.4 Catch Basin Rehabilitation

After analyzing the given files and documents from the client, it is apparent that many catch basins are deteriorating; therefore, they are not efficiently catching stormwater in heavy rainfall events. One conceptual idea may be to conduct a site visit around campus and identify catch basins that may need replacing. In addition to this, adding another pair of catch basins to existing pairs may be beneficial in collecting more rainwater and combatting low-level areas.

2.5.5 Grate Installation

After identifying the key flooding locations, a site visit was conducted by a GICO representative to identify any common patterns after a rainfall event. One key pattern that was identified and apparent in almost all the key flooding locations was that there are low areas in the parking lots. These low areas cause ponding. Many of the parking lots have areas of greater settlement, resulting in large sinks that hold the excess rainwater and thus cause ponding. This site visit took place while there was a rainfall event, and it was identified that grates seemed to have played a key role in managing how high the ponding level reached. Many of these ponding areas can cause excess water to build up in the parking lot and slope towards the foundation of the building halls, which may potentially cause flooding in the buildings and the parking lots, which can be a concern. The idea would be to install additional grates in the parking lots of key flooding locations to improve drainage and minimize ponding. In addition to this, it would be appropriate to re-pave the parking lots to fill low areas.

3 Design Alternatives

The following proposed systems were researched and discussed with the client in bi-weekly meetings. The proposed solutions were chosen based on previous client discussions, consulting professionals who specialize in municipal land development, carefully analyzing the provided documents from the client, and strategizing on what can be installed to improve conditions and more effectively manage excess stormwater. Additionally, the following conceptual designs are land-based and building-integrated based.

The client had expressed to GICO that they would appreciate the study of a concentrated site of interest on campus, that has excess stormwater flooding. As such, GICO will concentrate on Sutherland Hall. Sutherland Hall has been susceptible to 100-year rainstorms causing flooding to its basement and parking lot, as well as nearby buildings and streets.

GICO is committed to improving the flood resiliency of Sutherland Hall. The group believes that both present and future solutions should be considered. Having said that, GICO will present four potential solutions for current implementation, perform a weighted evaluation matrix on each, and select the highest-ranking option. Similarly, the group will also present four design approaches for future development around campus, that may be implemented in a building code for contractors to use when constructing new developments; this may include the potential rehabilitation of Sutherland Hall.

3.1 Present Solution Alternatives

The following solutions have been discussed with Queen's Facilities to address flooding around existing buildings. The solutions will be evaluated based on their stormwater management, constructability, construction duration, environmental impact, cost, pedestrian impact, and aesthetics.

3.1.1 Bioswales with Underdrains

Bioswales are an engineered landscape mechanism implemented in urbanized atmospheres to combat heavy rainfall by reducing surface runoff and promoting infiltration (Wu 2024). Bioswales are constructed to have a depression depth and are filled with vegetation. They are constructed along where water flows, ultimately catching runoff from main roads and from above where rain pours. It acts by naturally slowing down runoff volume, recharging the groundwater table due to its infiltration mechanism and continues to push water downstream to its catch basin at a controlled rate.

The client has provided technical topographical information illustrating high and low points around the area. Sutherland Hall drawings were also provided, in which the flow of water and designated catch-basins can be seen. From a site visit that was conducted by the team, many areas around Sutherland Hall lack permeable pavement, and hence lack in stormwater management infrastructure.

If implemented, bioswales would be installed around the radius of Sutherland Hall, as marked in green on Sutherland's plan view (provided by Queen's Facilities) in Figure 7. This layout also details the projected water flow in a rainfall event. Not only do bioswales ensure less storm runoff and promote infiltration, but they are feasible to implement, with low constructability. The bioswales can have trees planted in the depression along with other broadleaf plants to maximize evapotranspiration and reduce shedding surface water.

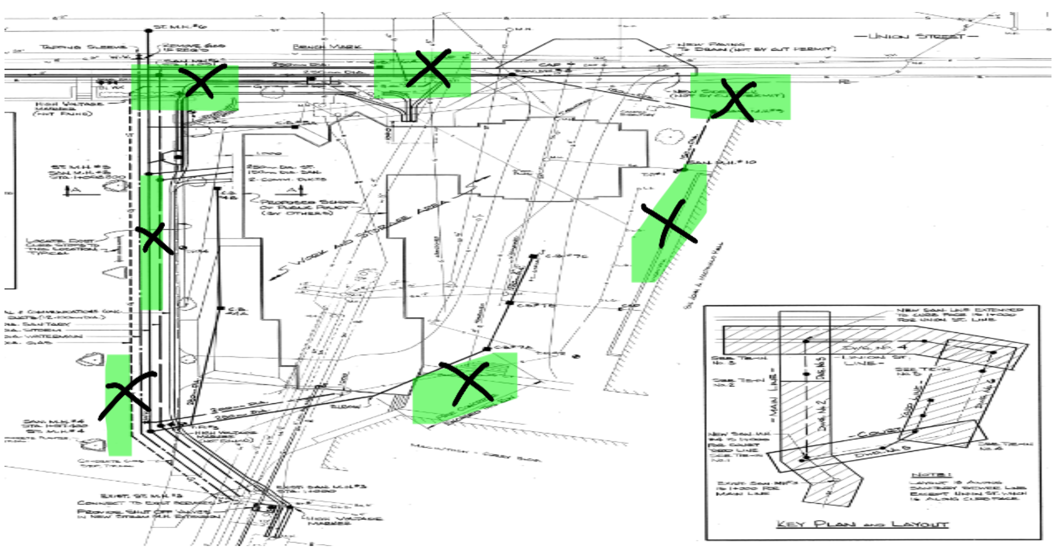


Figure 7: Plan View Sutherland Hall with Proposed Bioswale Locations (Queens Facilities 2024)

Shown below in Figure 8 is the proposed bioswale concept that is to be implemented at Sutherland Hall. This conceptual visualization of the bioswale design was taken from the Department of Engineering Services in Vancouver, BC (Vancouver 2023)

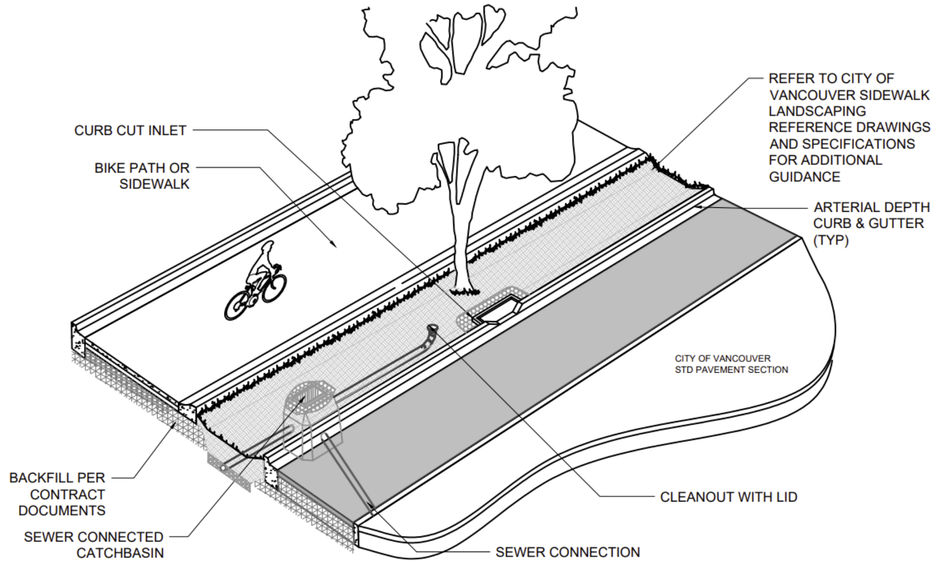


Figure 8: Bioswale 3-D Render (Vancouver 2023)

The cross-section and plan view of the proposed bioswale can be seen below in Figure 9 and Figure 10.

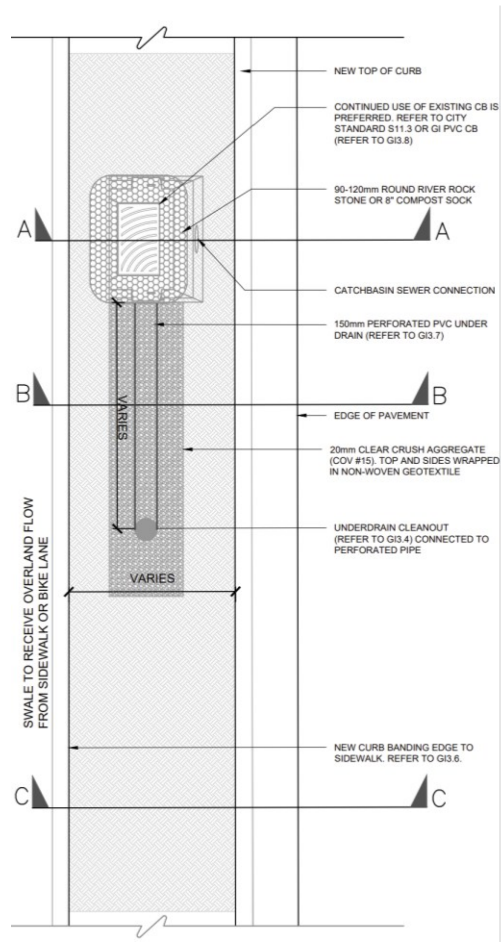


Figure 9: Bioswale Plan View (Vancouver 2023)

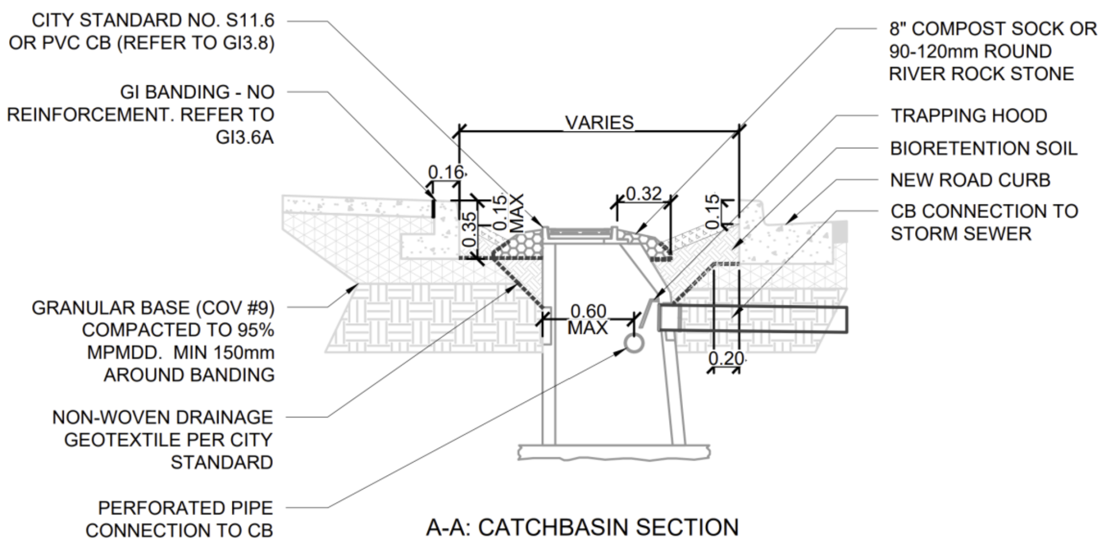


Figure 10: Bioswale Cross-Section (Vancouver 2023)

3.1.2 Infiltration Trench

GICO explored low impact development solutions to mitigate excess stormwater runoff, due to its feasibility in cost, construction, environmental impact, and limited use of heavy-civil machinery and equipment.

Infiltration Trenches are an environmentally sustainable mechanism to combat excess stormwater and promote natural infiltration. Implementing them around Sutherland Hall would reduce runoff around the surface perimeter and decrease the risk of flooding (CASQA 2003).

Figure 11 shows a cross section of the proposed infiltration trench where layers will be composed of sand, gravel and pea gravel. The infiltration trench will follow the perimetrical pathway of the catch-basins along Sutherland Hall. The trench will remove hardscape asphalt material and be replaced. Excavation during the construction phase will have to be conducted to create the trench. The maximum excavation depth anticipated for the trench would be approximately 1 meter, which can be seen in Figure 12.

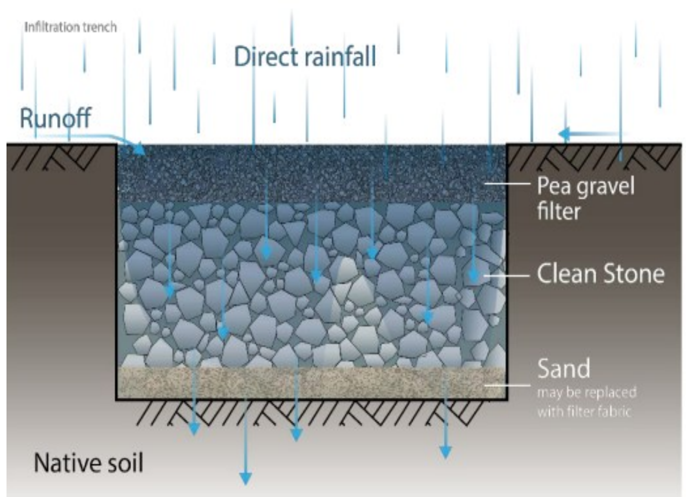


Figure 11: Cross Section of Infiltration Trench (CASQA 2003)

The construction of the trench can be a challenge, but it is still low impact as the excavation depth is less than a meter. The maximum excavation depth anticipated for the trench would be approximately 1 meter, which can be seen in Figure 12. This depth was taken to avoid the gas lines that are running under the grade. If excavation were to be past the gas line, this could drastically affect the cost, however, this can be built without doing that. The green lining represents the existing ground, and the blue marking represents the gas line in Figure 12.

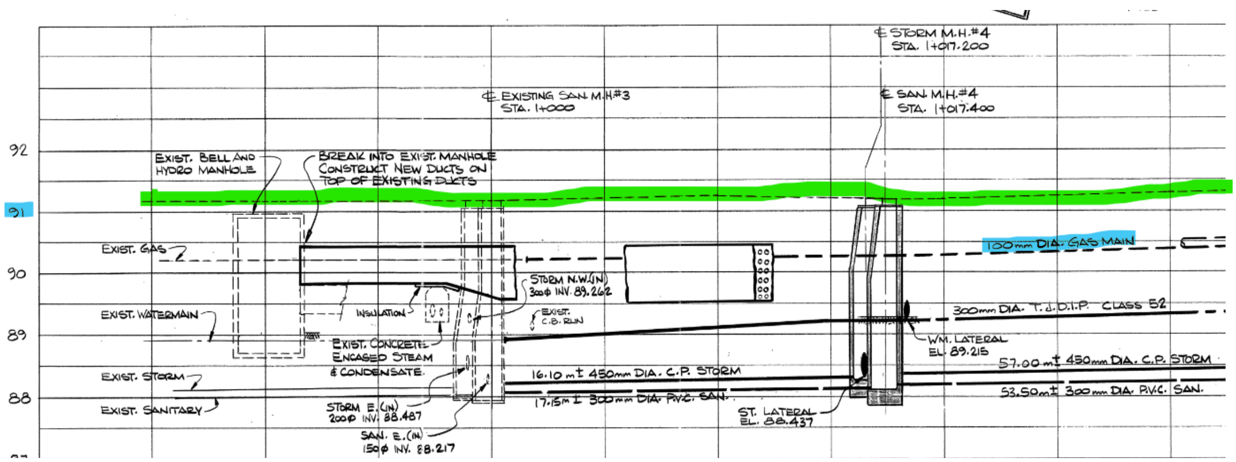


Figure 12: Profile View of Existing Ground and Excavation Depth with Gas Lines Marked (Queens Facilities 2024)

3.1.3 Permeable Interlocking Concrete Pavers (PICP)

Permeable interlocking concrete pavements (PICP) are designed with layers of varying-sized stones or aggregates beneath the surface, which filter and direct stormwater into the existing storm system underneath the existing grade (Belgard 2024). These pavers are engineered to slow down infiltration from heavy rainfall and have vegetation embedded between the space of each paver, making them an environmentally friendly alternative to traditional concrete pavements. The key design feature of permeable pavers that enhances drainage is their porous composition. This allows water to filter through, reducing runoff and minimizing the risk of localized flooding that accumulates on the surface and makes its way into Sutherland Hall's basement. Additionally, PICP pavers are heavier in weight and can create adequate compaction of the granular material underneath, which can prevent material from eroding (Belgard 2024). This not only stabilizes the ground but also reduces soil runoff, further improving water flow and drainage.

Unlike conventional pavements, permeable pavers feature more gaps between the stones, allowing stormwater runoff to drain efficiently. PICPs offer durability, are well-suited for areas with heavy foot traffic such as the premises of Sutherland Hall and provide an aesthetically pleasing look to the existing study area. Essentially, this method will consist of removing hardscape material along the front entrance of Sutherland Hall and replacing it with more permeable material. Examples of PICPs can be seen below in Figure 13 and Figure 14.

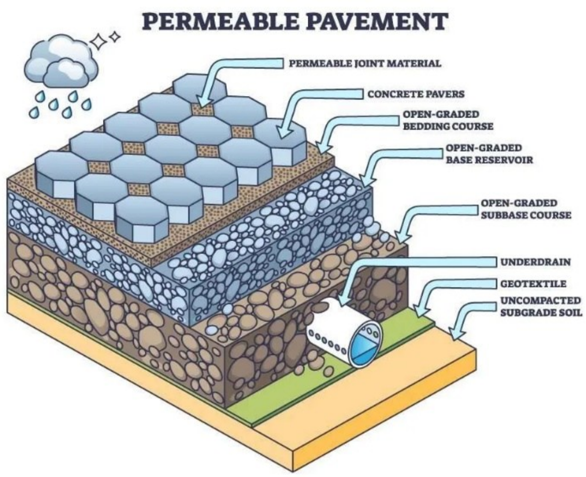


Figure 14: Permeable Pavement Cross-Section (Toronto 2023)

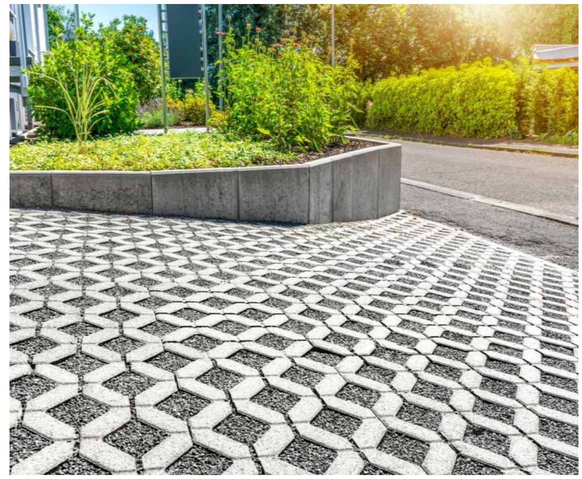


Figure 13: Permeable Pavement Plan View (Toronto 2023)

Studies have been conducted in measuring the volumetric runoff reduction behaviour in permeable concrete interlocking pavers, as shown below in Figure 15 (Toronto 2023). It was recorded that there was a 99% runoff reduction in a series of different areas within King City, Ontario (about 300 km west of Kingston) that had permeable pavers, supporting its use for stormwater management for Sutherland Hall (Toronto 2023).

LID Practice	Location	Runoff Reduction[1]	Reference
Permeable pavement without underdrain	Guelph, Ontario	90%	James (2002)
	Pennsylvania	90%	Kwiatkowski *et al.* (2007)
	France	97%	Legret and Colandini (1999)
	Washington	97 to 100%	Brattebo and Booth (2003)
	Connecticut	72%[2]	Gilbert and Clausen (2006)
Permeable pavement with underdrain	King City, Ontario	99%[4]	TRCA (2008b)
	North Carolina	98 to 99%	Collins *et al.* (2008)
	United Kingdom	50%	Jefferies (2004)
	United Kingdom	53 to 66%	Pratt *et al.*, 1995
	Maryland	45 to 60%	Schueler *et al.* (1987)
Runoff Reduction Estimate[3]		**85% without underdrain; 45% with underdrain**	

Figure 15: Measured Runoff Reduction for Permeable Pavers in King City, ON (Toronto 2023)

The proposed locations to install PICP and remove hardscape material is the entrance of Sutherland Hall and the conjunction between Sutherland Hall and Mackintosh-Corry Hall. Figure 16 and Figure 17 below show the plan view image of where the construction of PICP will take place.

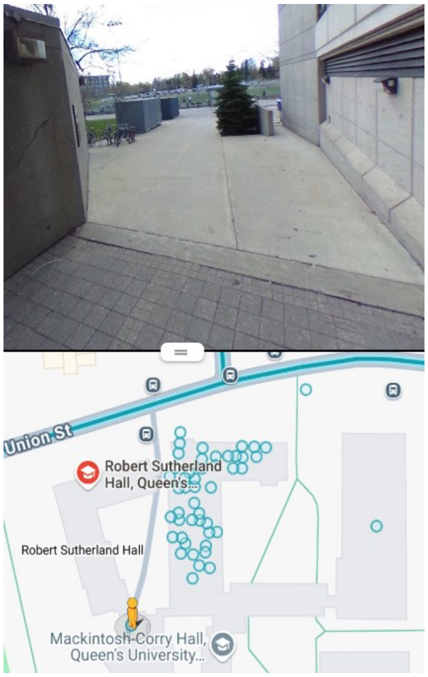


Figure 16: Proposed Locations of PICP Install ("Google Maps" 2024)

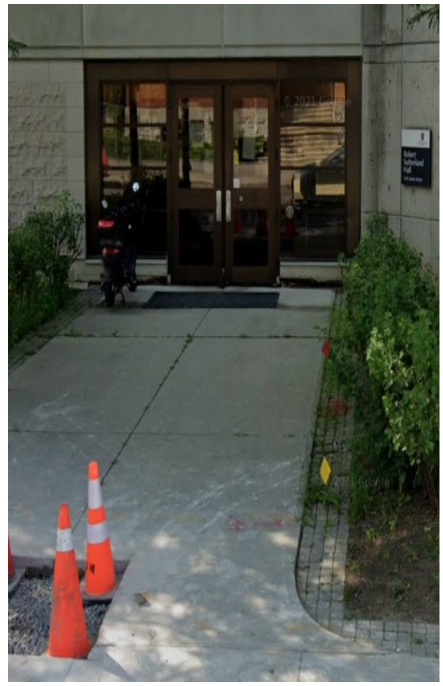


Figure 17: Proposed Locations of PICP Install ("Google Maps" 2024)

3.1.4 Grate Maintenance Monitoring System

During one of the visits to Sutherland Hall after a rainfall event, many grates were seen to have been clogged with leaves and debris. It was also apparent that these areas had excess stormwater runoff.

A Queen's Facilities staff member explained that routine checks by maintenance staff do occur for the grates. However, they are schedule-based. Clogging can happen at any time irrespective of the maintenance schedule, and if there was a heavy rainfall period where a scheduled routine check did not take place, then the grate can be susceptible to clogging.

GICO proposes a monitoring device to be installed inside the grates around Sutherland Hall, which can communicate and send signals to Queen's Facilities staff when the volume in the grate exceeds a baseline amount. This eliminates the need for routine checks by Facilities staff and only notifies the staff when the grate needs cleaning and is clogged. A continuous monitoring system would ensure that grates are always clog-free, allowing for continuous stormwater collection and minimizing local flooding.

There are a variety of industry sensors that are used for this exact reason, to monitor drainage grates and send signals to maintenance staff to clean. It is installed inside the grate and works wirelessly, as shown below in Figure 18. The figure shows the IOT

Ultrasonic Sensor, which is a Danish technology in grate monitoring and is used in the municipal engineering industry in Danish cities for stormwater management ("Reliable Remote Monitoring of Drain Grates" 2024).

Figure 18: IOT Ultrasonic Sensor installed inside Grate ("Reliable Remote Monitoring of Drain Grates" 2024)

3.2 Future Solution Alternatives

The following solutions are designed for future construction projects, to further increase storm water management. These solutions are higher budget and more creative long-term solutions, compared to the lower budget and quick implementation of the proposed present solutions.

3.2.1 Green Roof

As stated in the Background Research Section, green roofs (pictured below in Figure 19) use plants and vegetation to combat stormwater flooding through infiltration and evapotranspiration.

Figure 19: Example of a Green Roof (Probst Stuckmann 2023)

The key requirement for the successful integration of a green roof system is that the roof on which the system is placed, must be flat. If this is not the case, instead of infiltrating the soil, the stormwater will flow quickly down the sloped roof and won't be infiltrated. This would cause the green roof to be inefficient but also would mean less water for the plants and, therefore, would cause plant death. Additionally, if the roof is sloped, additional reinforcements would have to be constructed to keep the soil from being pulled off the roof by shear force ("Sloped Green Roofs" 2011).

Concerning green roof design, the group has evaluated two types of green roofs. They are extensive green roofs and intensive green roofs.

Intensive green roofs:

- Have deep substrate layers (250 to 750+ mm)
- Are smaller in area than extensive green roofs.
- Require more maintenance and landscaping.
- Include lawns, shrubs, and even trees.
- In terms of efficiency, intensive green roofs reduce annual runoff by 65 to 85% of annual precipitation, according to a study from Mentens, Raes, and Hermy in 2006 (Zhang et al. 2015).
- Costs around $25- $35 per square foot ("Green Roof Cost" 2023).

Extensive green roofs:

- Have a shallow substrate layer (less than 200 mm in depth).
- Cover a large area.
- Are lighter, require less structural support, and need less frequent maintenance.
- Extensive green roofs include mostly grass.
- Extensive green roofs reduce annual runoff by 27% to 81%(Zhang et al. 2015).
- However, according to the Gregoire and Clausen study (2011), using meta-analysis, extensive green roofs constructed to reduce stormwater runoff were able to intercept, retain and evapotranspirate 34% to 69% of precipitation with an average retention of 56% (Zhang et al. 2015).
- Costs around $10-$20 per square foot ("Green Roof Cost" 2023).

Looking strictly at the roof layout of the halls outlined in the report's scope, the four roofs are acceptable for green roof integration, as each has a large flat rooftop. This is seen below in Figure 20, Figure 21, Figure 22, and Figure 23. An added benefit of the green roof solution is that Queen's University Facilities already maintains over 140 acres of lawns, trees, flowers, and sidewalks throughout the four seasons; therefore, there is already a dedicated service for maintaining the proposed solution ("Facilities at Queen's University" 2025).

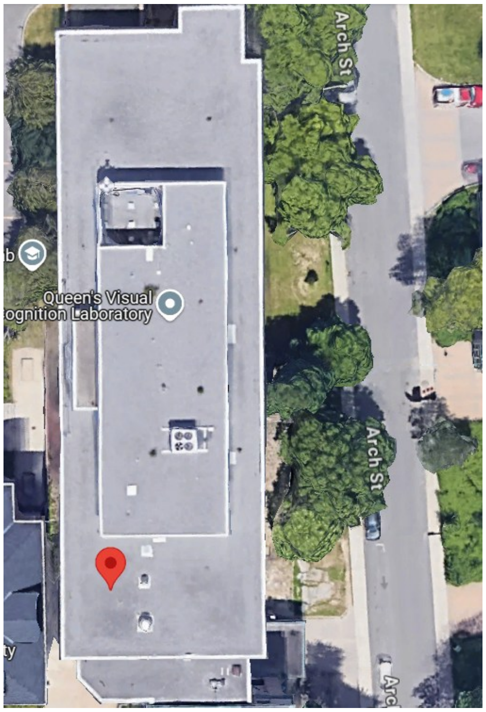


Figure 20: Roof of Humphrey Hall ("Google Maps" 2024)

Figure 21: Roof of Sutherland Hall ("Google Maps" 2025)

Figure 22: Roof of Mackintosh Corry Hall ("Google Maps" 2025)

Figure 23: Roof of Beamish Munroe Hall ("Google Maps" 2025)

3.2.2 Blue Roof

As discussed in Section 2.5, blue roofs collect and slowly discharge heavy stormwater through the roof's existing drainage system. This can be done in many ways, but the two main types of blue roofs are active and passive blue roofs. Active blue roofs use mechanical means to control the rate of water drainage. This is done through a computer that monitors water pressure against a valve and automatically controls the outflow based on that pressure. The computer also monitors the roof's water level to prevent overflow. The passive blue roofs do not require direct control systems; they use physical obstructions, pressure valves, and gravity to control drainage flow. Figure 24 below is an annotated cross-section of a passive blue roof system ("Design Considerations for Blue Roofs" 2017).

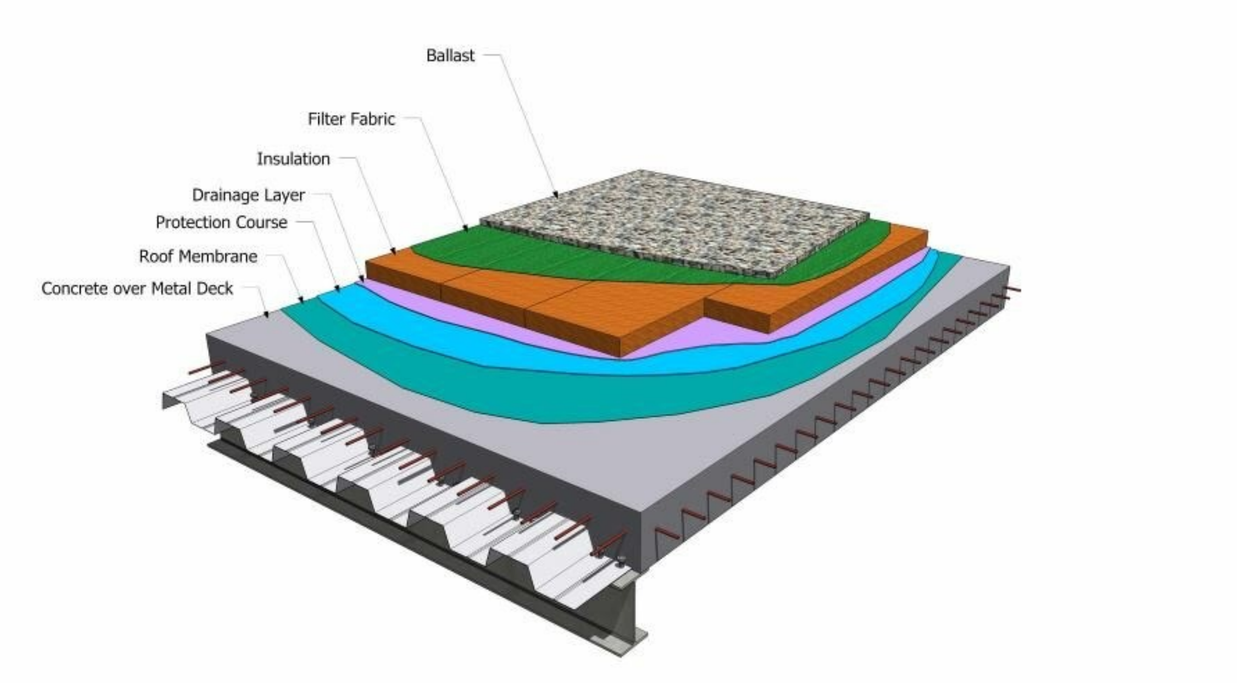


Figure 24: Blue Roof Cross-Section ("Design Considerations for Blue Roofs" 2017)

In terms of efficiency in stormwater management, managing stormwater runoff, and reducing flooding risk, blue roofs are known to be superior relative to green roof systems in terms of flat roofs. Green roofs, however, have the benefit of improving air quality and reducing energy costs.

Blue roofs are significantly cheaper than green roofs in recent years. A basic blue roof can cost as little as $1 per square foot ("The Rise of The Blue Roof" 2024). While the basic blue roofs are relatively cheap, smart blue roofs that recycle stormwater can cost as much as $365 per square meter ("The Rise of The Blue Roof" 2024).

3.2.3 Blue-Green Roof

Blue roofs are very efficient under stormwater management, but an alternative and innovative approach has been discovered during further research into blue roofs. This innovative approach is blue-green roofs. Blue-green roofs create an extra blue water retention layer underneath the green layer. This allows more stormwater to be stored and the valve to be opened in extreme precipitation periods. This allows for the water buffer capacity of the system to be maximized during extreme precipitation periods. The infiltration and evapotranspiration benefits of green roofs in terms of stormwater management are also applied, making stormwater management extremely efficient. Additionally, the environmental benefits of green roofs, such as improving air quality, are also present in the blue-green roof designs. The cross-section of a blue-green roof design can be seen below in Figure 25 (Busker et al. 2022).

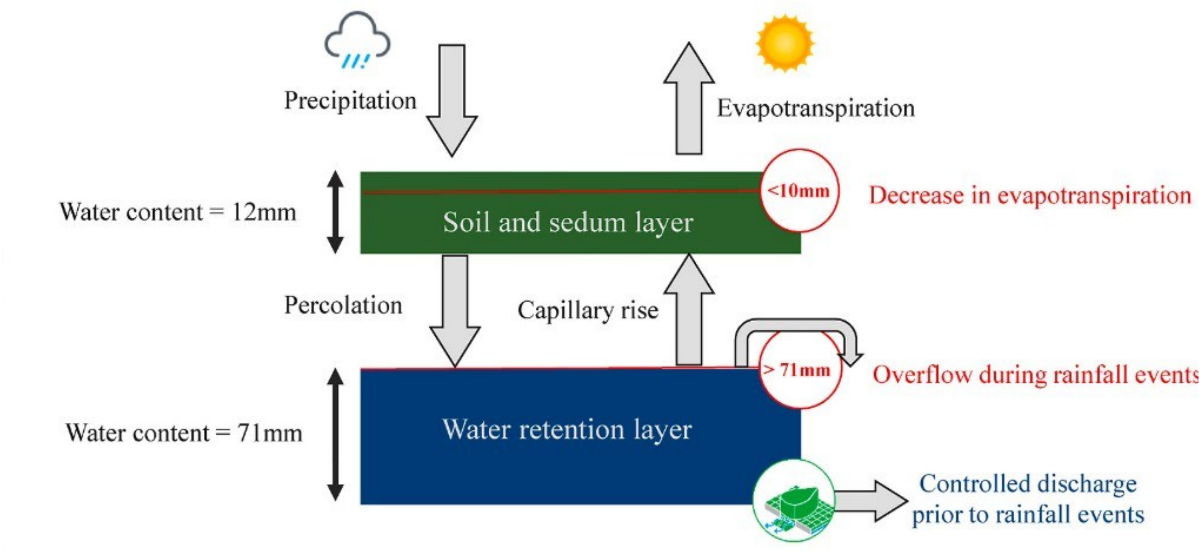


Figure 25: Blue-Green Roof Cross-Section (Busker et al. 2022)

The blue-green roof has a capture ratio during extreme precipitation (greater than 20 mm/hr) of 70% to 97% when set to anticipate the ensemble precipitation forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF) (Busker et al. 2022). Capture rate refers to the proportion of rainfall temporarily stored and managed on the roof surface, rather than immediately being discharged into the stormwater system. The analysis of the blue-green roof found that, without using the precipitation forecast and keeping the valve closed, the capture ratio was still 59%. These capture ratios are significantly higher than conventional green and blue roofs. Moreover, blue-green roofs have higher evapotranspiration rates than measured green roofs on a hot summer day, around 70% for the blue-green roofs compared to 30% for green roofs. (Busker et al. 2022).

Concerning the cost of implementing such a design, as it is a combination of the blue roof and green roof designs in its simplest form, it will be slightly more expensive. The cost of a blue-green roof installation ranges from $25-$35 per square foot (“Green Roof Cost” 2023).

4 Design Selection

The critical criteria used to evaluate the future solutions were based on the constraints provided by the client (Queen’s University Facilities) and are discussed in detail in Section 2.3. The evaluation criteria include constructability, environmental impact, cost, construction duration, pedestrian-friendliness, and aesthetic appeal. The evaluation matrices follow a "weight" and "score" sequence in which each constraint has a set weight based on how vital the constraint is, and the score is GICO's ranking in that category. The score will range from 1 to 5, with 5 being ranked best.

Environmental Impact – Weight: 5

- Considered fundamentally crucial to the success of the design project.
- Directly supports the project's primary focus: improving stormwater management on Queen's campus.
- Reflects the value placed on sustainable and environmentally responsible design choices.

Pedestrian Impact – Weight: 5

- Highly prioritized due to the importance of the student population as a key stakeholder.
- Ensures the design accommodates the daily movement, safety, and accessibility of students on campus.
- Mitigates disruptions to the pedestrian experience during and after construction.

Stormwater Management – Weight: 5

- The primary focus of the project is to improve water runoff control on Queen's campus.
- Weighted heavily to reflect its central role in evaluating the effectiveness of each proposed design.
- Aligns directly with the core objective of the project.

Cost – Weight: 5

- Weighted highly to reflect the budget constraints set by Queen's University.
- The design was required to be as cost-effective as possible to meet funding limitations.
- Also considers long-term cost implications and value for money.

Constructability – Weight: 5

- Given equal priority to cost due to the need to minimize construction duration.
- A longer construction period would negatively impact the student experience through prolonged disruption.
- Extended construction also increases labour costs, which conflicts with the budget-conscious approach of the project.

Aesthetics – Weight: 3

- While not essential for stormwater management performance, aesthetics are still valued.
- Important to both the client (Queen's University) and the student body for campus integration and visual appeal.
- Weighted accordingly to recognize its secondary, but still meaningful, importance.

Maintenance – Weight: 3

- Assigned a moderate weight based on the group's confidence in Queen's Facility Services to manage upkeep.
- The selected designs are not expected to require extensive ongoing maintenance.
- The rating reflects the team's intention to avoid placing additional strain on a maintenance team already managing a busy schedule.

4.1 Present Solutions

The solutions to be implemented for current buildings are evaluated below in Table 3.

Table 3: An Evaluation Matrix for the Proposed Present Designs

Criteria	Weight	Bioswales		Infiltration Trench		PICP		Grate Maintenance	
		Score	Weighted (Weight* Score)	Score	Weighted	Score	Weighted	Score	Weighted
Constructability	**5**	3	15	3	15	4	20	5	25
Environmental Impact	**5**	3	15	4	20	4	20	5	25
Cost	**5**	3	15	4	20	3	15	3	15
Construction Duration	**3**	3	9	5	15	5	15	3	9
Pedestrian Impact	**5**	2	10	4	20	5	25	5	25
Stormwater Management	**5**	3	15	4	20	5	25	2	10
Aesthetics	**3**	4	12	4	12	5	15	1	3
Total (sum)			**91**		**122**		**135**		**112**

PICP's were selected for the proposed present design, based off the evaluation matrix above. The scores for each design aspect in the evaluation matrix for PICP were assigned based on its superior constructability and minimal environmental impact, primarily due to the reduced need for gasoline-powered equipment. Excavation can be done with the use of hand digging rather than using heavy skid steer equipment. Due to the minimal use of equipment and shallow excavations, the cost would then be much cheaper than the other design options; however, since the PICP's are a unique make of interlock, it would still be a relatively expensive compared to traditional measures, making it a score of 3. Construction duration and pedestrian impact were both given a score of 5 because they require the least amount of time to construct and have the most accessible detour routes so that pedestrian traffic will not be impacted. Stormwater management was ranked as 5 as the calculations show the infiltration is at an appropriate level compared to traditional interlock concrete pavers that are not as permeable, so it was ranked high because it mathematically shows good infiltration performance. Lastly, aesthetics was given a 5 for PICP because it will remove existing plain concrete and replace it with a beige-coloured interlock stone that will match the building's colour and landscape.

4.2 Future Solutions

The solutions to be implemented for future buildings are evaluated below in Table 4.

Table 4: An Evaluation Matrix for the Proposed Future Designs

Criteria	Weight	Green Roof		Blue Roof		Blue-Green Roof	
		Score	**Weighted (Weight*Score)**	**Score**	**Weighted**	**Score**	**Weighted**
Constructability	**5**	4	20	4	20	3	15
Environmental Impact	**5**	5	25	2	10	5	25
Cost	**5**	3	15	5	25	3	15
Maintenance	**3**	3	9	4	12	2	6
Stormwater Management	**5**	3	15	4	20	5	25
Aesthetics	**3**	5	15	1	3	5	15
Total (sum)			**99**		**87**		**101**

Through the use of the weighted evaluation matrix (Table 4) the future design chosen for further investigation is the Blue-Green Roof system. Concerning constructability, green roofs and blue roofs both scored 20 points due to them both being difficult to construct, but there are plenty of businesses that specialize in their construction. Blue-green roofs, however, merge the two ideas and, therefore, would be more difficult to construct, which is why it was rated 15 points. The environmental impact of green roofs and blue-green roofs were rated the same (25 points) due to their environmental benefits, both coming from the vegetative layers, which are prominent in both designs. Blue roofs have a score of 10 due to them having little environmental benefit. Green roofs and blue-green roofs scored 15 points for cost due to their similar high cost of $25-$35 per square foot ("Green Roof Cost" 2023). Blue roofs, however, can be as little as $1 per square foot based on their complexity ("The Rise of The Blue Roof" 2024), which is why it was awarded 25 points. Green roofs were awarded 9 points for maintenance due to the high maintenance required to take care of plants on a recurring basis. The blue roof was awarded 12 points as regular maintenance is required but not as much as is needed with green roofs. However, as blue-green roofs are a merge of both systems, they require much more maintenance than blue and green roofs separately as the vegetation must be taken care of regularly, as well as the blue roof's mechanical maintenance and therefore was given 6 points. In terms of stormwater management, green roofs were given a score of 15 as the infiltration is effective but nowhere near as effective as blue roofs, which were given 20 points, and blue-green roofs, which were given 25 points, which encapsulates the benefits of both roof's stormwater management techniques. The last category that was outlined was aesthetics. The green and blue-green roof designs scored 15 points due to the beautiful vegetation, which creates a positive aesthetic. The blue roof, however, is just mechanical components and is not pleasant to look at, which is why it was given a score of 3 points.

4.3 Stormwater Diversion Plan

The final stormwater diversion plan will consist of two designs to improve rainwater management on the Queen's campus. Based on the weighted evaluation matrices above in Table 3 and Table 4, permeable interlocking concrete pavers and a blue-green roof system are the best approaches in terms of the selected criteria.

4.3.1 Present Solution: PICP

Permeable interlocking concrete pavers performed well in all categories, especially construction duration, pedestrian impact, and aesthetics. PICPs can be implemented relatively quickly to address flooding around current buildings on campus. Their porous composition allows for rainwater drainage directly into the existing storm sewer system, effectively managing excess water and reducing environmental impact. They also have no negative impacts on aesthetic or pedestrian use, as they are embedded in the ground like regular pavers. Their cost ranks about average with respect to the other options, however future maintenance costs will be minimal.

4.3.1 Future Solution: Blue-Green Roof Systems

Blue-green roof systems are ideal for future builds on campus, when they can be considered throughout the building's design process—and their weight can be accounted for. Blue-green roof systems excel in the categories of environmental impact, stormwater management, and aesthetics. They combine the best qualities of each individual roof system, providing the stormwater management capabilities of a blue roof, and the environmental benefits and aesthetic of a green roof. The trade-offs of these benefits are the complexity of the construction process, and the increased costs associated with the blue-green roof. A blue-green roof system is estimated to cost approximately $25 to $30 per square foot, compared to $20 per square foot for green roofs and $1 per square foot for blue roofs.

In summary, the designs meet the necessary regulatory compliance as discussed in Section 2.3. Their implementation will help mitigate the impacts of flooding, including environmental effects, health and safety risks, and cultural and ethical issues. Reducing these impacts will ensure Queen's meets the required standard of care.

5 Mathematical Models

Mathematical models were identified to better illustrate the drainage systems and help develop specifications for the final designs.

5.1 Rational Method

The rational method can be utilized to determine the peak flow over the Sutherland Hall grounds. The peak flow will be calculated and compared to the peak rainfall values provided by the client. The Rational Method is helpful for modelling PICPs because it effectively estimates peak runoff rates from a surface, using basic parameters like rainfall intensity, surface area, and a runoff coefficient. This allows for a quick comparison between permeable and impermeable surfaces and helps predict how much stormwater will infiltrate versus runoff. The total area of Sutherland Hall is 1045.01 m^2, and the total area of Sutherland Hall and its surrounding area is 3589 m^2, as depicted in Figure 26 and Figure 27 respectively.

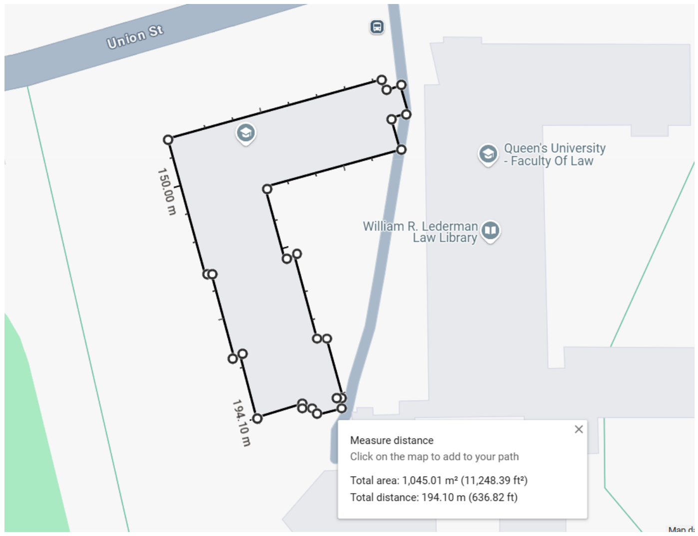


Figure 26: Area Measurement of Sutherland Hall (Google Maps 2024)

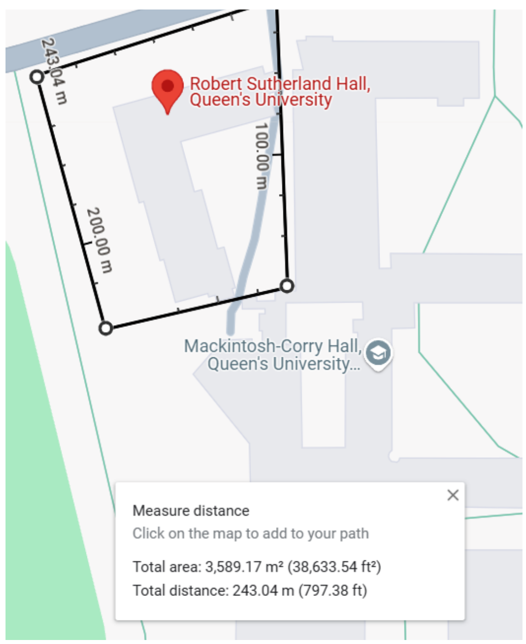


Figure 27: Total Area of Sutherland Hall and Surrounding Area (Google Maps 2024)

The rational method is modeled using Equation 1 below. Equation 1's variables are defined in Table 5. This calculation assumes a 25-year storm.

$$Q_p = Aci \qquad (1)$$

Table 5: Rational Method Variables

Variable	Definition
Q_p	Peak Flow (ft^3/s)
A	Area (acres)
c	Runoff coefficient
i	Rainfall intensity (inches/hour)

Since the general area of Sutherland Hall is impervious material (asphalt, concrete, impermeable surface) the runoff coefficient can be taken as 0.9. The rainfall intensity value can be taken as 8 mm/hr from the provided Sutherland Hall rainfall information, which can be converted to 0.312 inches/hr. Therefore, the peak flow can be calculated:

$$\boldsymbol{Q_p = Aci} = (0.88\ acres) * (0.9) * \left(0.312\,\frac{inches}{hour}\right) = \boldsymbol{0.247\ ft^3/s}$$

0.247 ft^3/s can be converted to 6.99 L/s, by multiplying a factor of 28.32. This compares more with the peak design flow of 4.88 L/s.

5.1.1 Infiltration Calculation of PICP

To further mathematically model the infiltration of the PICP and have a quantitative value for its infiltration, the Darcy's law equation for flow through porous material will be used to model this. It is important to know the amount of infiltration for PICP's because the amount can be compared to other variety of PICP's and the one with the highest infiltration will be the most appropriate to use, as infiltration is encouraged to combat excess stormwater runoff. Equation 2 below illustrates the mathematical model for infiltration in PICP's.

$$Q = \frac{kA\Delta h}{L} \tag{2}$$

Table 6: Darcy Flux through Porous Media Variables

Variable	Definition
Q	volumetric flow rate (m^3/s)
k	hydraulic conductivity (m/s)
A	cross-sectional area (m^2)
Δh	hydraulic head difference (m)
L	length of flow path (m)

Since the majority of the subgrade soil will be composed of ASTM gravel material, a mean hydraulic conductivity value, k, for gravel can be taken as 1×10^{-4} m/s. The cross-sectional area can be taken as 2544 m^2 as measured in the previous equation, the hydraulic head difference as 1 meter since construction will be above the potentiometric surface and will not impact any blow-out of water pressure when excavating. The length of the flow path can be taken as 243 m. Thus, resulting in a volumetric flow rate of 0.0014 m^3/s.

5.2 Blue-Green Roof Storage

A blue-green roof system can be modelled mathematically as a modular green roof system placed on top of a blue roof detention layer. The total storage of the system can be calculated using Equation 2, below (Martin and Kaye 2020). The storage value will be used to size the depth of the roof system and evaluate its effectiveness in water collection.

$$S = A_R(\Phi H_G + H_B) + \forall_{soil} \tag{3}$$

Equation 2's variables are defined below in Table 7.

Table 7: Storage Equation Variables

Variable	Definition
S	Storage capacity (m^3)
A_R	Plan area (m^2)
Φ	At field capacity porosity
H_G	Depth of the upper green roof submodule (m)
H_B	Depth of the lower blue roof submodule (m)
$\forall_{soil}$	Soil retention storage volume (m^3)

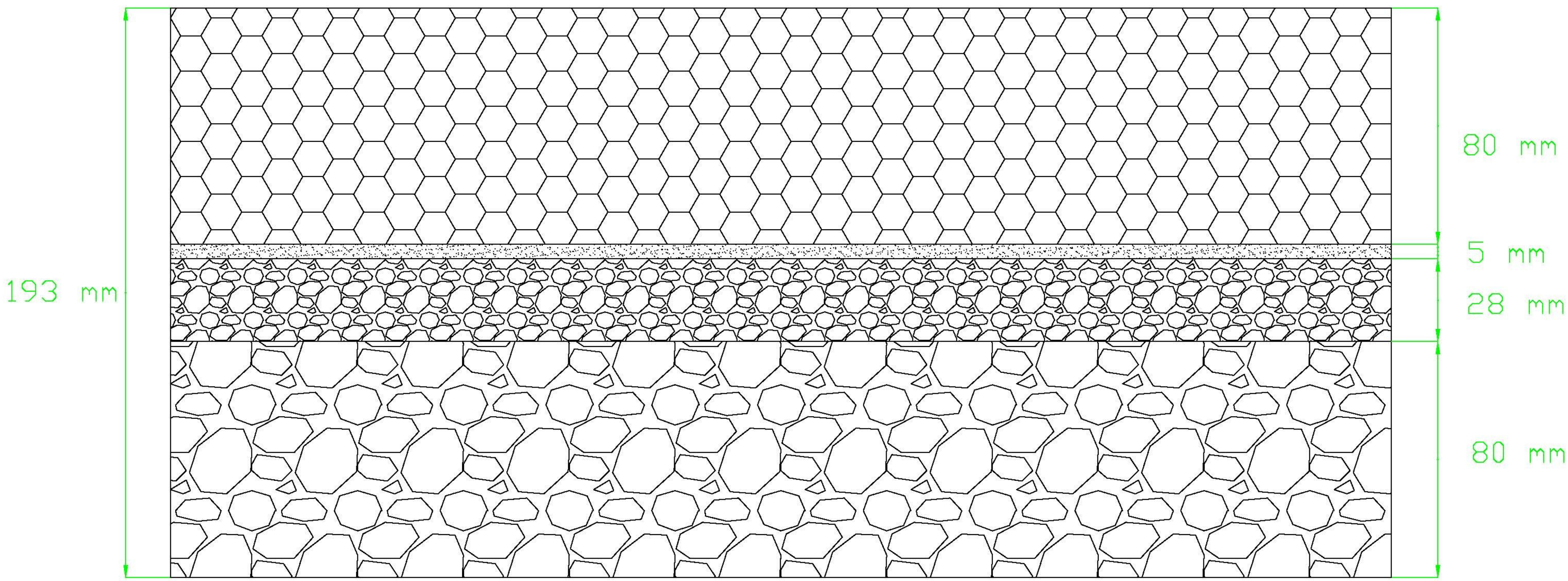
6 Design Specifications

The details of both designs were developed in consideration of the project's design criteria, constraints, and mathematical models.

6.1 Permeable Interlocking Concrete Pavers

The cross-section of the permeable interlocking concrete pavers designed by GICO consists of four layers: a permeable interlocking concrete paver layer, ASTM No. 8, ASTM No. 57, and ASTM No. 2. The PICP layer acts as a traffic-bearing surface that allows for water infiltration (Federal Highway Administration 2015). The ASTM No. 8 layer has particles under 9.5 mm, and its purpose is to create a level bed for the PICP (Mutual Materials 2012).

The ASTM No. 57 layer supports the structural loads as well as provides good drainage (Mutual Materials 2012). The particles for this layer are around 9.5 – 25 mm. Lastly, the ASTM No. 2 layer provides stability for the system as well as a high void space (35-40%), which will be used for water storage (Maryland Department of the Environment 2019). An AutoCAD drawing of the PICP cross-section can be seen below in Figure 28. This design took inspiration from the standard T-850.131 PICP used by the City of Toronto, which consists of a 40-80 mm ASTM No.2 clean washed stone sub-base, 14-28 mm thick ASTM No. 57 stone layer, ASTM No.8 5mm crushed aggregate and lastly the 80mm thick permeable pavers that will be flush with the existing grade (City of Toronto 2021). The PICP will be constructed around the Sutherland Hall area. This area equates to around 2544 m^2 and is outlined in Figure 26. The mean hydraulic conductivity of the PICP layers will be around $1x10^{-4}$ m/s, the flow path's total length is 243 m, and the hydraulic head difference is 1 m.



CIVIL 460 - Capstone Project

FIGURE NO.: 1	TITLE: PICP Cross Section	
GROUP NAME:	G.I.C.O.	(Group A)
GROUP MEMBERS:	Christopher Ridolfi, Ossaid Khan, Grace McAuley, Ivan Bogomolsky	

LEGEND

- ASTM No.2
- ASTM No.57
- ASTM No.8
- Permeable Interlocking Concrete Paver

SCALE:
1 : 0.725

Figure 28: PICP Cross-Section Drawing

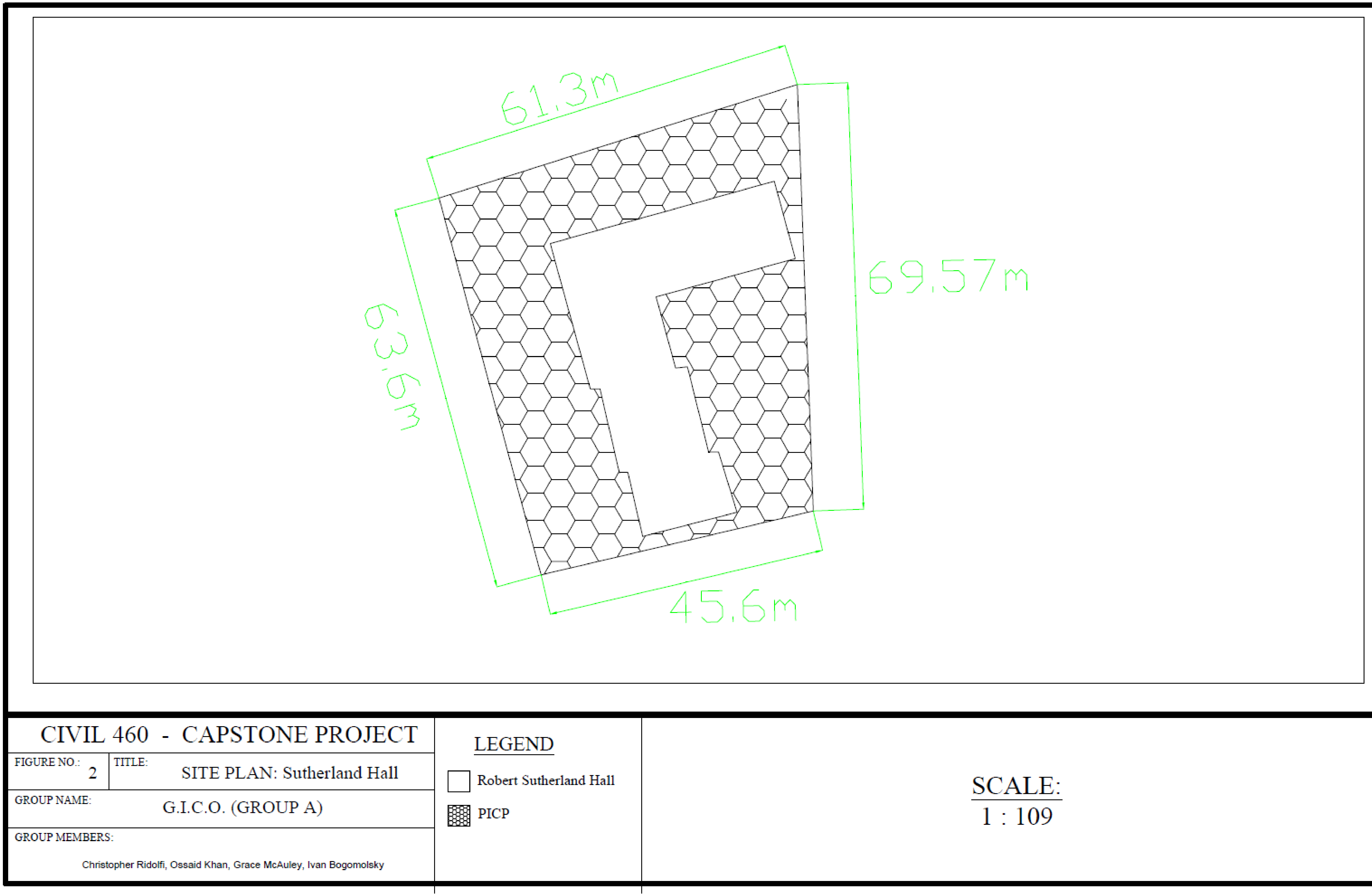


Figure 29: PICP Site Plan Drawing

6.2 Storage Capacity of Blue-Green Roof

The weight of a blue-green roof system must be accounted for in the design of a building. As such, the exact specifications of the system will depend on the specifications of the building. The blue-green roof system may vary based on building dimensions and the project's budget. For the purposes of this report, the LiveRoof Blue-Green detention system will be analyzed *to demonstrate its effectiveness in stormwater mitigation; however,* similar systems are also available from other manufacturers and may be more suited to a specific project. It will be assumed that the system will be installed on the roof of Beamish Monroe Hall (BMH), one of the key flooding locations.

6.2.1 LiveRoof System

LiveRoof is Michigan-based company that produces green and blue roof systems throughout the United States and Canada. It has supplied and installed systems at several universities, including the University of Toronto campus in Mississauga ("University of Toronto Mississauga Green Roofs" 2024). In addition to their environmental benefits, LiveRoof systems are often selected for their versatility and simplistic design and installation process.

The LiveRoof Blue-Green system consists of two sub-modules, an upper vegetation module and lower RoofBlue Detain system. The green layer comes in 4 different options, with varying soil depths and capacities, while the RoofBlue Detain system is standardized.

Technical drawings provided by the manufacturer of the complete system are pictured below in Figure 30 and Figure 31.

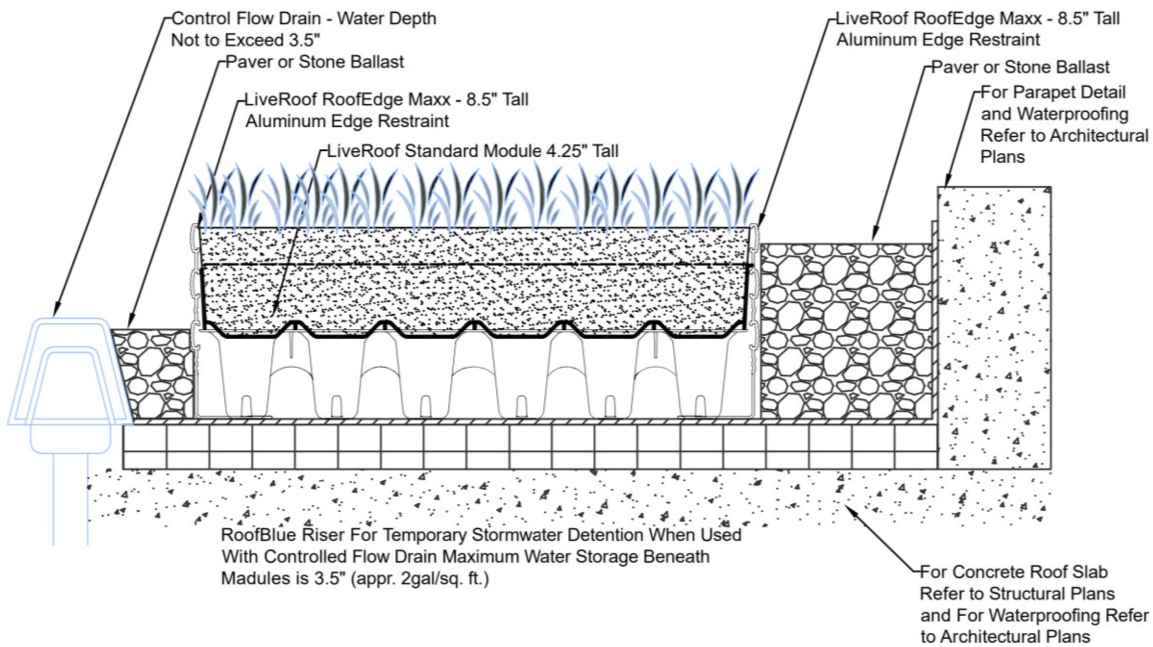


Figure 30: LiveRoof Blue-Green Module Cross-Section ("Blue Green Roof Solutions" 2025)

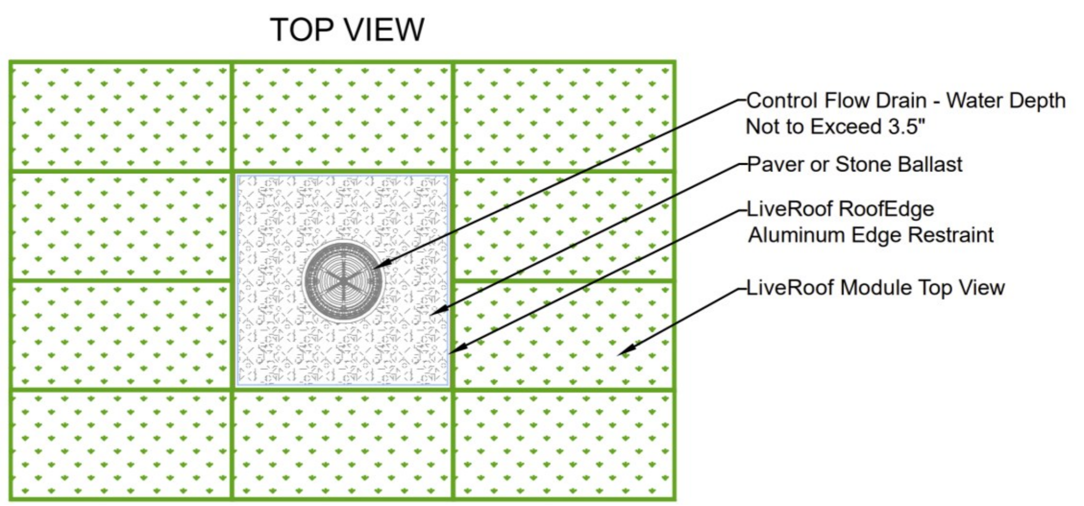


Figure 31: LiveRoof Blue-Green Module Plan View ("Blue Green Roof Solutions" 2025)

6.2.1.1 Stormwater Detention Process

The LiveRoof Blue-Green system utilizes risers, pictured below in Figure 32, to elevate the vegetative layer and allow for additional water storage beneath it. During rainfall events, water is absorbed by the vegetation until it is saturated, after which, it settles into the detaining system until it is slowly released to the ground by control flow roof drains. The detention storage can hold up to 89 mm of rainwater, though the drains should be opened daily during significant rainfall events. Based on the system's design, even at maximum capacity, the roots of the plants are not submerged in the held water, preventing root rot. Excess water is absorbed by the vegetation by travelling up a cloth in contact with both layers.

Figure 32: LiveRoof Blue-Green System ("Blue Green Roof Solutions" 2025)

6.2.1.2 System Specifications

The RoofBlue Detain system can hold a maximum water depth of 89 mm, with an approximate capacity of 80 L/m^2 ("Blue Green Roof Solutions" 2025). The blue module can add up to 0.9 kPa to the roof's loading, for consideration in the building's design ("Blue Green Roof Solutions" 2025).

Specifications for the green module depend on the size selected. Details for each size are summarized below in Table 8.

Table 8: LiveRoof Green Module Details ("Blue Green Roof Solutions" 2025)

	LiveRoof Module Size			
	Lite	**Standard**	**Deep**	**Maxx**
Soil Depth	65 mm	110 mm	250 mm	200 mm
Maximum Fully Saturated Weight (varies by vegetation type and maturity)	<0.8 kPa	<1.4 kPa	<2.4 kPa	<3.1 kPa
Plant Moisture Storage	10.1 L/m^2			
System Storage	28.2 L/m^2	44.4 L/m^2	59.7 L/m^2	80 L/m^2

6.2.1.3 System Sizing

To demonstrate the stormwater mitigation capabilities of the LiveRoof Blue-Green system, BMH will be used as an example to support the system. BMH roof was estimated using Google Maps to be 2733 m^2, as pictured below in Figure 33.

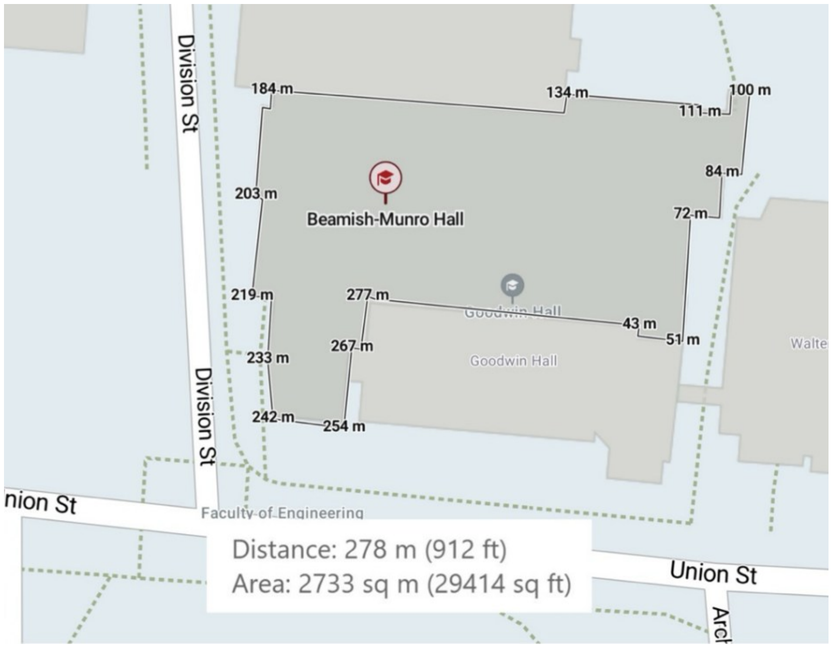


Figure 33: BMH Area ("Google Maps" 2025).

Assuming 60% of the roof can be used for the system, there is 1640 m^2 of available space.

Using Equation 1 from Section 5.2, the storage can be calculated based on the system's dimensions, resulting in a capacity of 207.62 m^3. Values used in this calculation are summarized below in Table 9.

Table 9: Storage Calculation Values

Variable	Definition
S	Storage capacity (m^3)
A_R	1640 m^2
Φ	0.25
H_G	0.11 m
H_B	0.089 m
$\forall_{soil}$	16.56 m^3

Based on the manufacturer's specifications from Section 6.2.1.2 for the RoofBlue Detain module and the "Standard" green module, the total storage capacity is estimated to be

124.40 L/m^2, or 204 m^3 total for the roof of BMH. This value (based on the manufacturer's specifications) is within 2% of the estimation conducted using the storage equation, suggesting that the initial estimation is valid.

7 Design Evaluation

7.1 Permeable Interlocking Pavers Design Evaluation

Since the majority of the subgrade soil will consist of ASTM-rated gravel, an average hydraulic conductivity value (k) of 1×10^{-4} m/s can be used. The plan view area, determined from the previous calculation, is 2544m^2. A hydraulic head difference of 1 meter is assumed, as the construction will occur above the potentiometric surface, eliminating concerns about water pressure blowout during excavation. The flow path length is taken as 243 meters. Based on these parameters, the resulting volumetric flow rate is approximately 0.0014 m^3/s.

A significant difference becomes evident when comparing the infiltration capacity of the permeable interlock surface to the subgrade soil. The estimated infiltration rate through the surface of standard interlocking pavers (that are non-permeable) pathway is approximately 0.00001 m^3/s. In contrast, the calculated infiltration rate through the PICPs that are primarily composed of ASTM-rated gravel using Darcy's Law is 0.0014 m^3/s, having a much higher infiltration rate than standard interlocking pavers. This means the PICPs are capable of accepting water at a rate 150 times greater than the current subgrade. Such a disparity highlights the impact PICPs have in increasing infiltration, reducing direct runoff, and combating localized flooding as compared to traditional interlocking pavers.

7.2 Blue-Green Roof Design Evaluation

The blue-green roof system is designed to effectively manage stormwater by combining the benefits of both blue and green roofs. The total storage capacity of the system is a critical factor in its ability to mitigate flooding. Based on the calculations in Section 5.2, the blue-green roof system on Beamish Munro Hall has a total storage capacity of 207.62 m^3. This storage capacity is achieved through the combination of the green roof's vegetation layer, which absorbs and retains water, and the blue roof's detention layer, which holds excess water and releases it slowly over time.

The system's ability to store such a significant volume of water ensures that during heavy rainfall events, the roof can capture and retain a large portion of the stormwater, preventing it from overwhelming the existing drainage systems. This is particularly important for buildings like BMH, which have experienced recurring flooding issues. By reducing the volume of water that needs to be managed by the stormwater infrastructure, the blue-green roof system significantly lowers the risk of flooding around the building.

The effectiveness of the blue-green roof system is further enhanced by its ability to handle extreme precipitation events. As discussed in Section 3.2.3, the system has a capture ratio of 70% to 97% during extreme rainfall events (greater than 20 mm/hr). This means that even during the most intense storms, the system can retain a substantial amount of water, reducing the likelihood of flooding. Additionally, the system's ability to release water slowly over time ensures that the stormwater infrastructure is not overwhelmed, further mitigating the risk of flooding.

In terms of environmental benefits, the blue-green roof system also contributes to reducing the urban heat island effect, improving air quality, and enhancing biodiversity. The vegetation layer on the roof helps to cool the building and the surrounding area, while also providing a habitat for various plant and animal species. These benefits align with Queen's University's sustainability goals and contribute to creating a more climate-resilient campus.

8 Implementation

The implementation of both designs is discussed below. The group has thoroughly considered the necessary construction tasks and estimated their duration.

8.1 Construction Tasks & Timeline

The construction tasks and timeline for both designs may depend on future factors such as site preparation, weather conditions, material procurement, and labour availability, however a general estimate is provided below.

8.1.1 PICP at Sutherland Hall

PICP construction will take place in 2 stages. This is because, both locations of interest where PICP installation will occur are in the way of the building's entrance. The first proposed location will be the entrance walkway that is facing Union Street. This location consists of 155 m^2 of PICP installation and removing the existing concrete walkway. Once that stage is completed and opened for public usage, the construction of PICP installation in location 2 will proceed in the area facing Tindall field. The time it will take for each stage of PICP installation will depend on a few different aspects, that will mostly depend on the contractor awarded the work, the contractor's crew size, equipment availability, municipal building permits, and the weather conditions. Table 10, shows the construction sequence of PICP installation and the approximate days it may take for the specific task, for both locations. The installation is expected to take 16 working days.

Table 10: PICP Construction Sequence and Duration

Task	Estimated Time to Complete (Days)
Existing Concrete Removal	2
Excavation & Site Preparation	1
Base Installation (Granular layers)	1
Bedding Layer Installation	1
Laying Pavers (30–50 m^2/day for a 2-labour crew)	7
Edge Restraints & Joint Filling	2
Final Compaction & Cleanup	2
Total	16

8.1.1.1 PICP Considerations

PICP installation around the Robert Sutherland Building will be done in 2 key locations to combat flooding and promote more stormwater infiltration around the building premises and reduce runoff. The first location will be the main entrance walkway that faces Union Street, as seen in Figure 17, while the second location is near the alley between Mackintosh-Corey and Robert Sutherland Hall, near Tindall Field, as seen in Figure 16. While the construction takes place in the first location, the entrance to the building will be closed, and a detour sign will be placed directing traffic to go to the rear entrance of the building. This will be for approximately 7 days until the Union Street location is completed. Once it is completed, the entrance facing Union Street will now be opened to the public, and the rear entrance near the second proposed construction location will be closed until completed. This would be the most appropriate detour plan during the construction phase, as the building entrances will still be accessible.

8.1.2 Blue-Green Roof on Beamish Munro Hall

The installation of the blue-green roof system will be carried out in two main stages to ensure proper integration with the building’s structure and to minimize any potential disruptions. The first stage will involve the installation of the blue roof detention layer, which is critical for water retention and controlled discharge. The second stage will focus on the installation of the green roof vegetation layer, which provides additional stormwater management and environmental benefits. The construction timeline will depend on factors such as the contractor’s crew size, equipment availability, municipal building permits, and weather conditions.

The first stage of construction will focus on installing the blue roof detention layer, which is designed to hold and slowly release stormwater. This stage will involve the following tasks:

1. Roof Preparation: The existing roof surface will be inspected and prepared for the installation of the blue roof system. This includes ensuring the roof is structurally sound and applying a waterproofing membrane to prevent leaks.
2. Installation of Control Flow Drains: Control flow drains will be installed to regulate the discharge of water from the detention layer. These drains are essential for managing the flow rate during heavy rainfall events.
3. Laying the Detention Layer: The blue roof detention layer, consisting of modular units designed to hold water, will be installed. This layer will be carefully aligned and secured to ensure proper water retention and controlled release.

Once the blue roof detention layer is completed, the second stage will involve the installation of the green roof vegetation layer. This stage will include the following tasks:

1. Installation of the Vegetation Module: The green roof vegetation layer, consisting of pre-planted modular trays, will be installed on top of the blue roof detention layer. These trays are designed to promote plant growth and provide additional stormwater absorption through evapotranspiration.
2. Soil and Plant Installation: Soil and vegetation will be added to the modular trays, ensuring proper coverage and alignment. The vegetation will be selected based on its ability to thrive in the local climate and provide maximum stormwater management benefits.
3. Final Inspection and Testing: Once the green roof layer is installed, the entire system will be inspected to ensure proper functionality. Water flow tests will be conducted to verify that the control flow drains are operating correctly, and that the system can handle the expected volume of stormwater.

An estimate of the blue-green roof construction duration is summarized below in Table 11.

Table 11: Blue-Green Roof Construction Sequence and Duration

Task	Estimated Completion Time (Days)
Stage 1	
Roof Preparation	3
Installation of Control Flow Drains	2
Laying the Detention Layer	5
Stage 2	
Installation of Vegetation Module	4
Soil and Plant Installation	4
Final Inspection and Testing	2
Total Time	20 days

8.1.2.1 Blue-Green Roof Considerations

Installation of the LiveRoof blue-green system will have minimal impact to students and faculty as it will take place during the buildings initial construction—before it is open to the public. Prior to installation, the roof must also be fitted with a waterproofing membrane and control flow valves as specified by the systems manufacturer. Additionally, as previously mentioned, the weight of the system (estimated to be 2.3 kPa for a standard green and blue module, based on the specifications in Section 6.2.1.2) must also be accounted for prior throughout the design process, in order to comply with the necessary building codes.

8.2 Maintenance

This section will explore the required maintenance protocol for the selected final designs. This will provide the client with what to expect when the final designs are implemented.

8.2.1 Permeable Interlocking Concrete Pavers Maintenance Procedures

Maintenance for PICPs will address weed growth and winter conditions.

8.2.1.1 Weed Growth

With PICP's installed, weed growth can occur and sprout through the paver's seams. This can be aesthetically displeasing to the overall campus architecture. As well as cause infiltration issues as the weeds block the porous material and prevent adequate drainage (Toronto 2023). Monthly maintenance should take place by Queen's Facilities' staff to pull out weeds while they are small between the pavers. In the event maintenance does not occur the mentioned issues may arise, potentially impacting the pavers themselves.

8.2.1.2 Winter Maintenance

The PICP's will require snow removal, however this falls under the current responsibilities of Queen's staff. According to one study, PICPs require 75% less salt than regular impervious pavement (Toronto 2023). Too much salt can create potential groundwater contamination as the chlorides from the salt can seep through the porous material and should be distributed at a lesser volume. Snow machines and shovel cleaning mechanisms can be used on PICP's like any other pavement material.

8.2.2 Blue-Green Roof Maintenance Procedures

Semi-annual inspections should be conducted to assess the roofs components and check for damage or other issues. Between inspections, maintenance of the vegetative layer will be similar to a typical planting bed, requiring watering, weeding, pruning, and cleaning as needed ("Inspection and Maintenance: Green Roofs" 2022).

During significant rainfall events, the detention layer should be drained every 24 hours. Outlets should also be checked to ensure they are draining properly. Leaks may need to be patched by repairing the water-proofing membrane.

8.3 Consideration of Codes and Regulations

The installation of both the permeable interlocking concrete pavers (PICP) and the blue-green roof system must comply with local, provincial, and university-specific codes and regulations to ensure safety, environmental protection, and structural integrity. For the PICP system, compliance with the Ontario Building Code and City of Kingston bylaws is essential, particularly in terms of stormwater management, accessibility, and environmental protection. The design must meet the requirements outlined in the Ontario Stormwater Management Planning and Design Manual, ensuring proper infiltration and runoff control. Additionally, the system must adhere to the Accessibility for Ontarians with Disabilities Act (AODA), maintaining accessible pathways for all users. Environmental regulations must also be followed to prevent groundwater contamination and ensure the granular layers beneath the pavers effectively filter pollutants.

For the blue-green roof system, compliance with structural load requirements is critical, as the system adds significant weight to the building's roof. The design must align with the Ontario Building Code for live and dead loads, ensuring the roof can safely support the water retention layer, vegetation, and soil. Waterproofing and drainage standards must also be met to prevent leaks and ensure proper water flow. The system must comply with stormwater management regulations, demonstrating its ability to retain and slowly release water to reduce peak flow into the municipal drainage system. Environmental and fire safety regulations further ensure that the vegetation and soil used do not introduce invasive species or pose fire risks. Both systems must also align with Queen's University Building Standards, which emphasize sustainability, climate resilience, and long-term maintenance. By adhering to these codes and regulations, the PICP and blue-green roof systems will meet legal and safety requirements while contributing to the university's commitment to environmental stewardship and infrastructure resilience.

9 Innovation

Innovative aspects of the final designs are discussed below.

9.1 Permeable Interlocking Pavers

PICPs can be used strategically to harvest rainwater from heavy rainfall events. This can be done by directing the downstream slope in the area of the PICPs and directing the excess runoff water into a catchment area, whether it is a plastic tray at the end of the downstream slope or into a water tank below grade; this can be an effective tool in preserving rainwater and recycling it back into the campus.

9.2 Blue-Green Roof

The blue-green roof system combines the strengths of blue and green roofs to deliver an innovative and adaptable solution for stormwater management. By integrating a water retention layer beneath a vegetated surface, it maximizes both stormwater storage and ecological benefits. This design not only manages large volumes of water during extreme precipitation events but also enhances biodiversity, improves air quality, and reduces the urban heat island effect, aligning with Queen's University's sustainability goals.

Innovation is further demonstrated through the system's adaptability to future climate challenges. Smart technologies, such as sensors and automated valves, can regulate water discharge in response to rainfall forecasts, ensuring the system remains efficient during changing weather conditions. This dynamic approach anticipates the projected increase in rainfall intensity by 2080.

While the blue-green roof system has a higher upfront cost, its benefits outweigh the initial investment. It reduces strain on municipal stormwater infrastructure, lowers energy costs through thermal regulation, and extends the lifespan of building materials. As a benchmark for sustainable construction on campus, this solution provides both immediate functionality and long-term resilience, supporting Queen's efforts to create a climate-resilient campus.

10 Cost Estimation

The cost estimation for both selected final designs is proposed below. Cost estimations were taken from industry sources that either build or provide material for the proposed solutions. Building contractors and designers specializing in urban stormwater management systems such as blue-green roofs provided a preliminary quote price for different building areas. While Sutherland Hall may be suitable for future rehabilitation, the cost of blue-green roof systems is an average cost the client may expect for future building development.

The cost estimation for PICP's was taken by researching permeable interlocking material cost per square foot by industry suppliers, as well as manually completing a quantity take-off in the amount of gravel sub-base needed, and how much volume of asphalt is present in the intended area of construction that will have to be removed. Once the volume and area quantities were taken, an industry price was applied to it by price per square meter.

10.1 Permeable Interlocking Concrete Pavers

The front entrance of Sutherland Hall is the first location of PICP installs, consisting of an area of 16.66 m^2. The location between Mackintosh-Corry and Sutherland Hall consists of an area of 547 m^2, these areas were measure from Google Maps. This sums to a total working area of 564 m^2. Below is a table summarizing the quantity takeoff conducted with its applied cost per meter cubed. It is important to note that from the Sutherland Hall civil drawings and as shown in Figure 12 the working depth from the existing grade to the gas line is 1 meter. The thicknesses of the identified material will sum to a value of less than 1 meter so that the gas line is the least amount of risk involving the gas line during construction. It is also important to note that a factor of 1.13 was applied to the volume to convert it to a measurement of tonnes, as industry suppliers sell by dollar per tonne. The PICP cost estimate is summarized below in Table 12.

Table 12: Cost Estimate for PICP

Material	**Depth (mm)**	**Area (m^2)**	**Volume (m^3) (Depth * Area)**	**Cost ($ per ton)**	**Total Cost (tonne*$/tonne)**
ASTM No.2	80	564	45	$26/tonne	$1322
ASTM No.57	28	564	16	$65/tonne	$1175
ASTM No. 8	5	564	28	$55/tonne	$1740
Permeable Interlocking Concrete Paver	80	564	45	$12/square meter	$540

Therefore, the total cost to install permeable interlocking concrete pavers in the selected locations of Sutherland Hall would be $4777.

10.2 Blue-Green Roofs

As previously mentioned in Section 3.2.3, the cost per square foot for installing a blue-green roof system ranges between $25 and $35, depending on the complexity of the design, materials used, and labor required. For the purpose of this cost estimation, a conservative value of $32.50 per square foot has been chosen. This value accounts for all major components, including the specialized water retention layer, vegetation, necessary structural reinforcements, and professional installation.

To estimate the cost for one of the proposed locations, the roof area of Beamish Munro was analyzed using Google Maps, which provided an approximate measurement of approximately 17,650 square feet. This building was chosen as a representative area due to its significance as a site of recurring flooding and its potential to serve as a model for future blue-green roof installations across campus.

By multiplying the total square footage by the selected rate of $32.50 per square foot, the estimated cost for implementing a blue-green roof system on Sutherland Hall is $573,625. This figure includes all associated costs for materials, labour, and installation.

10.3 Total

Adding the total costs for both the present and future solutions, the total cost estimate is $578,402.

It is worth noting that the future solution contributes to more than 99% of this budget.

11 Schedule

The key project deliverables and their corresponding submittal dates are shown below in Table 13. The section highlighted in green represents key deliverables that have been completed by their designated submittal date.

Table 13: Table of Key Deliverables and their Expected Submittal Dates

Key Deliverable	Expected Submittal Date
Work Plan	September 26th 2024
Progress Report	November 22nd 2024
Draft Final Report	March 21st 2025
Final Presentation	March 31, 2025
Final Report	April 18th 2025

The project's updated Work Breakdown Structure is below in Figure 34. The WBS includes the total number of hours estimated to be spent completing each section. The categories in green have been completed, while the unhighlighted categories will be completed in the future. Additionally, a detailed schedule of the project lifecycle in the form of a Gantt Chart can be found in Appendix C as Figure C-1, Figure C- 2, Figure C- 3, Figure C- 4, and Figure C- 5.

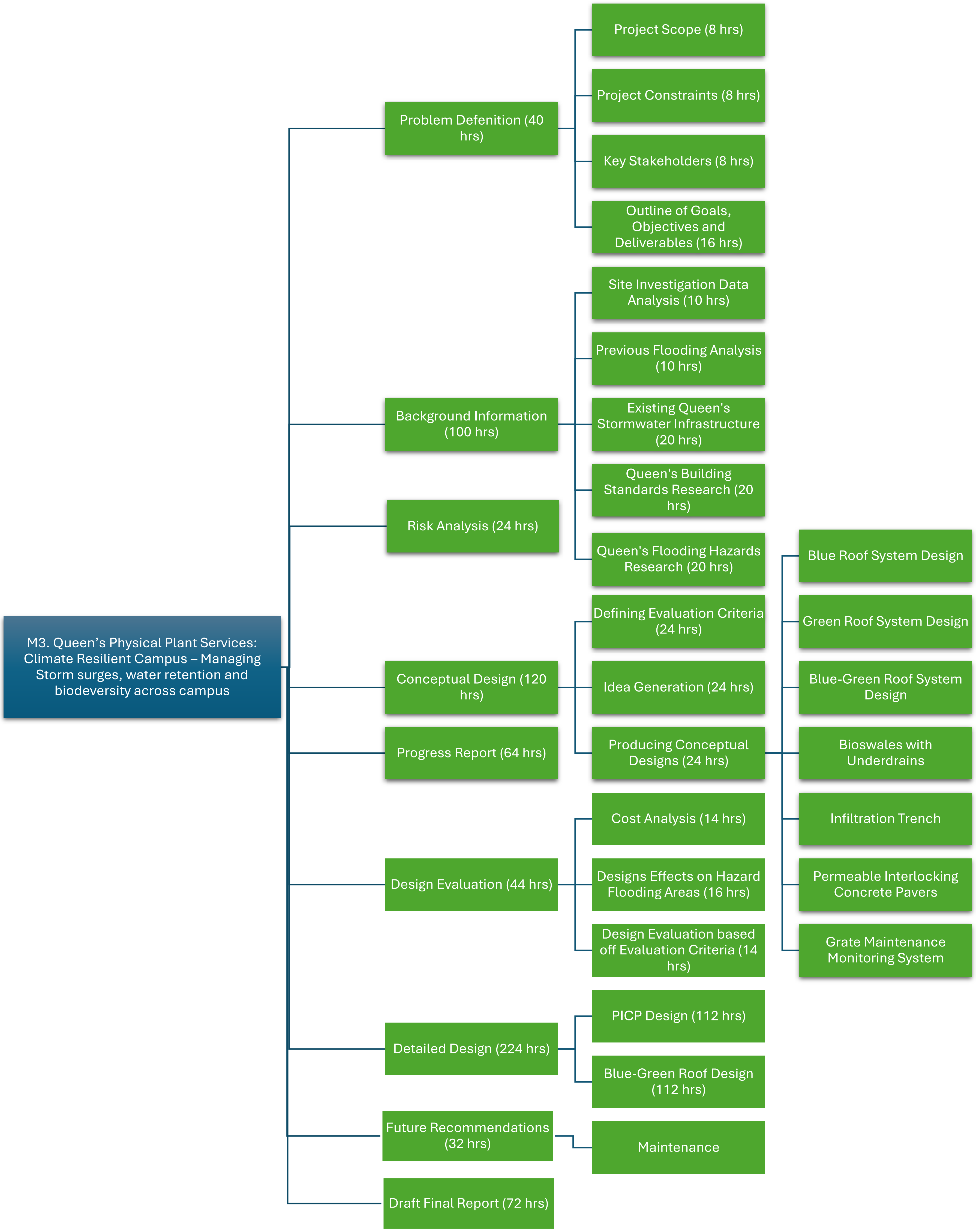


Figure 34: Work Breakdown Structure

12 Risk Assessment

A risk assessment was performed for both the present and future design and are summarized below in Table 14 and Table 15.

Table 14: Present Solution Risk Assessment

Risk	Risk Type	Reasoning
Weed Growth	Design	Weed growth can impact infiltration as it blocks porous material, can pop pavers off when too large, and be a tripping hazard for pedestrian traffic, ultimately creating a fault in the design
Construction and Hazardous Material	Environmental	This is a risk because since these are permeable pavers, any hazardous material that may leak into the pavers can make its way down and contaminate the groundwater, which poses an environmental risk.
Pedestrian Impact	Health/Stakeholder	The construction of this design can significantly impact the ability of pedestrians/students to walk around campus and access Sutherland Hall. This poses a risk to stakeholder approval and the health of pedestrians.

Table 15: Future Solution Risk Assessment

Risk	Risk Type	Reasoning
Leaks	Structural	Due to incorrect installation, root growth, and temperature changes, leaks can occur in the structure. This can impact structural integrity and cause flooding.
Structural Capacity	Structural	Due to the added weight on top of the rooftop, the structural capacity of the building needs to be recalculated. If this is not done properly, a roof collapse can occur.
Drainage	Design	If the drainage system becomes blocked (potentially by soil and vegetation), there can be drainage issues resulting in stormwater build-up and flooding.
Plant Death	Design/Environment	If the plants and vegetation are not looked after by Queen's Facilities, then plant death can occur, which will cause the effectiveness of the design solution to drop drastically.

13 Group Dynamics

GICO Inc. was developed in September of 2024 by four 4th year civil engineering students at Queen's University. Upon development, the team defined roles and responsibilities within the group. These roles, summarized below in Table 16, helped maintain productivity over the course of the project.

Table 16: Summary of Roles

Role	Individual	Responsibilities
Project Manager	Christopher Ridolfi	• Manage meetings and documentation • Communicate with client • Set up team meetings
Technical Lead	Ossaid Khan	• Lead design process • Address technical concerns
Quality Assurance Lead	Grace McAuley	• Maintain report and design quality
Health and Safety Lead	Ivan Bogomolsky	• Manage constraints • Ensure compliance with codes and standards

13.1 Conflict Resolution

The established roles also helped reduce conflicts amongst the group that may have been caused by misunderstandings of responsibilities.

If conflict did arise, the team discussed a conflict resolution plan, in which the group would meet to discuss the issue in their weekly meeting. If the issue could not be resolved within a team meeting, the group would then reach out to a teaching assistant for further support. The team experienced minor disagreements over the course of the project, as expected in group work, all of which were resolved in a team meeting.

The main issue the group addressed was the distribution of work. Some group members contributed more heavily to specific tasks than other members. The group acknowledged this and redistributed the workload of the tasks that followed to make up for this.

14 Next Steps

The next steps for the Climate Resilient Campus project involve finalizing the design details, obtaining necessary permits, and preparing for construction. The team will work with the City of Kingston and other relevant authorities to obtain the necessary permits, ensuring compliance with local stormwater management regulations and building codes. Once permits are secured, contractors with experience in permeable pavement and blue-green roof installations will be identified and selected, with detailed cost estimates and timelines obtained to guide the process. A comprehensive construction plan will then be developed, including timelines, resource allocation, and contingency plans to address potential delays or issues. Additionally, a monitoring and maintenance plan will be established for both systems, outlining regular inspections, cleaning, and repairs to ensure long-term effectiveness. Finally, the Queen's University community will be engaged through clear communication about the upcoming construction, its benefits, and progress updates while addressing any concerns from students, faculty, and staff to ensure a smooth implementation process.

15 Conclusion

The Climate Resilient Campus project by GICO Inc. tackles the complex stormwater challenges faced by Queen's University due to intensifying rainfall linked to climate change. By combining analysis, stakeholder collaboration, and innovative design methodologies, the project has identified two solutions: permeable interlocking concrete pavers (PICP) for near-term infrastructure improvements and blue-green roof systems for future campus sustainability.

PICP was chosen for its simple integration with existing infrastructure, efficient water diversion capabilities, and minimal maintenance demands, making it an ideal choice for areas like Sutherland Hall. The blue-green roof system exemplifies innovation, blending stormwater retention with ecological benefits and aesthetic enhancements, aligning with the university's commitment to environmental sustainability.

With a total project budget of $578,402, these solutions address both pressing flooding issues and the broader need for long-term climate resilience. This investment ensures that Queen's University not only mitigates immediate risks but also establishes itself as a leader in adaptive, sustainable infrastructure.

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Appendix A: Meeting Minutes

GICO's meeting minutes are summarized below in Table A-1.

Table A-1: Project Meeting Minutes

Meeting Title	Date	Duration (hrs)	Participants	Topics of Discussion and Information Gained
Bid Declaration and Priority List	September 4th, 2024	1	Full Team	N/A
SOQ & Bid Presentation Creation Meeting	September 4th, 2024	2	Full Team	N/A
Bid Presentation Group Preparation Meeting	September 5th, 2024	1	Full Team	N/A
Client Meeting	September 10th, 2024	0.5	Nathan Splinter Shawn Milne, David Gerrish, Reanna Mcilveen, Ivan Bogomolsky, Ossaid Khan, Christopher Ridolfi	- Given key deliverables. - Given notes on potential solutions and areas of focus. - Asked to create a OneDrive Folder for project information/document sharing. - Asked to set up a Bi-Weekly Client Meeting.
TA Meeting	September 17th, 2024	0.5	Full Team and Stephen O'Meara	- We were told to have the WBS mostly finished, and the work plan started by the next TA meeting. - We were informed that the design solutions in the work plan are expected to be preliminary.
Team Meeting	September 17th, 2024	0.5	Full Team	N/A
TA Meeting	September 24th, 2024	0.5	Full Team and Stephen O'Meara	- Were told to add the expected hour duration to WBS. - Stephen told us that we should include technical writing in the WBS. - Informed we should add a responsibility assignment matrix. - Told to have tiered stakeholders in our stakeholder identification section.

Team Meeting	September 24th, 2024	0.5	Full Team	N/A
Client Meeting	October 8th, 2024	0.8	Grace, Ossaid, Ivan	- New ideas: Bio squals, depaving – increasing hard scraping, grading and landscaping, reducing permeable surfaces, review topography across campus – look for channels and low lying areas - Solution may be a combination of improvements - Told to focus on problem spots - Consider practices for routine maintenance and cleaning - address grate clogging and sediment buildup etc. - Recommend best practices (consider monitoring technology). For example: Pressure sensor filters indicating when cleaning is needed (Needs based rather than monthly) - Add Internal facility staff as stakeholders – speak with Phil wright, Brian Magen from insurance - We are missing topography data for water routes – we should maybe research technology/software (lidar) for assessing this.
TA Meeting	October 8th, 2024	0.34	Grace, Ossaid, Ivan	No relevant information gained or discussed.
Team Meeting	October 8th, 2024	1	Full Team	Weekly Team Meeting.
TA Meeting	October 22, 2024	0.34	Full Group	Workplan Feedback: - Need to put a brief explanation before tables

				- Put environmental impacts for constraints - Reformat running sentence in objective - Hours should total 720 - Move the qualification section to the appendix - If the figure and table is in the appendix, then you label it as A-1 , A-2 etc - Two figure captions for gantt chart and change to appendix heading label. Poster Submission due date: - Due date is incorrect.
Team Meeting	October 22, 2024	1	Full Group	
Client Meeting	October 29, 2024	0.25	Full Group	- Speak with faculty members regarding maintenance. Schedule a meeting. - Southland is a good choice according to client - Maybe go on the southland area during storm event to see flows
TA Meeting	October 29, 2024	0.25	Full Group	- Have workplan edited and start conceptual design by next meeting - Edit the workplan and start progress report as it's a lot of writing and designing.
Team Meeting	October 29th, 2024	1	Full Team	- Weekly Team Meeting.
Team Meeting	November 7, 2024	1	Full Group	- Discussed Progress Report - Divided up Progress Report
Client Meeting	November 12, 2024	0.34	Grace, Ivan, Chris	- For flow calculations need peak flow, peak capacity, and compare to peak Rain - Discussed our designs.

TA Meeting	November 12, 2024	0.5	Grace, Ivan, Chris	- Cost estimate is based on the solution this time. Not super in depth. Material and labor (cost estimate is just on the chosen design) - Do separate budget for future and present - For WEM some categories could be cost, constructability, environment. - WEM categories stem from constraints and what stakeholders want. - Look at Progress report slideshow - Look at Risk assessment example and have it in the progress report - Also think of innovation with respect to your design - Give Progress report to Stephen before next TA meeting or 19/20th for feedback -
Team Meeting	November 12, 2024	1	Full Team	- Weekly Team Meeting.
Weekly TA Meeting	November 19, 2024	0.5	Full Team	- Have a risk assessment section.
Team Meeting	January 3, 2025	0.5	Full Group	- Poster Presentation Creation
Team Meeting	January 5, 2025	1.5	Full Group	- Poster Presentation Creation and Preparation
Team Meeting	January 15, 2025	1	Full Group	- Discussion of next steps following poster presentation.
Weekly TA Meeting	January 17, 2025	0.5	Full Group + Stephan O'Meara	- Poster Feedback
Client Meeting	January 23, 2025	0.25	Nathan Splinter Shawn Milne, David Gerrish, Reanna Mcilveen, Ivan Bogomolsky, Ossaid Khan, Christopher Ridolfi	- Discussed poster presentation, and it was decided by the client that a midterm presentation is not required. - We will be conducting a presentation at the end of the year in the facilities conference room.
Team Meeting	January 28, 2025	1.5	Full Group	- Research and Discussion
Weekly TA Meeting	January 31, 2025	0.5	Full Group + Stephan O'Meara	- Providing project updates.
Team Meeting	February 4, 2025	1	Full Group	- Research and Discussion

Team Meeting	February 11, 2025	0.5	Full Group	- Design Research and Discussion
TA Meeting	February 28, 2025	0.5	Full Group	- Provided project updates.
Team Meeting	March 4, 2025	1.24	Full Group	- Draft Final Report Division and Discussion
Client Meeting	March 6, 2025	0.4	Ossaid Khan and Christopher Ridolfi	- Were told to be familiar with permitting and regulation concerning the city of Kingston. - Consider alternative paths for pedestrian travel for PICP design. - Told to create AutoCAD drawings.
Team Meeting	March 10, 2025	0.75	Full Group	- Discussing Draft Final Report Progress.
Client Meeting	March 20, 2025	0.4	Full Group	- Discussion of Draft Final Report Submission, sending the client the report and provide capstone feedback to client.

Appendix B: Meeting Logbook

GICO’s meeting logbook can be seen below in Figure B-1 to Figure B- 6.

Date	Activity	Time Spent (Hr)	Group Member	Hours Per Week	
Week 1					
September 4, 2024	Bid Declaration & Priority List	1	Full Group	Week 1	17.50
September 4, 2024	SOQ & Bid Presentation Creation	2	Full Group		
September 4, 2024	SOQ & Bid Presentation Formatting	1	Grace McAuley		
September 5, 2024	Bid Presentation Group Prep	1	Full Group		
September 6, 2024	Client and Manger Email	0.5	Christopher Ridolfi		
Week 2					
September 9, 2024	CIVL 460 Deliverable Schedule	0.5	Christopher Ridolfi	Week 2	3.50
September 10, 2024	Client Meeting	0.5	Ivan, Christopher, Ossaid		
September 10, 2024	Client Meeting Presentation Creation	0.75	Christopher Ridolfi		
September 11, 2024	Set Up Bi-Weekly Client Meeting and Onedrive Folder	0.75	Christopher Ridolfi		
Week 3					
September 17, 2024	Work Plan TA Meeting & Team Meeting	1	Full Group	Week 3	14.00
September 21, 2024	Work Plan (Gannt Chart)	4	Christopher Ridolfi		
September 22, 2024	Work Plan (Gannt Chart and WBS)	4	Christopher Ridolfi		
September 21, 2024	Work Plan (Cover Letter and Intro)	2	Grace McAuley		
Week 4					
September 24, 2024	Work Plan TA Meeting & Team Meeting	1	Full Group	Week 4	44.50
September 24, 2024	Risk Analysis and Design Evaluation	1	Christopher Ridolfi		
September 24, 2024	Work Plan (Background Info, stakeholders, formatting)	5	Grace McAuley		
September 24, 2024	Work Plan (Preliminary Research, Objectives, Conceptual Ideas)	8	Ossaid Khan		
September 25, 2024	Work Plan Editing	1	Christopher Ridolfi		
September 25, 2024	Work Plan Editing	1	Ossaid Khan		
September 25, 2024	Work Plan Gannt Chart Edits	1	Christopher Ridolfi		
September 26, 2024	Work Plan Formatting and Editing	4	Grace McAuley		

Figure B-1: Picture of Project Logbook Page 1

September 26, 2024	Work Plan Formatting and Editing	4	Grace McAuley		
September 25, 2024	Work Plan (Contstraints, work completion plan, preliminary cost estimate, conclusion)	6	Ivan Bogomolsky		
September 26, 2024	REM	1	Christopher Ridolfi		
September 26, 2024	Workplan Editing	3	Full Group		
September 27, 2024	Minor Workplan edit and Sending work plan to the client	0.5	Christopher Ridolfi		
Week 6					
October 8th, 2024	Client Meeting	0.8	Ossaid Khan and Grace McAuley	Week 6	14.28
October 8th, 2024	TA Meeting	0.34	Ossaid Khan and Grace McAuley		
October 8th, 2024	Team Meeting and Research	3	Full Group		
Week 7					
October 22, 2024	TA Meeting	0.34	Full Grouo	Week 7	28.36
October 22, 2024	Team Meeting and Research	5	Full Group		
October 25, 2024	Peer Review Assignment	1.5	Christopher Ridolfi		
October 25, 2024	Peer Review Assignment	1.5	Ossaid Khan		
October 25, 2024	Peer Review Assignment	1.5	Ivan Bogomolsky		
October 25, 2024	Peer Review Assignment	2.5	Grace McAuley		
Week 8					
October 29, 2024	Client Meeting	0.25	Full Group	Week 8	12
October 29, 2024	TA Meeting	0.25	Full Group		
October 29, 2024	Research	6	Ivan Bogomolsky		
October 29, 2024	Team Meeting	1	Full Group		
Week 9					
November 7, 2024	Team Meeting	1	Full Group	Week 9	17
November 8, 2025	Research	6	Ivan Bogomolsky		
November 8, 2024	Research & Data Review	3	Ossaid Khan		
November 10, 2024	Research & Data Review	4	Ossaid Khan		
Week 10					
November 12, 2024	Client Meeting	0.34	Grace McAuley, Ivan Bogomolsky, Christopher Ridolfi		

Figure B- 2: Picture of Project Logbook Page 2

November 12, 2024	TA Meeting	0.5	Grace McAuley, Ivan Bogomolsky, Christopher Ridolfi	Week 10	21.52
November 15, 2024	Progress Report	3	Christopher Ridolfi		
November 15, 2024	Progress Report	6	Grace McAuley		
November 16, 2024	Progress Report	6	Ossaid Khan		
November 17, 2024	Progress Report	4	Ossaid Khan		
Week 11					
November 19, 2024	Progress Report	6	Ossaid Khan	Week 11	55
November 20, 2024	Progress Report	7	Ossaid Khan		
November 21, 2024	Progress Report	5	Grace McAuley		
November 21, 2024	Progress Report	6	Christopher Ridolfi		
November 22, 2024	Progress Report	5	Christopher Ridolfi		
November 22, 2024	Progress Report	8	Grace McAuley		
November 22, 2024	Progress Report	8	Ossaid Khan		
November 22, 2024	Progress Report	10	Ivan Bogomolsky		
Winter Break					
January 3, 2025	Team Meeting	0.5	Full Group	Week 0	2
Week 1					
January 5, 2025	Poster Meeting	1.5	Full Group	Week 1	51.5
January 6, 2025	Poster	3.5	Grace McAuley		
January 9 2025	Presentation Creation	3	Full Group		
January 11 2025	Presentation Practice	3	Full Group		
January 13 2025	Group Presentation Practice	2	Full Group		
January 13 2025	Poster Presentation	2.5	Full Group		
Week 2					
January 15, 2025	Team Meeting	1	Full Group	Week 2	27
January 16, 2025	Design Planning and Fixing	5	Ossaid Khan		
January 16, 2025	Research	6	Christopher Ridolfi		
January 17, 2025	TA Meeting	0.5	Full Group		
January 17, 2025	Research	8	Ivan Bogomolsky		
January 18, 2025	Research	2	Grace McAuley		

Figure B- 3: Picture of Project Logbook Page 3

Week 3					
	Team Meeting	0.75	Full Group	Week 3	27
January 21, 2025	Design Planning and Fixing	4	Ossaid Khan		
January 21, 2025	Design Modelling	3	Grace McAuley		
January 23, 2025	Client Meeting	0.25	Ossaid, Ivan, Chris		
January 23, 2025	Design Research and Planning	5	Christopher Ridolfi		
January 23, 2025	Design Research and Planning	8	Ivan Bogomolsky		
January 24, 2025	Research + Modelling	3	Grace McAuley		
Week 4					
January 26, 2025	Design Planning and Fixing	3.5	Ossaid Khan	Week 4	35.5
January 27, 2025	Design Planning	8	Ivan Bogomolsky		
January 28 2025	Design Planning and Fixing	6	Christopher Ridolfi		
January 28 2025	Team Meeting	1.5	Full Group		
January 30, 2025	Research and Data Review	6	Grace McAuley		
January 31, 2025	TA Meeting	0.5	Full Group		
January 31, 2025	Formatting + Editing	4	Grace McAuley		
Week 5					
February 4 2025	Team Meeting	1	Full Group	Week 5	29
February 6, 2025	Deisgn Planning and Fixing	5	Ossaid Khan		
February 6, 2025	Design Planning and Research	8	Ivan Bogomolsky		
February 6, 2025	Design Planning and Research	6	Christopher Ridolfi		
Febraury 7, 2025	Design Planning	3	Grace McAuley		
February 9, 2025	Research	3	Grace McAuley		
Week 6					
February 11 2025	Team Meeting	0.5	Full Group	Week 6	20
February 12, 2025	Design Planning and Research	5	Christopher Ridolfi		
February 12, 2025	Design Planning and Research	8	Ivan Bogomolsky		
February 12, 2025	Design Planning and Fixing	5	Ossaid Khan		
Reading Week					
February 19, 2025	Design Research	7	Ossaid Khan		
Febraruy 20, 2025	Design Research and Planning	6	Grace McAuley		

Figure B- 4: Picture of Project Logbook Page 4

Febraruy 20, 2025	Design Research and Planning	6	Grace McAuley	Reading Week	32
February 20, 2025	Design Research and Planning	6	Christopher Ridolfi		
February 20, 2025	Design Research and Planning	8	Ivan Bogomolsky		
February 20, 2025	Scheduling	1	Christopher Ridolfi		
February 21, 2025	Design Research	4	Grace McAuley		
Week 7					
February 25, 2025	Draft Report Formatting	2	Grace McAuley	Week 7	30
February 27, 2025	Report Discussion	3	Full Group		
February 27, 2025	Desing Research	6	Christopher Ridolfi		
February 27, 2025	Desing Research	8	Ivan Bogomolsky		
Febraury 28. 2025	TA Meeting	0.5	Full Group		
Week 8					
March 4, 2025	Team Meeting	1.25	Full Group	Week 8	33.3
March 5th 2025	Document formatting and hour logging	1.5	Grace McAuley		
March 6, 2025	Design Research and Planning	4	Ossaid Khan		
March 6, 2025	Client Meeting	0.4	Ossaid Khan and Christopher Ridolfi		
March 7, 2025	Draft writing and Research	9	Christopher Ridolfi		
March 8, 2025	Draft writing	5	Grace McAuley		
March 8, 2025	Draft Report Planning	8	Ivan Bogomolsky		
Week 9					
March 10, 2025	Team Meeting	0.75	Full Group	Week 9	85.75
March 11, 2025	Draft Report - Team Dynamics	1.75	Grace McAuley		
March 12, 2025	Design Modelling & Writing	6	Grace McAuley		
March 12, 2025	Research and Draft Report	8	Ivan Bogomolsky		
March 12, 2025	Research and Draft Report	10	Ossaid Khan		
March 13, 2025	Draft Report	5	Ossaid Khan		
March 13, 2025	Draft Report	9	Christopher Ridolfi		
March 13, 2025	Research and Writing	8	Grace McAuley		
March 14, 2025	Draft Report	8	Grace McAuley		
March 15 2025	Draft Report	5	Grace McAuley		
March 16, 2025	Draft Report	6	Grace McAuley		

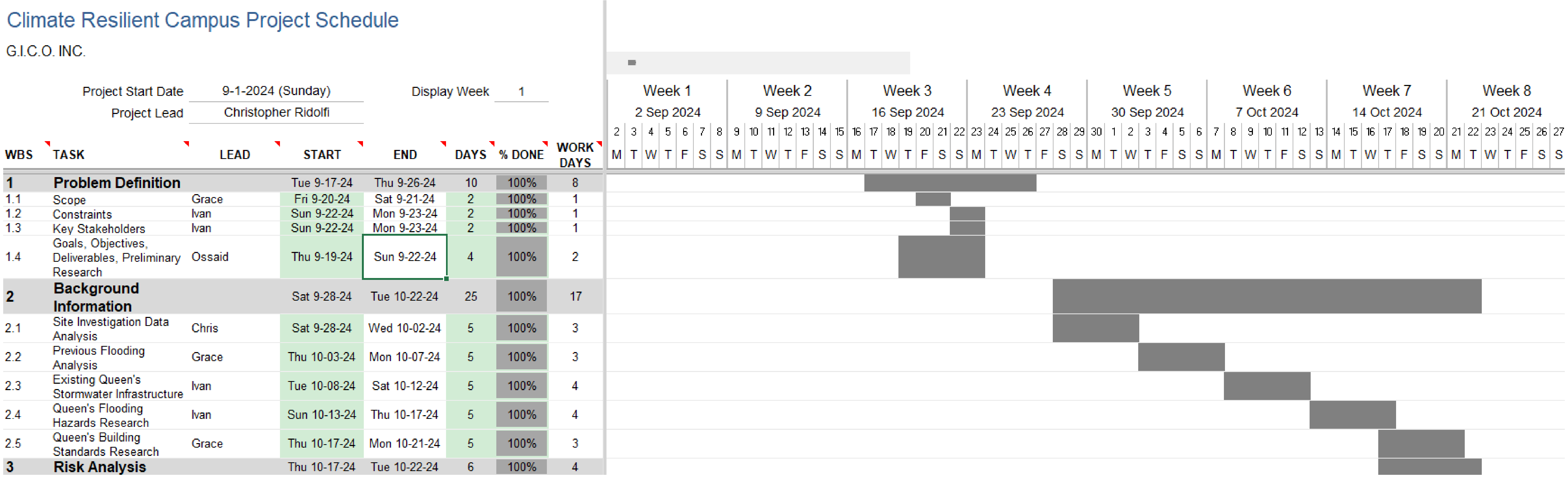
Figure B- 5: Picture of Project Logbook Page 5

March 16, 2025	AUTOCAD Drawing	6	Christopher Ridolfi		
March 16 andd 17, 2025	Draft Report	10	Ivan Bogomolsky		
Week 10					
March 17, 2025	Draft Report	9	Christopher Ridolfi	Week 10	109
March 18, 2025	Draft Report -Calculations	8	Ossaid Khan		
March 18, 2025	Draft Report	7	Grace McAuley		
March 18, 2025	Draft Report	9	Christopher Ridolfi		
March 19, 2025	Draft Report	9	Christopher Ridolfi		
March 19, 2025	Draft Report	4	Grace McAuley		
March 19, 2025	Draft Report	5	Ossaid Khan		
March 20, 2025	Draft Report	8	Ossaid Khan		
March 20 2025	Draft Report Editing	6	Grace McAuley		
March 21 2025	Draft Report Final Additions	5	Grace McAuley		
March 21 2025	Draft Report Meeting	7	Full Group		
March 21 2025	Draft Report Section Completion	8	Ivan Bogomolsky		
March 22 2025	Draft Report Editing	3	Ossaid Khan		
Week 11					
March 31, 2025	Final presentation Creation and Presentation	6	Full Group	Week 11	36
March 31, 2025	Final editing and send to client	3	Full Group		
Total Hrs					
			Ivan Total Hrs		180.68
			Grace Total hrs		190.82
			Ossaid Total Hrs		182.88
			Chris Total Hrs		184.08
			Total Hrs		745.71

Figure B- 6: Picture of Project Logbook Page 6

Appendix C: Gantt Chart

GICO's Gantt Chart is depicted below in Figure C-1, Figure C- 2, Figure C- 3, Figure C- 4, and Figure C- 5.



Climate Resilient Campus Project Schedule

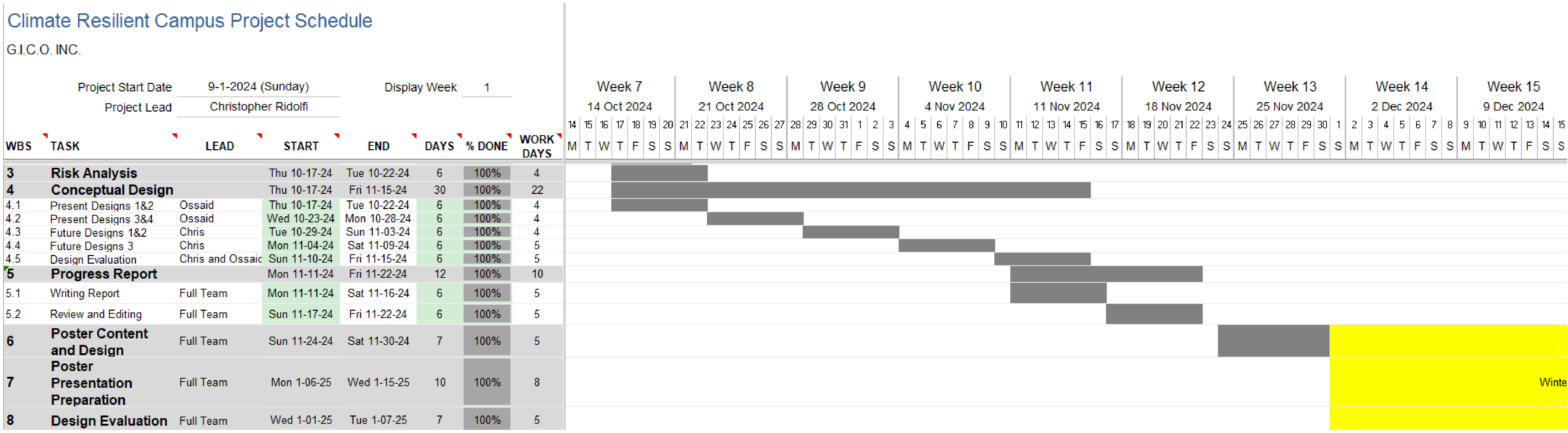
G.I.C.O. INC.

Project Start Date: 9-1-2024 (Sunday) | Display Week: 1

Project Lead: Christopher Ridolfi

WBS	TASK	LEAD	START	END	DAYS	% DONE	WORK DAYS
1	**Problem Definition**		Tue 9-17-24	Thu 9-26-24	10	100%	8
1.1	Scope	Grace	Fri 9-20-24	Sat 9-21-24	2	100%	1
1.2	Constraints	Ivan	Sun 9-22-24	Mon 9-23-24	2	100%	1
1.3	Key Stakeholders	Ivan	Sun 9-22-24	Mon 9-23-24	2	100%	1
1.4	Goals, Objectives, Deliverables, Preliminary Research	Ossaid	Thu 9-19-24	Sun 9-22-24	4	100%	2
2	**Background Information**		Sat 9-28-24	Tue 10-22-24	25	100%	17
2.1	Site Investigation Data Analysis	Chris	Sat 9-28-24	Wed 10-02-24	5	100%	3
2.2	Previous Flooding Analysis	Grace	Thu 10-03-24	Mon 10-07-24	5	100%	3
2.3	Existing Queen's Stormwater Infrastructure	Ivan	Tue 10-08-24	Sat 10-12-24	5	100%	4
2.4	Queen's Flooding Hazards Research	Ivan	Sun 10-13-24	Thu 10-17-24	5	100%	4
2.5	Queen's Building Standards Research	Grace	Thu 10-17-24	Mon 10-21-24	5	100%	3
3	**Risk Analysis**		Thu 10-17-24	Tue 10-22-24	6	100%	4

Figure C-1: Gantt Chart



Climate Resilient Campus Project Schedule

G.I.C.O. INC.

Project Start Date: 9-1-2024 (Sunday) | Display Week: 1

Project Lead: Christopher Ridolfi

WBS	TASK	LEAD	START	END	DAYS	% DONE	WORK DAYS
3	**Risk Analysis**		Thu 10-17-24	Tue 10-22-24	6	100%	4
4	**Conceptual Design**		Thu 10-17-24	Fri 11-15-24	30	100%	22
4.1	Present Designs 1&2	Ossaid	Thu 10-17-24	Tue 10-22-24	6	100%	4
4.2	Present Designs 3&4	Ossaid	Wed 10-23-24	Mon 10-28-24	6	100%	4
4.3	Future Designs 1&2	Chris	Tue 10-29-24	Sun 11-03-24	6	100%	4
4.4	Future Designs 3	Chris	Mon 11-04-24	Sat 11-09-24	6	100%	5
4.5	Design Evaluation	Chris and Ossaic	Sun 11-10-24	Fri 11-15-24	6	100%	5
5	**Progress Report**		Mon 11-11-24	Fri 11-22-24	12	100%	10
5.1	Writing Report	Full Team	Mon 11-11-24	Sat 11-16-24	6	100%	5
5.2	Review and Editing	Full Team	Sun 11-17-24	Fri 11-22-24	6	100%	5
6	**Poster Content and Design**	Full Team	Sun 11-24-24	Sat 11-30-24	7	100%	5
7	**Poster Presentation Preparation**	Full Team	Mon 1-06-25	Wed 1-15-25	10	100%	8
8	**Design Evaluation**	Full Team	Wed 1-01-25	Tue 1-07-25	7	100%	5

Figure C- 2: Gantt Chart Continued

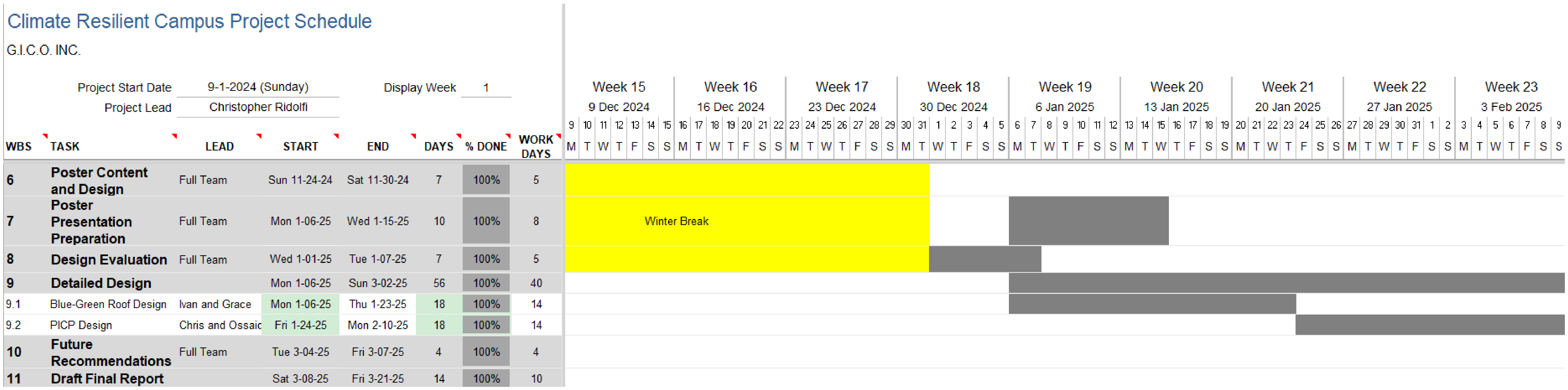


Figure C- 3: Gantt Chart Continued

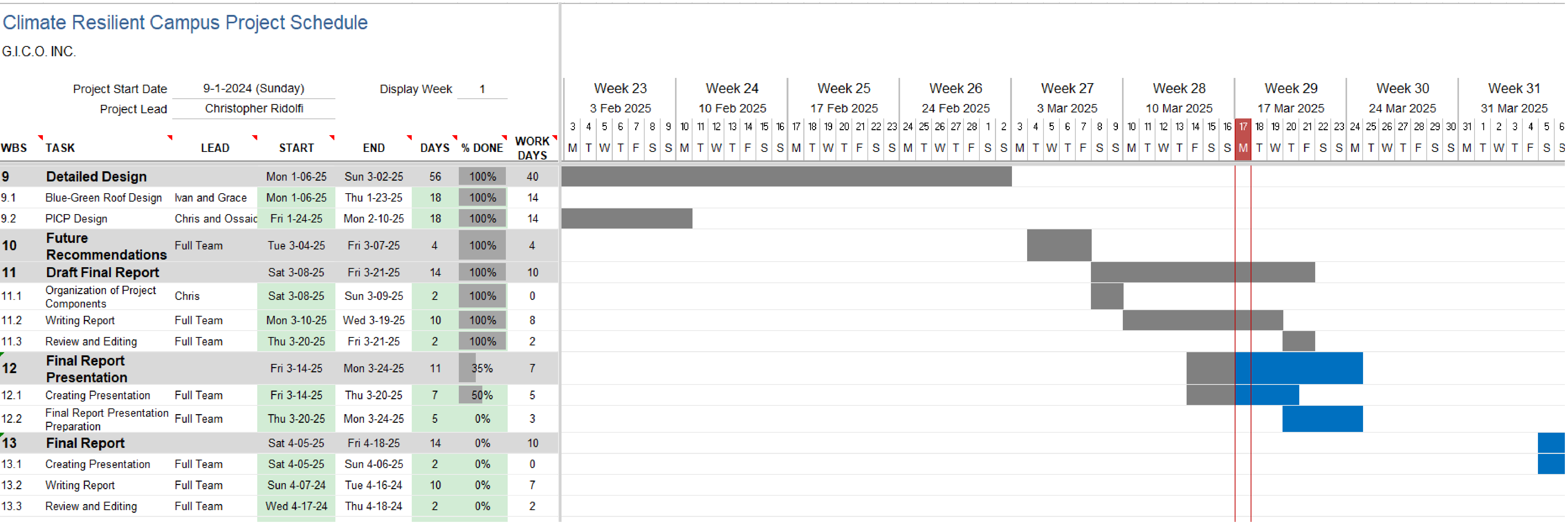


Figure C- 4: Gantt Chart Continued

Climate Resilient Campus Project Schedule

G.I.C.O. INC.

Project Start Date	9-1-2024 (Sunday)
Project Lead	Christopher Ridolfi
Display Week	1

WBS	TASK	LEAD	START	END	DAYS	% DONE	WORK DAYS
13	**Final Report**		Sat 4-05-25	Fri 4-18-25	14	0%	10
13.1	Creating Presentation	Full Team	Sat 4-05-25	Sun 4-06-25	2	0%	0
13.2	Writing Report	Full Team	Sun 4-07-24	Tue 4-16-24	10	0%	7
13.3	Review and Editing	Full Team	Wed 4-17-24	Thu 4-18-24	2	0%	2

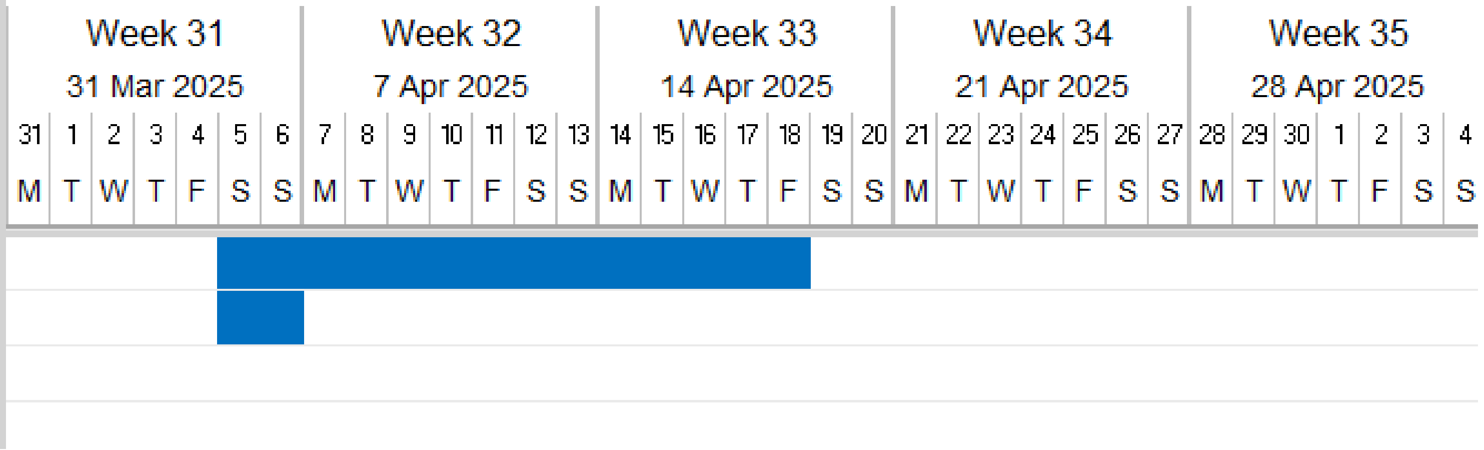
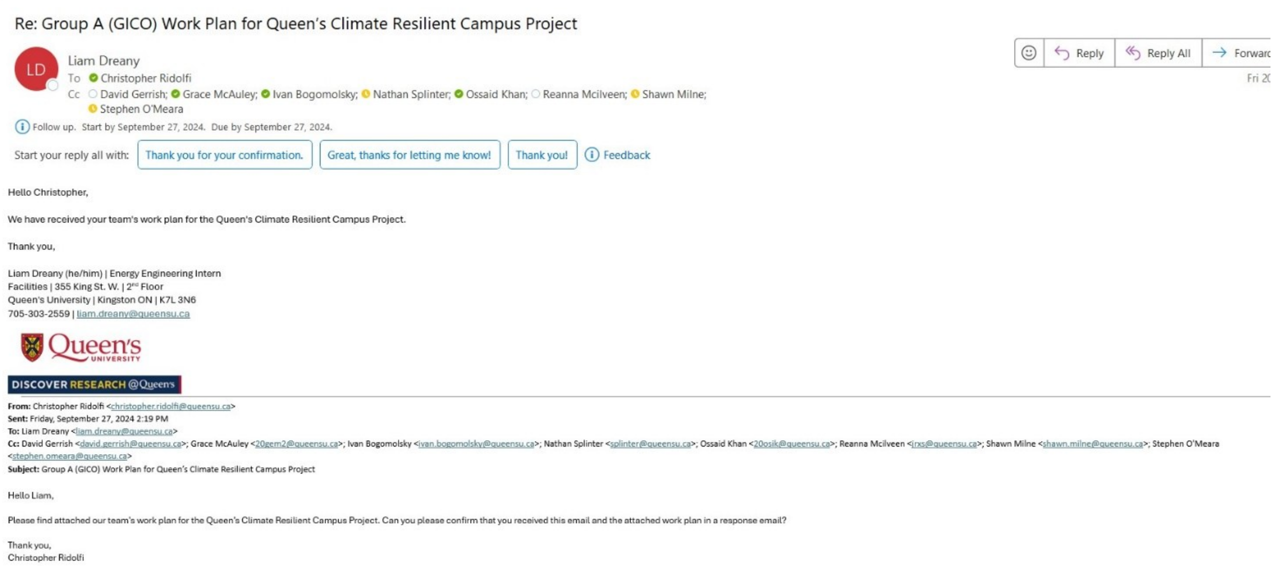


Figure C- 5: Gantt Chart Continued

Appendix D: Work Plan Acknowledgement Email

Acknowledgment that the client received GICO's work plan is depicted below in Figure D-1.



Re: Group A (GICO) Work Plan for Queen's Climate Resilient Campus Project

Liam Dreany
To Christopher Ridolfi
Cc David Gerrish; Grace McAuley; Ivan Bogomolsky; Nathan Splinter; Ossaid Khan; Reanna Mcilveen; Shawn Milne; Stephen O'Meara

Follow up. Start by September 27, 2024. Due by September 27, 2024.

Start your reply all with: Thank you for your confirmation. Great, thanks for letting me know! Thank you! Feedback

Reply | Reply All | Forward

Hello Christopher,

We have received your team's work plan for the Queen's Climate Resilient Campus Project.

Thank you,

Liam Dreany (he/him) | Energy Engineering Intern
Facilities | 355 King St. W. | 2nd Floor
Queen's University | Kingston ON | K7L 3N6
705-303-2559 | liam.dreany@queensu.ca

Queen's University

DISCOVER RESEARCH @Queen's

From: Christopher Ridolfi <christopher.ridolfi@queensu.ca>
Sent: Friday, September 27, 2024 2:19 PM
To: Liam Dreany <liam.dreany@queensu.ca>
Cc: David Gerrish <david.gerrish@queensu.ca>; Grace McAuley <20gem2@queensu.ca>; Ivan Bogomolsky <ivan.bogomolsky@queensu.ca>; Nathan Splinter <splinter@queensu.ca>; Ossaid Khan <20osik@queensu.ca>; Reanna Mcilveen <jrxs@queensu.ca>; Shawn Milne <shawn.milne@queensu.ca>; Stephen O'Meara <stephen.omeara@queensu.ca>
Subject: Group A (GICO) Work Plan for Queen's Climate Resilient Campus Project

Hello Liam,

Please find attached our team's work plan for the Queen's Climate Resilient Campus Project. Can you please confirm that you received this email and the attached work plan in a response email?

Thank you,
Christopher Ridolfi

Figure D-1: Client Acknowledgement Email

Appendix E: Assignment of Duties

The team's assignment of duties is summarized below in Table E-1.

Table E-1: Group Member Responsibilities

Report Section	Group Member Responsible
Transmittal Letter	Grace McAuley
Executive Summary	Grace McAuley
Introduction	Grace McAuley
Background Information	Grace McAuley
Scope	Grace McAuley
Constraints	Ivan Bogomolsky
Stakeholders	Grace McAuley
Background Research	Ossaid Khan
Design Alternatives	Ossaid Khan
Potential Present Solutions	Ossaid Khan
Potential Future Solutions	Christopher Ridolfi
Evaluation Matrix	Ossaid Khan and Christopher Ridolfi
Design Selection	Grace McAuley

Design Calculations	Ossaid Khan, Christopher Ridolfi and Grace McAuley
Final Designs	Ossaid Khan, Christopher Ridolfi, and Grace McAuley
Design Evaluation	Christopher Ridolfi, Ossaid Khan and Ivan Bogomolsky
Implementation	Grace McAuley, Ivan Bogomolsky, Christopher Ridolfi, and Ossaid Khan
Cost Estimation	Ivan Bogomolsky
Schedule	Christopher Ridolfi
Risk Assessment	Christopher Ridolfi
Next Steps	Ivan Bogomolsky
Conclusion	Ivan Bogomolsky
Appendices	Christopher Ridolfi