April 11, 2020

Project Manager
Infrastructure Ontario
Suite 2400, 1 Dundas St. West
Toronto, Ontario
M5G 1Z3

Dr. Andrea Bradford, Ph.D, P. Eng
Associate Director Undergraduate Studies
School of Engineering, University of Guelph
Guelph ON, N1G 2W1
519-824-4120 x52485

Re: Final Design Report for ‘One Water’ System at Yorklands Green Hub

Dear Project Manager,

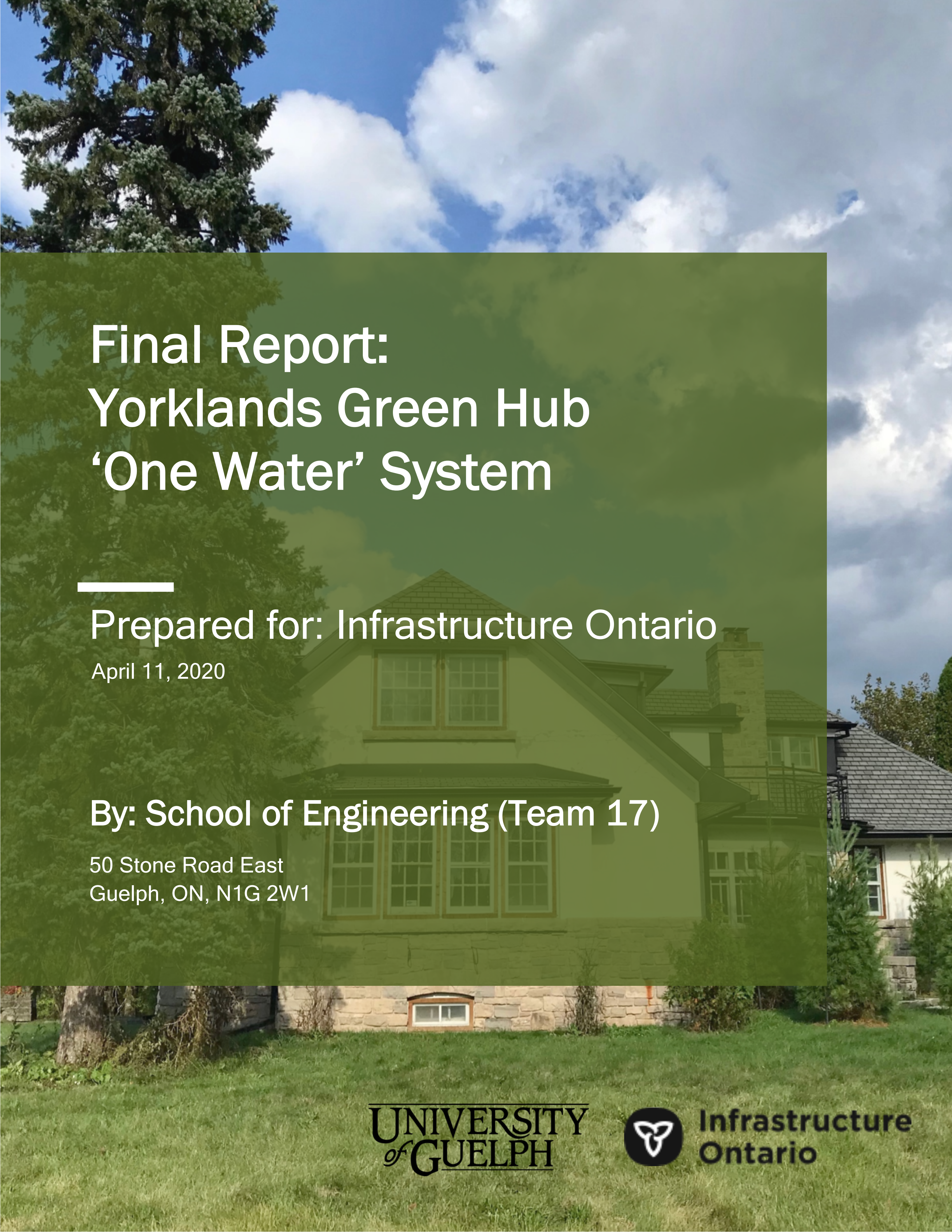
Enclosed is the Final Design Report in response to Yorklands Green Hub (YGH) request for university student design projects to support their future Sustainable Environments Centre (the Centre) on Parcel 2 of the Guelph Correctional Facility lands. As discussed with our YGH contact, Norah Chaloner, our team of Environmental and Water Resource Engineering students at the University of Guelph has developed a final design for a ‘One Water’ system at the Centre. The ‘One Water’ approach is a self-sustaining system which uses and returns water on-site with no reliance on municipal systems. The water reuse system includes stormwater and greywater collection for reuse applications in the planned facilities, followed with an on-site decentralized wastewater treatment system. The pumps used for water distribution in the system will be powered by a set of solar panels on the centre’s roof.

This Final Design Report includes background information on stormwater management approaches, stormwater and greywater reuse, on-site wastewater treatment systems, and sustainable energy. The conceptual design alternatives and evaluation phases are summarized from the interim report, and the final design solution is presented in detail. Considerations of the life cycle impacts, local environmental protection, public safety, and social benefits are discussed. System financing is estimated and an analysis of economic feasibility for YGH is also included. Finally, identification of next steps and key project opportunities for refining the final design is summarized. This final report shall be used to support the implementation of a functional and sustainable ‘One Water’ system design upon successful purchase of the Parcel 2 lands from Infrastructure Ontario.

Should you have any further questions or concerns, please do not hesitate to contact the design team.

Sincerely,

Alana Valle, Jake Martin, Ana Brankovan and Elli Shanen



Final Report: Yorklands Green Hub ‘One Water’ System

Prepared for: Infrastructure Ontario

April 11, 2020

By: School of Engineering (Team 17)

50 Stone Road East
Guelph, ON, N1G 2W1

University of Guelph

Infrastructure Ontario

EXECUTIVE SUMMARY

Sustainability has become an important set of challenges faced by today's modern societies, and educational centres have an integral role in promoting the future environmental health of the planet. As such, this design project focuses on applying resource conservation for a proposed public Sustainable Environments Centre in coordination with the interests of Yorklands Green Hub (YGH). The vision of this not-for-profit organization is to promote demonstrational facilities for resource conservation, to educate the public on the value of natural heritage space, and to encourage healthy, resilient communities [1]. The scope of this project is to design a 'One Water' reuse system consisting of stormwater and greywater collection for non-potable water uses at the YGH. A well will be installed to meet potable water needs, and a decentralized wastewater treatment system will treat and return the water back on-site. Finally, a renewable energy system will be designed to meet the power demands of the system. By adopting innovative reuse systems for water available on-site, this design disconnects the YGH from municipal supply and maintains the local natural water cycle.

The team exercised several idea generation techniques in reference to the criteria and constraints of YGH to develop potential design alternatives for each system component including stormwater capture, on-site wastewater treatment, and on-site renewable energy generation. Alternatives were then evaluated through a criterion weighting and ranking system. Upon sensitivity analysis of two alternative scenarios with revised criteria weighting, a preferred design solution was identified to carry forward into detailed design. Through revisions to optimize the design including revisions to reuse system demands and pump selection, a final 'One Water' system design was reached.

The solution uses bioretention, a green roof and rooftop collection for capturing stormwater runoff from the site's impervious areas into a storage tank located at the Centre for water reuse purposes. To treat the effluent wastewater generated at the site, a septic tank and leaching bed returns the collected stormwater back on-site while protecting the local environment and meeting requirements to minimize contamination risks. Finally, to power the system, eight 400W solar panels provide energy for the water reuse and potable water well system pumps. The system can operate year-round, with the reuse tank empty for an average of 15 hours a year. Climate change modelling indicates a reduction in operational hours, but the design's scalability allows for additional water capture from impervious site areas such as the parking lot. To help limit the design's environmental impact, a life cycle analysis was completed and recommendations for alternative materials or construction practices are subsequently made that can significantly reduce these impacts. The projected capital and annual maintenance costs are $173,300 and $4,900 respectively. From municipal water use savings and visitor admission fees, costs can be recovered in under 8 years.

During the period from September 1 to April 11, the team progressed on track with the project schedule. The final project fees include $67,900 spent, which accounts for 90% of original project budget. To further refine the system's design, a winter season hydrologic investigation to determine the system performance in sub-zero temperatures and precise future expansion scenario analysis for scalability requirements can be made. The 'One Water' system for YGH's Sustainable Environments Centre is overall an innovative educational opportunity and acts as a demonstrational tool for future developments that share similar values to Yorklands Green Hub.

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LIST OF ACRONYMS/TERMS

CCME	Canadian Council of Minister of the Environment
CEI	Community Energy Initiative
City	City of Guelph
CVC	Credit Valley Conservation
GCC	Guelph Correctional Centre
GID	Guelph Innovation District
GIS	Geographic Information Systems
LID	Low Impact Development
LCA	Life Cycle Analysis
MBR	Membrane Bioreactor
MCDM	Multi-Criteria Decision Matrix
MECP	Ministry of the Environment, Conservation and Parks
OGS	Oil and Grit Separator
OBC	Ontario Building Code Act
PV	Photovoltaic
PWQO	Provincial Water Quality Objectives
Site	Yorklands Green Hub Parcel 2
SWM	Stormwater Management
TRCA	Toronto Region Conservation Authority
TSS	Total Suspended Solids
US EPA	United States Environmental Protection Agency
YGH	Yorklands Green Hub

1 INTRODUCTION

The focus of this project is the design of a 'One Water' System as requested by Yorklands Green Hub (YGH) for their future Sustainable Environments Centre (the Centre). This report includes a description of the project requirements and background information, an overview of the design process approach and a detailed description of the final design for the preferred design alternative.

1.1 Problem Description

Yorklands Green Hub, a not-for-profit organization, wants to repurpose the former Guelph Correctional Centre (GCC) into a public Sustainable Environment Centre. This Centre will be a self-sustaining education and environmental community hub, which will showcase innovative small-scale agricultural, energy and environmental sustainability initiatives [1].

YGH has expressed an interest in investigating designs for the Site from university students and the community, which will be taken into consideration when the Site design is finalized. Several designs have been proposed by other groups, including designs for sustainable greenhouses and for the site layout and landscaping. No design has been proposed for sustainable retrofitting of the former Superintendents House or for the on-site water systems. Therefore, this design project will focus on a self-sustaining 'One Water' system to service the new Centre, the greenhouses and the landscape irrigation system. The system design will include four parts:

- Stormwater and greywater collection and treatment,
- Decentralized wastewater treatment,
- Distribution pumps for the above systems and a potable water well; and
- Sustainable energy technologies to power the system.

The purpose of the Centre will be to promote environmental stewardship and conservation through educational programs and demonstrations [2]. YGH has outlined goals for the purpose of the centre, which focus on sustainable local food production, wise water use and wetland protection, energy conservation and technologies for sustainable food production, and the natural and cultural heritage of the Site [1]. This design project will support YGH to achieve these goals for the Centre, especially with respect to the goals for wise water use, wetland protection, and energy conservation.

The achievement of the YGH goals is important for the environment as they echo the goals of larger scale environmental plans such as the United Nation 2030 Sustainable Development Goals. The goals from the United Nations that resonate with the goals of YGH for this Site are Goal #3 for good health and well-being, Goal #4 for quality of education, and Goal #11 for sustainable cities and communities [3]. Therefore, the YGH's plans to become a sustainability education centre that builds urban resiliency would contribute to Canada's efforts to reach 2030 Sustainable Development Goals.

In addition to the goals of the United Nations, the YGH goals also resonate with the goals of the Guelph Innovation District (GID) Secondary Plan. The GID secondary plan aims to facilitate the development of 162 hectares of land in the eastern edge of the City of Guelph to support an economic cluster focused on green-economy and innovation sector jobs [4]. The plan includes energy sustainability and community energy policies that promote carbon neutrality, solar technologies and retrofitting heritage building facilities [4]. Therefore, achievement of the YGH's goals for the Site in energy conservation and natural heritage will contribute to the success of the GID plan in promoting economic growth for the City of Guelph. The YGH Centre will also improve resident's quality of life in the City of Guelph by promoting community engagement and support.

Furthermore, the proposed Centre will provide a space to further the public's education regarding sustainable living and the site's cultural and natural heritage. Public education is an essential aspect of promoting environmental sustainability for the community. The 'One Water' design for the YGH Site will provide an opportunity for community members to learn about sustainable technologies and water and energy conservation practices that they can apply in their own homes. Therefore, the 'One Water' design at YGH will to have a greater impact on the environmental health of the community.

1.2 Site Description

The property is located at 785 York Road in Guelph, Ontario and contains the former GCC buildings and land. The provincially owned GCC operated from 1909 to 2002 and rehabilitated inmates by providing them with opportunities to develop employable skills through landscaping and farming work. The property is now considered a provincially significant heritage site.

The former GCC property was divided into parcels for sale by its owner (Infrastructure Ontario) and YGH is interested in obtaining ownership of Parcel 2, which will therefore be the focus of this project. As part of their plan to create the Centre, YGH has expressed two immediate goals:

- Secure the 70-acre former GCC property to be designated as heritage/cultural [2].
- Secure and retrofit the existing Superintendents House as a centre for interactive educational programs [2].

The 70-acre Site consists of wetlands, two man-made ponds, streams, meadows and the former Superintendent's House [1] as presented in Figure A-1 (All figures are provided in). As determined by the Grand River Conservation Authority's mapping tool [5], the site is not located on a floodplain but contains a provincially significant wetland on the North perimeter.

The superintendent's two storey house is located adjacent to a paved access road stretching Parcel 2 and is currently not in use. Previously, the building used municipal water and wastewater services with connections still present but non-operational at the time of this project. A large parking area is also in the vicinity of the superintendent's house and adjacent to flat open green space. Existing site topography can be seen in Figure A-2 and suggests suitable flat grading for stormwater capture near the house and parking lot. Adjacent features to the site include the Eramosa River to the South, York Road to the West, Watson Parkway to the North, and the remaining GCC buildings to the East. It was noted by YGH that future road reconstruction on York Road will push the road and creek along its ditch further into the Western boundary of Parcel 2.

1.3 Project Scope and Objectives

As previously mentioned, this project includes the design of a stormwater and greywater collection and reuse system coupled with a decentralized wastewater treatment system. The whole system is aimed to be powered by renewable energy sources. Overall, these components will constitute a self-sustaining system, referred to as a 'One Water' system. The system will service the new educational centre in the former Superintendents House, the greenhouses, and the site landscape irrigation in a manner that aligns with the YGH goals. The main components of this design include:

- Stormwater and greywater collection, treatment and distribution systems to service the greenhouses and landscape irrigation, and non-potable water demands at the new Sustainable Environmental Centre
- Decentralized wastewater treatment system to service all the wastewater demands at the Site
- Renewable energy sources to service the energy requirements of the various water distribution pumps required in each of these systems

The stormwater collection and treatment system will be designed to capture 90% of the average annual rainfall from the impervious surfaces at the Site, such as building rooftops, parking lots and roads. Therefore, the layout of the future redeveloped property is required. An estimated Site layout will be used for the design, based on conversations with YGH on their plans. The architectural plans and internal room layout for the proposed education centre will not be provided as part of the design. Additionally, it should be noted that the design of the irrigation systems themselves, for the greenhouses and landscaping, will not be included in this project.

The greywater collection and treatment system will be designed to collect greywater from the washroom sinks and showers in the new Centre to be reused for non-potable applications such as the washroom toilets. The collection and treatment system for the greywater produced at the future educational centre will be designed based upon estimated water demands and usage rates. Furthermore, it is anticipated that a small-scale treatment system will likely be required to treat the collected water prior to reuse. A general design of this treatment system will be provided based on the relevant guidelines. The specific design of the water distribution system within the building will not be completed as part of this project.

With respect to the decentralized wastewater treatment system, it must be noted that the City of Guelph standards do not allow for partial servicing of sites [6]. Previously, the building used municipal water and wastewater services with connections still present. Therefore, to incorporate the decentralized wastewater treatment system, the Site will be disconnected from the current municipal supply and serviced by a private well for potable water needs. The design of this private potable water well and treatment system will not be considered as part of this design project.

2 BACKGROUND

The following section provides an outline of the background information collected to further describe various components of the design. Additionally, constraints and criteria that define the objectives and limitations to the design project are discussed.

2.1 'One Water'

Typically, water systems for drinking water, wastewater, greywater and stormwater are managed separately with independent municipal systems. The 'One Water' approach is a way to holistically manage water systems by connecting each of the components [7]. By applying this approach, a full cycle is achieved where the water is taken from the source, distributed through the water systems and released back to the watershed [7]. The 'One Water' system approach used for this project is described by Figure 2-1 below.

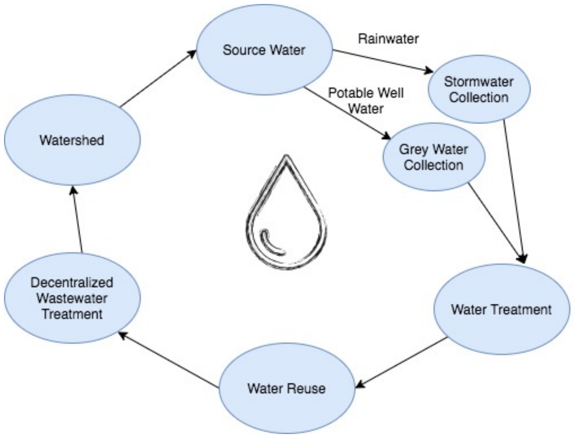


Figure 2-1: 'One Water' System

Overall, the main benefit of the 'One Water' approach is that disruption to the water cycle and water balance are minimized in comparison to conventional urban management systems. This is because 'One Water' is an integrated approach that mimics the interconnectedness of the hydrologic cycle more closely compared to common municipal systems.

2.2 Existing Applications

There are several existing applications of the 'One Water' systems approach and of sustainable water systems in general, even for community education hubs like YGH, which are helpful references for the development of this project.

2.2.1 'One Water' Applications

The idea of the 'One Water' approach for better water resource management is not new, however, the full-scale implementation of this approach is not common practice. However, this idea is becoming more popular. The guiding principles of this approach are commonly being applied by engineering consultants, and some are currently developing 'One Water' systems. For example, WSP Global Inc., an engineering consulting company, has been promoting the application of the 'One Water' approach for managing water systems, mainly in British Columbia [7]. They have been developing guidelines to support the application of this approach to municipal water and wastewater systems.

2.2.2 General Sustainable Water System Applications

Within the Guelph community, an example of a successful sustainable water system that uses reclaimed stormwater is the 10 Carden Shared Space (10C) building. 10C is a not-for-profit organization that offers a space for community events and meetings [8]. The building is equipped with a sustainable water system that collects stormwater from the rooftop into a tank that supplies the kitchen and washrooms in the building. The kitchen and washrooms in this building are similar to the kitchen and washrooms that YGH will operate in their new education Centre. Therefore, a site visit was conducted at the 10C building to gain a better understanding of the demands and logistics of the 'One Water' system for this project.

Another example of a successful application of a sustainable water system nearby the Guelph area is the Evergreen Brick Works campus, located in Toronto, Ontario. Evergreen Brick Works is a very similar enterprise to YGH. Evergreen had transformed a deteriorating heritage building into a hub which showcases sustainable environmental initiatives and provides a public space for the community [9]. One of the initiatives that Evergreen Brick Works has incorporated into their campus is rainwater barrels to harvest rainwater which is reused within the building to service sinks and other greywater uses.

2.3 Literature Review on Existing Technologies

To fully understand the various components required for the development of the water reuse and wastewater treatment systems requested by the client, the following literature review has been completed. The following sections separate the system into its major components and provide a review of the technologies available and their potential applications.

2.3.1 Stormwater Management Design Approaches

Stormwater management (SWM) will play a crucial role in the design of the 'One Water' system for the Centre. The following two subsections discuss common approaches in hydrologic modelling for SWM analysis and Low Impact Development (LID) features including how they may be a beneficial approach for site stormwater management.

Site Hydrologic Analysis Techniques

The Ontario Ministry of Transportation outlines the different methods that may be suitable in calculating flow rates and categorizes them into either non-hydrographic methods or hydrographic methods [10]. Non-hydrographic methods calculate peak flow rates based on statistical analysis of either precipitation or stream flow records [10]. The analysis takes statistical representations of the precipitation on-site or at nearby stations in combination with physical catchment parameters to estimate runoff flow rates generated in return period storm events [10]. This approach does not consider flow on a temporal scale and thus no hydrograph of the resulting flow is produced [10].

Hydrographic methods do address the temporal distribution of precipitation and produce results of flow rates over time [10]. The two types of hydrograph methods that can be used depend on whether precipitation data is available as a single event or continuous precipitation records [10]. Continuous modelling uses long term precipitation data to generate estimates of runoff, infiltration, and evapotranspiration with results that approximate reality better than single event modelling [10].

Low Impact Development Features

The US EPA defines Low Impact Development as a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible [11]. This strategy adopts structural practices that mimic predevelopment hydrology through the processes of infiltration, evapotranspiration, and detention of stormwater [11].

These practices are also noted to be effective at removing nutrients, pathogens, and metals from runoff while reducing the volume and intensity of runoff flows in storm events [11].

LID Features include bioretention cells, infiltration chambers or trenches, green roofs, enhanced swales, and permeable surfaces. The adoption of LID features in stormwater management has been encouraged by studies that compare their ability to reduce runoff and enhance water quality compared to traditional SWM infrastructure. A summary of these green infrastructure technologies including their general design applications and treatment abilities is included in Appendix D.

A study published in 2013 by the University of New Hampshire compared pollutant removal efficiencies of both traditional and LID SWM features at a large parking lot in Durham, New Hampshire [12]. Traditional infrastructure included a dry and wet ponds while the LID features tested included a bioretention cell, a gravel wetland, and porous asphalt [12]. Water quality data reported average TSS removal efficiencies of about 74% for the pond features while the average for the LID features was around 96% [12]. Additionally, the ponds were incapable of removing phosphorous, while the LID features removed 48% on average [12]. Total nitrogen removal efficiency was about 29% for the ponds but varied significantly between LID features from 0% to 75% [12].

LID infrastructure also costs less in comparison to traditional infrastructure. A study completed by the TRCA in 2013 reviewed the costs of various LID features with a traditional oil and grit separator system for providing stormwater quality enhancement. The LID features were comparable in both initial capital costs and net present value measured at 50 years with a 5% interest rate, ranging from $54 to $73 per square meter of impervious area treated [13]. The benefits of stormwater quality enhancement and runoff were considered in a second analysis. When the features were evaluated based on cost per kilogram of TSS removed, it was found that the LID features had initial capital costs that were 24 to 44% lower and net present value costs 35 to 77% lower than that of the OGS system [13]. While these systems often require more frequent maintenance, established research identifies LID practices as a cost-effective SWM solution.

2.3.2 Applications of Stormwater and Greywater Reuse

As part of the design, the collected stormwater and greywater will be reused for various end uses, and therefore must comply with any applicable standards or guidelines.

Stormwater Reuse

Treatment of the collected stormwater in this design is completed by the LID features and the parameter concentrations should comply with the applicable standards. For the use of the reclaimed stormwater for agricultural irrigation (i.e., for the proposed on-site greenhouses) or for landscape irrigation on-site, the following federal and provincial standards are applicable:

- Canadian Environmental Quality Guidelines for the Protection of Agricultural Water Uses, published in 1999 by the Canadian Council of Ministers of the Environment (CCME) [14];
- Canadian Environmental Quality Guidelines for the Protection of Aquatic Life - Freshwater, published in 1999 by the CCME [14]; and
- Provincial Water Quality Objectives (PWQO) updated in March 2019 by the Ministry of the Environment, Conservation and Parks (MECP) [15].

These guidelines were developed to aid in the protection of sensitive crop species that may exposed to toxic substances in irrigation water and to protect aquatic life and the quality of Canada's surface water bodies. They should be used in combination to ensure acceptable water quality results.

For the purposes of this project, it is not feasible for collected stormwater to be sampled to ensure compliance. YGH should test for compliance with these standards if the design is implemented.

Greywater Reuse

The collected greywater (i.e. the wastewater produced from any washroom sinks or showers) at the Site can be reused to service the non-potable uses such as toilets or urinals in the building. The design and treatment of the greywater system should follow the guidelines outlined in the Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing, published in January 2010 by Health Canada [16]. These guidelines present a risk-based approach to ensure protection of public health over the long term. With respect to the treatment system for the greywater collected, the effluent water quality must comply with the standards in Table 1 of the document. Additionally, a management framework is outlined in the document which should be followed to monitor the system at start-up and then through periodic verification.

2.3.3 On-site Wastewater Treatment Technologies

Decentralized wastewater treatment system (DWTS) is a broad term that generally relates to the variety of approaches available for collection, treatment, and dispersal of wastewater for dwellings, institutions, or even entire communities [17]. These systems can be effective alternatives to centralized wastewater treatment, which differ from DWTS in that they rely on collection of sewage from surrounding areas via an underground pipe system for treatment at one large scale facility. Some key differences between the two system types are summarized in the following table:

Table 2-1: Referenced from Wateraid Technical Guidelines for DWTS Design [18]

Topic:	Centralized Systems	Decentralized Systems
Reliability	Require complex operation and maintenance schedules for optimal performance.	Less intensive maintenance for similar performance.
Environmental Impact	Can generate partially or untreated wastewater that that may not meet discharge standards if poorly maintained. Requires high energy supply to operate.	When properly maintained, treated wastewater can be disposed into local water channels or reused on-site. Energy requirements low to zero.
Affordability	High cost due to installation, sewerage network, operational and maintenance costs. Substantial grants or government funding typically required for construction.	More affordable due to lower capital cost and use of more locally available materials. Portions of system may also use natural technologies.

Understanding the goals of the project outlined in Section 1 of this report and in reference to the partial servicing constraint, the option of connecting the site's buildings to the sanitary sewer system off of York Road for treatment at the Guelph Wastewater Treatment Plant is not an allowable option due to the planned use of a drinking water well on-site. Additionally, a decentralized system will be more suited in ensuring impacts to the site water balance are minimized as collected stormwater in the reuse system will ultimately return back to the site through the wastewater treatment system. Understanding that a decentralized system is necessary, the following subsections outline several potential technologies currently practiced in the industry that may be incorporated into this project.

Septic Tank and Leaching Bed Systems

Generally, septic systems are on-site treatment units consisting of an underground pipe transporting wastewater from the building to the tank where settling, scum removal and breakdown of organic materials can occur [17]. After the primary treatment occurring in the tank, the effluent drains via gravity or a pump to the leaching bed; a grid like system of perforated PVC pipes with stone and unsaturated native soil surrounding the pipes [17]. This bed allows the effluent to seep into the ground where bacteria and other organisms process the wastewater further [17]. The soils below essentially act as a filter to remove organic and biological contaminants [17]. Soil under the stone layer of the bed in a properly functioning system can remove up to 99% of the E.Coli for every 30cm of soil depth [17].

Like any wastewater treatment system, it is vital to ensure this type is maintained correctly. Part 8 of the Ontario Building Code Act identifies sizing, design, and maintenance procedures for these systems. The OBC also states these types of systems are only suitable for applications with an expected daily wastewater flow rate less than 10,000 litres per day [19]. Flows above this require more advanced treatment methods. When improperly designed or maintained, these systems can have detrimental environmental effects through contamination of local surface or groundwater. Performing regular maintenance such as annual effluent filter replacement, tank inspections, and testing of well water three times a year for indicator bacteria can all help to minimize this risk [17].

Septic systems are often popular wastewater management solutions in rural areas where sanitary sewer networks are not available for connecting properties to a nearby centralized wastewater treatment plant. These systems are also beneficial in that leaching beds can be expanded for increased discharge rates. The systems can also be completely passive systems where suitable elevation change is available to allow for a gravity fed network. To reduce contamination risks, the Ontario Building Code Act has outlined various minimum setback requirements for septic systems in relation to sensitive features such as drinking water wells, surface water bodies, and the seasonal high groundwater table elevation [17]. Overall these systems can offer a passive, simple wastewater treatment solution for small sites that, when designed and maintained properly, provide long term effective treatment of household wastewater [17].

2.3.4 Potable Water

The City of Guelph is located above two drinking water aquifers and relies on groundwater to meet potable water demands. The City has 21 operational municipal wells which are used for its central supply system [20]; however, private wells are also permitted. The City of Guelph does not allow for partial servicing, therefore sites such as the YGH would be required to completely rely on either municipal water and wastewater services or on its own on-site supply and treatment systems [6]. Considering YGH's sustainability and environmental protection objectives, the site's potable water system design shall consist of an on-site private well for potable water supply.

Regulations and specifications for the installation of a new well are identified in the Ontario Water Resources Act and the Ontario Building Code Act, and include placing the well at a high elevation on the property, where the ground slopes away from the property to avoid contamination [21]. Additionally, the location should ensure septic systems are down grade from the well and minimum distances from such contaminant sources are maintained [19]. The groundwater should also be treated for potable use through method's such as UV treatment, filtration and/or chlorination [21].

2.3.5 Sustainable Energy

As the worlds urban population continues to increase, the need for reducing carbon and other greenhouse emissions increases [22]. This is apparent from examining both global and local sustainable energy goals. The UN sustainability development goal #7 outlines the need to increase the share of renewable energy in the global energy mix by 2030 [23]. On a local scale, the Community Energy Initiative (CEI) is Guelph's commitment to use and manage renewable energy resources [24]. The CEI's main goal is for Guelph to become a Carbon Net Zero community by 2050. To contribute to sustainable development and education, the integration of renewable energy resources is an essential component to the repurposing of the GCC into the future YGH. The main types of renewable energy resources applicable to the YGH are solar energy, wind energy and renewable biogas. A sustainable energy system will allow for minimized environmental impact and would be more cost effective in the long run. From the preliminary design, solar energy was selected as the appropriate technology and a discussion of this energy generation system is provided in the following section.

Solar Energy

Solar energy is often viewed as essential for sustainable energy systems as it is versatile and abundant. The main methods of harnessing solar energy are implemented through photovoltaics (PV) for energy production and solar heating and cooling [25]. PVs take light energy and convert it directly into electrical current. PVs can generate and supply electricity to buildings and system equipment through either off-grid or net metering systems. An off-grid system requires batteries to store excess energy generated while net-metered systems sell excess electricity generated to the grid and buys it back during dark periods. The ability to generate energy through all seasons and climates makes solar energy a reliable renewable resource.

Solar PV systems have two main methods of installment, racked roof mounting integrated into building structures or ground mounted [25], each system has its own benefits. Roof mounting systems can save on required space for installation as they make use of otherwise non-useful roof space. While round mounted systems can be designed to be seasonably adjustable to follow the movement of the sun to increase electricity production.

The amount of electricity generated by PVs can be maximized by performing meteorological, atlas, and geographical information systems (GIS) analyses [26]. In 2012, the CEI conducted a study to assess the solar energy production potential using PV panels for the City of Guelph. It was found that PV panels mounted to inclined roof top orientations allowed for more energy production than horizontally positioned panels. The study indicated the Guelph had a large potential for energy generation through PV panels, with minimal seasonal variation.

PV solar panels are sized according to the energy demand of the facility or process it is supplying. The peak sunlight hours and panel wattage are also needed for these calculations [27]. Typical solar panels range from low wattage to high wattage, 150W - 445W. High wattage individual PV panels are relatively low cost at $275 per panel [28]. As individual solar panels are cost effective, solar energy systems are extremely well scalable as extra panels can be added easily to increase production capacity.

2.4 Constraints and Criteria

To further define and describe the goals of the proposed designs, several constraints and criteria have been identified for the system and have been justified. The constraints and the criteria are outlined in Table 2-2 and Table 2-3 below, respectively.

Table 2-2: Constraints for Treatment System Design

	Constraints	Justification
1	Design is restricted to area included in the site boundary outside of floodplain and GRCA regulated area, as shown on Figure A-2 in [5].	The design will be implemented for the development plans of YGH and will therefore be limited to their property in accordance with all floodplain and Grand River Conservation Authority (GRCA) Regulated Area.
2	Any design aspects requiring energy (e.g., pumps for water supply system, etc.) will be satisfied via sustainable on-site energy sources.	Sustainable energy from on-site sources is important to achieve some of the YGH goals, including being self-sustaining and having a focus on energy conservation and sustainable living technologies.
3	As opposed to municipal water servicing, a local drinking water source is requested by the client Yorklands Green Hub.	Zero reliance on municipal water supply is important to meet the goals of YGH. This can be achieved by maximizing reliance on the reuse system in fulfilling water usage demands for the toilets while potable water needs will be provided from a local well drilled on-site.
4	Project site cannot be partially serviced (ie. Watermain connection but no sanitary sewer connection or vice versa).	City of Guelph standards do not allow for partial servicing of sites [6]. Thus, to become disconnected from municipal water supply, the site must also incorporate a decentralized wastewater treatment system.
5	Mixing of the reused greywater and stormwater supply with the potable	Mixing of reclaimed water with potable water supply could result in contamination. Potential

	water supply to the building must be prevented.	presence of pathogenic microorganisms or some chemicals in reclaimed water may pose a health risk if the water is used for purposes other than toilet or urinal flushing.
6	Wastewater System Design must meet the design, effluent quality, and setback requirements set out under Section 8 of the Ontario Building Code Act [19].	Any wastewater discharge included in the design will satisfy all applicable guidelines in the OBC. These regulations have been created to protect the environment and public health.
7	The Stormwater Management System must be designed to capture 90% of average annual rainfall as per the CVC Low Impact Development Guidelines [11].	To meet typical Municipal stormwater management standards, sites using LID practices must meet targets for water quality storm events, which translates to the capturing of 90% of average annual rainfall.
8	The water supply and wastewater treatment system design must be able to accommodate all water demand requirements for YGH.	The YGH site plan to include a classroom, greenhouse, kitchen in the main house and landscaping. The on-site water and wastewater systems are to meet the water demand of this site plan.
9	Reclaimed greywater must satisfy the applicable water quality standards for non-potable uses.	Greywater reused for washroom facilities at the building will meet standards outlined in the "Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing" [16]. These regulations ensure water reuse systems protect public health and maximize effectiveness of water treatment.

Table 2-3: Criteria for Treatment System Design

#	Applicability	Criteria	Justification
1	Common Criteria	Minimize capital cost	Minimal cost makes the design more feasible for the YGH to finance and implement.
2		Minimize operation and maintenance needs	High cost and work requirements reduce feasibility of maintaining system operation in the long-term.
3		Other benefits	Additional environmental, ecological, educational or aesthetic benefits can increase the value of YGH and contribute to their community objectives.
4		Site and environmental cost/disruption	Short component lifecycles with non-recyclable parts result in increased environmental harm. Local environmental disruption such as noise and poor water quality can negatively impact local wildlife and visitors. Disruption of site can impact value of heritage structures and functionality of YGH.
5		Scalability potential	Ability to increase scale of components is crucial to YGH's ability to increase its operations in the future.
6	Wastewater System	Minimize energy requirements	High energy demands increase the quantity of renewable energy systems required and its corresponding cost. System also becomes increasingly vulnerable to power cuts.
7		Maximize treatment quantity per area	High treatment quantity reduces footprint required for system and loading capacity during peak usage.
8	Stormwater Management System	Maximize capture ability	High capture ability reduces quantity of LIDs required and corresponding cost; increases land available for other uses.
9		Maximize water treatment ability per unit area (Footprint)	High treatment ability increases water quality and reducing system maintenance requirements due to debris and fouling.
10	Energy	Maximize output per unit	High output per unit reduces the number of units required and corresponding cost and space needs.

3 DESIGN PROCESS AND SOLUTION

This section presents the approach to developing and evaluating design alternatives for the various components of the 'One Water' system at YGH's future Sustainable Environment Centre. A detailed conceptual description of several researched technologies for the three design components (i.e., stormwater collection, wastewater treatment and renewable energy generation) is outlined. Furthermore, a description of the identified preferred alternative based on the design evaluation results is presented.

3.1 Design Resources Overview

To effectively understand the scope, limitations, steps of the design process, and evaluation procedures for this design project, many resources, reference documents, and engineering tools were accessed. An overview of these different information sources and tools is provided in the following table.

Table 3-1: Overview of key project resources and tools with description of their purpose.

'One Water' System Design Project Tools and Resources	
Item	**Purpose Justification**
Water Reuse System	
Stormwater Management Planning and Design Manual [29], Credit Valley Conservation LID Manual [11]	Design guidelines followed in Low Impact Development design for stormwater capture component of system.
PCSWMM Modelling Software	Software program used in support of stormwater collection aspect of the 'One Water' system. Program supported continuous modelling that allowed for hourly precipitation analysis and graphical interface that helped with site layout.
ArcMAP (GIS Software)	The program allowed the geospatial data to be formatted and converted to proper file types required in PCSWMM.
ENGG*4370 Urban Watershed Systems Design	Course notes referred to in design of green roof and bioretention cell sizing. Included calculation check for cell drawdown ability and increased footprint size for capturing intense storm flows.
Environment and Climate Change Canada [30]	Online database of historical weather data for hourly precipitation at the Pine Grove station, climate normal for the KW airport, and temperature records for turfgrass station in Guelph. Data was used to develop the model climatic conditions in PCSWMM.
Ontario Climate Change Data Portal [31]	Online data portal for climate change modelling data in Ontario. Guelph area data obtained and used to determine necessary data adjustment in climate change scenario modelling.
Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing [16]	Guidelines for design of the greywater treatment system in order to meet base quality needs for water used in toilet flushing.

ENGG*4770 Physical and Chemical Treatment of Water and Wastewater	Course notes referred to in design of greywater treatment system, specifically the sizing of the flocculation/sedimentation tank, sizing of the sand filter and chlorine dosage.
Wastewater Treatment System	
Ontario Building Code Act [19]	Section 8 used for determining appropriate decentralized wastewater treatment system classification, setback requirements for the septic system (from wells, buildings, and surface water), septic tank and leaching bed sizing, and installation specifications.
Ontario Well Records Portal [32]	Online portal used to access water well records for wells nearest to the Site. Records used to approximate soil type and ground-water level at the Site where the leaching bed was to be placed.
Dr. Bassim Abbassi, Ph.D, P.Eng.	Professor with the University of Guelph and expert in decentralized wastewater treatment systems. Consulted for the appropriate selection of a decentralized wastewater treatment system and design process involved.
Renewable Energy Generation and Pump Systems	
Natural Resource Canada [33]	Solar resource data used to approximate the photovoltaic potential for the YGH site.
Rainbow Power Company [34], Canadian Solar [35]	Solar companies used to gather solar panel and solar system information used for the design of the YGH solar energy system.
ENGG*4760 Biological Wastewater Treatment Design	Course textbook and notes referenced for wastewater pump sizing calculations.
General Project	
City of Guelph Official Plan Amendment [4]	Document referred to for background info on-site zoning, parcel areas, and development plans of surrounding area.
Scholar's Geoportal	Shared University geospatial dataset program used to collect geospatial data on the project site including topography, soil type, and GRCA regulated areas.
Google Earth	Aerial imagery tool used for development of proposed site layout figures, system design schematics, review of existing features, and inspection for fulfillment of setback requirements.

Guelph Sewer Use Bylaw [6]	Regulatory document referred to for determining feasibility and limitations on-site servicing policies within City of Guelph.
OpenLCA Software	Life cycle assessment tool used for quantifying environmental impacts during installation and disposal of the various design components.
Norah Chanoler and Alex Smith, Yorklands Green Hub	Organization representatives project team met with throughout project development for information on the existing site, a tour of the property, and objectives of the YGH group.
Dr. Andrea Bradford, Ph.D, P.Eng.	Professor with the University of Guelph and expert in LID stormwater management, including life cycle analysis. Consulted regularly on design components and advised on procedures or resources to follow throughout project.
Akul Bhatt, MASc.	Ph.D candidate with University of Guelph and expert in OpenLCA software and academic experience with life cycle assessments. Consulted for the setup and development of a life cycle assessment for the 'One Water' system.
Microsoft Excel	Analytical tool for data analysis. Used in organization of precipitation data, climatic data for continuous model as well as gathering and presentation of model output results. Also used for iterative calculations of water demand.

3.2 Project Idea Generation

Several strategies were used through the idea generation phase of the design process to determine design alternatives. The primary step in the development of the alternatives was brainstorming sessions to generate ideas based on the team's existing knowledge of technologies related to the three design components. Following these brainstorming sessions of previous knowledge, a literature review was conducted to further explore the technologies discussed and to expand the team's knowledge on new technologies available that would potentially be valuable for this project.

The brainstorming sessions and literature review generated a long list of alternatives, which was refined by eliminating technologies which would clearly not suit the objectives of this project. Two key factors were considered when eliminating alternatives. One of the key considerations for this design project is the inclusion of the goals and objectives outlined by YGH to achieve their vision for the Site in the future. For example, to comply with their goal of wanting to be a self-sustaining environment hub, only solutions which could potentially be scaled to service the Site with minimal municipal support were examined. The other determining factor for the design alternatives was the restrictions that are presented by the layout of the Site. Examples of these restrictions include the available area within the property for construction of design components, the depth of the water table within the Site boundaries and the compatibility of the existing topographical grading of the Site for stormwater collection.

Based on this process, several acceptable design alternatives were identified for each of the three components of the design project. With respect to the greywater collection and treatment system, no alternatives had to be evaluated as strict guidelines are set out in the *Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing* for design of this type of system.

3.3 Design Alternatives and Evaluation

Based on the literature review conducted on stormwater collection systems, wastewater treatment systems, and sustainable energy sources, design alternatives were conceptualized for each system component. The description of these conceptual design alternatives, the process used to evaluate them, and the full evaluation of alternatives is included under Appendix C as an excerpt from the Interim Report prepared in February 2020.

3.4 Preliminary Design Solution

Overall, the best alternative for each of the three main components of the design were selected to be implemented in the YGH 'One Water' system. For the stormwater collection system, selected LID's include a green roof installed on the portable classroom addition and a bioretention cell to collect and treat runoff from the parking lot. An underground water storage tank will collect rooftop runoff from nearby buildings such as the visitor centre, greenhouse, and gazebo. Greywater recycling from building sources such as water fountain, sink, and shower effluent will be used to supplement stormwater reuse. The greywater can be stored in a separate chamber of the tank to be used for toilet flushing with appropriate pre-treatment measures. This aspect is investigated in Section 3.5 Design Optimization to determine if it shall be incorporated in the final design.

With respect to the wastewater treatment system, the selected technology is an underground septic tank and leaching bed system to be installed in the greenspace area adjacent to the new education centre, as this system requires very minimal energy and maintenance. A raised leaching bed may have been required if soil analysis indicates an inadequate percolation time. This check is discussed in the wastewater section of the final design description.

A well will be installed near the visitor centre for supply of potable water needs in compliance with the Ontario Building Code Act setback requirements considered to minimize risk for contamination. The potable, reuse and wastewater distribution systems will all require pumps to move the water to its various destinations. A shallow well pump, submersible effluent pump, and sump pump will be sized for water distribution from the well, septic tank, and reuse storage tank respectively. For the renewable energy source that powers the pumps, solar panels were selected to be applied to the roof top of the new Centre or potentially placed on racks in the greenspace area. Given weather variability and changes in energy generation, a storage battery will be installed to supply renewable energy over extended periods where power generation is low.

3.4.1 Water Demand Calculation

To determine how much water is required to service the Centre at YGH and how much wastewater is required to be treated by the wastewater treatment system, several flow calculations were completed using Excel software. The design flows calculated include the following:

- Total influent water required to service greenhouse and landscape irrigation;
- Total influent potable water required to service the fountains, kitchen and sinks/showers;
- Total influent water demand to service the toilets;
- Greywater collected in the building;
- Influent water demand to service the toilets from stormwater (stormwater or potable water); and
- Total effluent water flow to the wastewater treatment system.

The influent flows were used to determine how much stormwater needs to be collected from the Site to service the required end uses and the storm/greywater collection system was designed through hydrologic modelling based on these flows. The effluent water flows were used to determine the design of the wastewater treatment system, as per the OBC. The specific calculations and steps are outlined and discussed in subsequent sections of this report.

An outline of the parameters utilized, and the various calculations and results completed to develop system flow demands is provided in Appendix F. The assumptions for each of the parameters are also listed with the calculations. Assumptions are based on literature values, discussions with YGH, and best estimates. Any literature values used are referenced in Table F-12 of Appendix F.

3.4.2 Preliminary Modelling

A PCSWMM model was created for analysing stormwater capturability from impervious surfaces on the future Sustainable Environments Centre property. In addition to the key modelling assumptions presented within section 6.1 Design Assumptions, the catchment parameters, key model data inputs, and selected LID feature parameters are reported in Appendix G of this report. Overview images of the full scale preliminary PCSWMM model and a crop of the area around the Centre is provided in Appendix H.

A continuous model on the hydrologic modelling software PCSWMM was used to design the stormwater reuse component of the 'One Water' system and estimate its capacity for site applications. Continuous modelling is valuable to capture this time versus volume relationship of the tank as it can reflect instances of low precipitation for long periods of time where the tank may become completely empty and thus unusable. The storage tank was sized to meet the average demand flows for up to twelve days. The tank fills during a storm and slowly loses volume as reuse applications draw from it. This effect was mimicked by implementation of a pump feature in the model with a flow rate determined from the calculated non-potable water demands of the site, outlined in Appendix F of this report. Additional benefits of continuous modelling include its ability to incorporate climatic weather for the calculation of evaporation rates, capturing temporal variations in rainfall intensity, and capturing the relationship between seasonal precipitation and reuse water availability in the system.

To run a continuous model, hourly precipitation data obtained from the Pine Grove station over an eight-year span was added for model simulation. Climate data including daily maximum and minimum temperatures from the Guelph Turfgrass climate station, less than one kilometer from the site, was input to the model for the same time period (January 1, 2012 and December 31, 2019). Finally, monthly average windspeeds were obtained from a historical climate data site and adopted in the model. Temperature and wind speed were incorporated such that evaporation could be factored into the continuous simulation and improve the accuracy of the system behaviour.

Stormwater routing on-site is generally flexible given the flat grading and proximity of impermeable surfaces to the storage tank. In addition, design of the LID features can be adapted to create conditions more favourable towards infiltration or routing to the storage tank respectively. Given this flexibility, two potential scenarios are presented in this report for analysis:

- Scenario 1:
    - Stormwater runoff is collected in the reuse tank from the rooftops of the Centre, classroom via a green roof, the gazebo structure, and the greenhouse. Runoff from the parking lot area will be directed to an adjacent bioretention cell for treatment, detention and infiltration purposes.
- Scenario 2:
    - Stormwater runoff is collected from the rooftops of the Centre, classroom via a green roof, and the greenhouse, as well as from the parking lot's bioretention cell via an underdrain. The bioretention cell in this scenario is given a seepage rate of 0.01mm/hr to mimic implementation of an impermeable liner.

With catchments and LID features set up, the storage tank and pump were given size parameters and flow rates respectively based upon the design process provided in Appendix G. The model was simulated for the time period of January 1, 2014 to December 31, 2019, giving an analysis of system function for six years. Simulation findings under both scenarios are summarized in Table 3-2.

Table 3-2: Select preliminary PCSWMM model results from both modelling scenarios.

General Model Results	
Average Annual Precipitation (mm)	761
Average Annual Impervious Catchment Runoff (mm)	67
Average Annual Impervious Catchment Infiltration and LID Drainage (mm)	625
Average Annual Impervious Catchment Evaporation (mm)	68
Average Annual Impervious Catchment Runoff (m^3)	520
Average Annual Impervious Catchment Infiltration and LID Drainage (m^3)	4,760
Average Annual Impervious Catchment Evaporation (m^3)	3,110

Scenario 1	
Average Annual Stormwater Reuse System Capturability (m^3)	521
Average annual Stormwater Reuse (m^3)	214
Average Storage Tank Depth (m)	0.77
Average Annual Days of Empty Reuse Tank (days)	22
Scenario 2	
Average Annual Stormwater Reuse System Capturability (m^3)	4,750
Average annual Stormwater Reuse (m^3)	227
Average Storage Tank Depth (m)	1.18
Average Annual Days of Empty Reuse Tank (days)	0.2

The results indicate that a stormwater collection tank drawing from impervious runoff sources on-site can feasibly provide for reuse needs in either scenario. Optimization of the system by adopting more accurate reuse water demand flows and greywater recycling may further improve the effectiveness of the stormwater reuse component and is investigated in the following section.

3.5 Design Optimization

Two main aspects of the 'One Water' system were iteratively designed under altered conditions to optimize the overall design; the water reuse modelling and the energy demand calculations.

3.5.1 Water Reuse Modelling Optimization

To optimize the reuse system design and more accurately determine its ability to meet on-site water needs, the following revision phases were taken:

1. Introduce a seasonal variation in reuse flow demand, reducing the flow rate in the winter due to no need for landscaping irrigation
2. Introduce the greywater reuse component that supplies water for toilet flushing, further reducing the overall stormwater reuse flow rate throughout the year
3. Investigate performance ability by reducing tank volume and reviewing change in frequency of average annual operation

With the reduced demand rates, the tank was then over its recommended size. Stormwater collection tank is suggested to be sized for storing around ten to twelve days' worth of water [11]. This drawdown rate is suggested to ensure the system is has capacity to capture significant volumes of the runoff generated from the next storm [11]. The 7.5m^3 stormwater chamber of the tank is thus too large in these reduced demand phases, with a 19-day supply under phase 2 for example. The third optimization revision was performed to reduce the number of days the tank supplies water for, and to reduce the overall tank volume for reduced financial costs. In this third phase, the tank's overall volume remains at 7.5m^3, but the PCSWMM model tank was adjusted to a 4.8m^3 volume to represent the stormwater chamber's volume.

A comparison of the two preliminary model scenarios while adopting this reduced tank volume is provided in Figure 3-1. Scenario 1 represents collection from all impervious areas except for the parking lot's bioretention cell, while scenario 2 adds an impermeable liner and drain pipe from the bioretention cell to also be collected in the reuse tank.

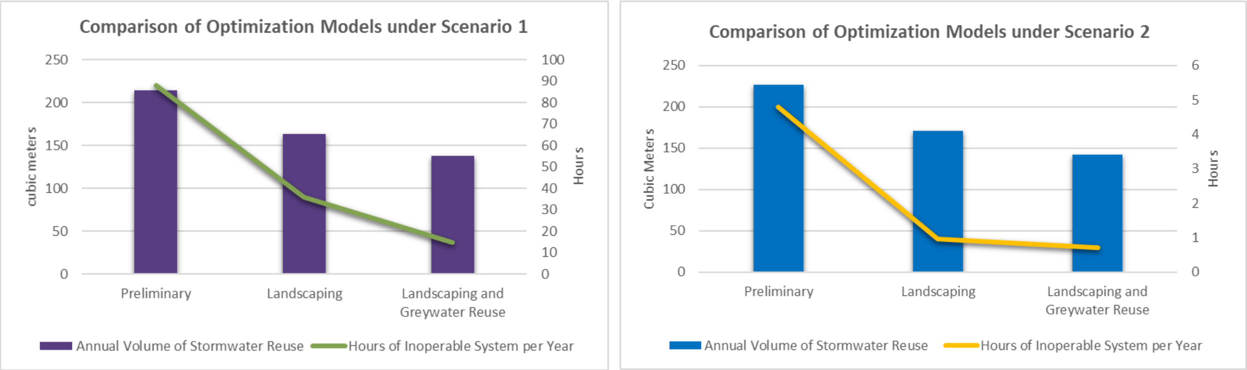


Figure 3-1: Overview of system performance in optimization scenarios 1 and 2 with the reduced stormwater tank volume applied.

The results of this process show that under both scenarios, the different optimization phases reduced the average annual inoperable hours of the tank. The reduction is a clear function of the reduced reuse demand rates on the stored stormwater in the two optimization phases. The significant drop in annual volume of captured stormwater between the preliminary design and first optimization phase stems from the combination of a reduced flow demand and the reduced tank volume from 7.5m^3 to 4.8m^3. The smaller reduction in captured volume from phase 1 to 2 is from the continued reduction in flow demand given the greywater is helping to supply toilet flushing.

With these optimization phases complete, the additional material and costs to connect the bioretention cell to the reuse system are clearly not worth the slight reduction in operable hours of the reuse tank. Both scenarios under the final optimization phase show the stormwater reuse chamber empty for less than 24 hours on average each year. The additional cost to add an impermeable liner and drain pipe with over 100m of length is not worth the minimal reduction in well water usage. Additionally, the parking lot is an existing impervious area and thus would not technically require stormwater management in a pre to post site hydrology analysis. With no water collection need and the management of parking lot runoff optional, YGH can choose to greatly reduce the size of the cell from its original 540m^2 footprint and 1.3m depth, or not construct a bioretention cell entirely. Understanding these aspects, the final design shall be performed using the Scenario 1 layout.

It is suggested that the client install at least a portion of this original bioretention cell for the educational and environmental benefits. As discussed in the literature review, these cells are effective pollutant removal systems and would be useful if road salts or sand is used during the winter to clear the parking lot, for example. The cells are also useful for educating students and the public on stormwater management practices with environmental and aesthetic benefits they can adopt at their own homes. In the final design and subsequent analyses, it was assumed YGH will move forward with the full sized bioretention cell to meet the project constraint of capturing 90% of average annual rainfall, however please note items such as the capital cost and lifecycle analyses discussed later in this report can be optimized by reducing the cell's size.

3.5.2 Energy Demand Optimization

To optimize the energy demand of the pumping system, an iterative approach was used. In the first calculations, lower wattage 350W solar panels were selected for the design. Using the 350W panels, the calculated number of solar panels needed would be too large for the available roof area. The power rating of the solar panels was increased to 375W and then 400W. The 400W panels were chosen as they generate more power and can be sourced locally from Canadian Solar, a solar PV manufacturer in Guelph [35]. To account for the higher cost of the 400W panels, pumps were resized to ensure there was no power losses and maximize efficiency. The energy demand calculations are presented in Appendix F.

4 FINAL DESIGN OVERVIEW

Following identification and optimization of the preferred design alternatives for the 'One Water' system, a final design solution was developed. This includes information on the process the team has followed and calculation techniques that have been used in developing the design. The design approach and an overview of the system including its key subcomponents is provided in the following sections.

4.1 Design Approach

To arrive at the final design, a systematic process was used. Key tasks leading up to the preliminary design included project scope identification, design alternatives identification and grading, sensitivity analysis and preliminary design development. During this phase, the preliminary PCSWMM stormwater model was created and flow calculations for water and wastewater were completed. After reviewing the preliminary design with our faculty advisor, the design calculations and models were refined to size the system components, which were then optimized using an iterative process. Further analysis of the final design included lifecycle assessment using OpenLCA, and an economic analysis. Lastly, the final project deliverables including a poster and this report were completed. The detailed sequence of steps in the design approach is outlined in Figure 4-1 below.

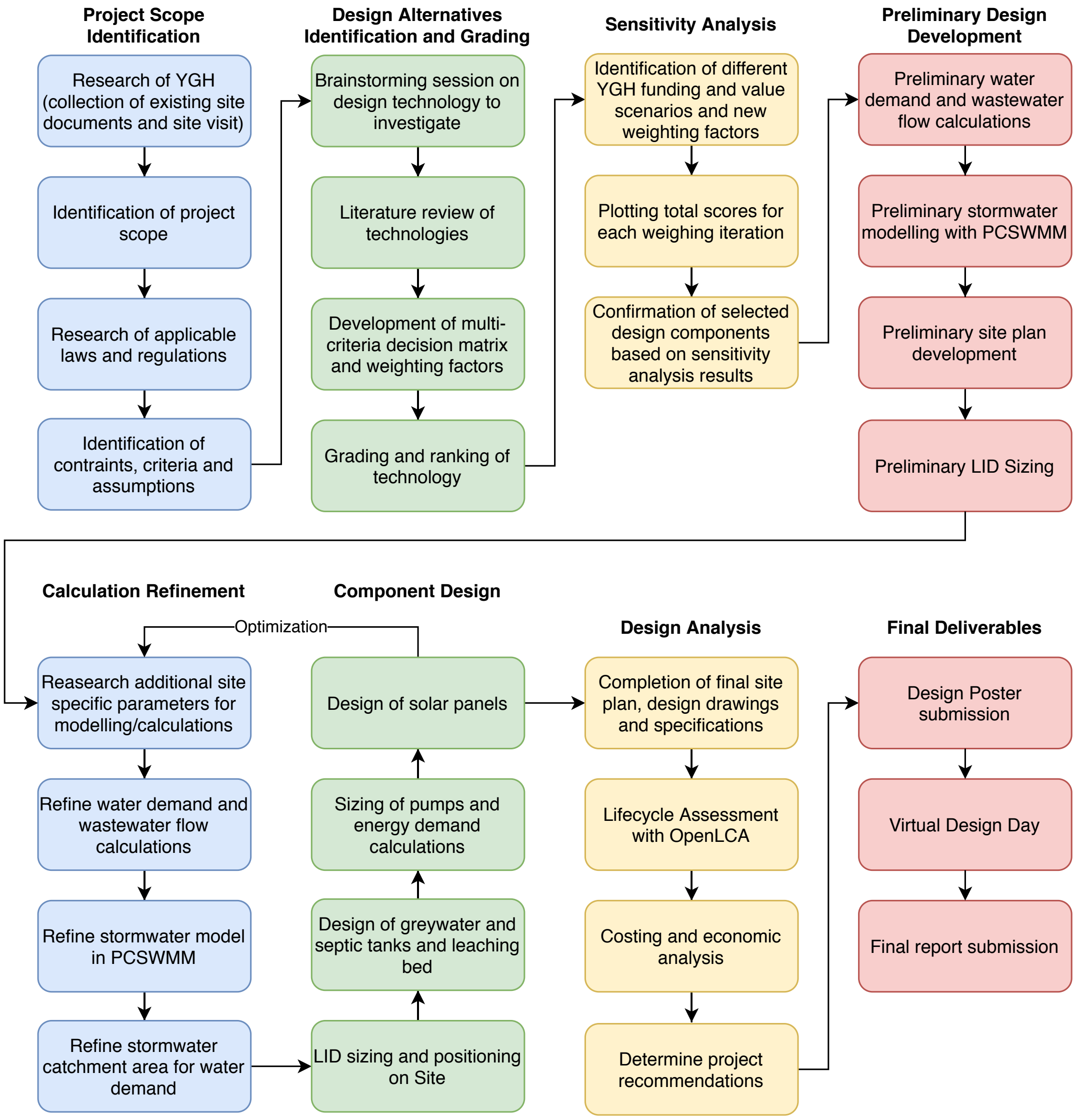


Figure 4-1: Design process leading up to the completion of the final design and deliverables

4.2 Final Design Description

The following sections break up the overall Yorklands Green Hub 'One Water' system into its main components for a detailed description of their designs and how they fit into the overall system.

4.2.1 Final Design Results Summary

The site layout showing the positions of each component included in the final design are presented in Figure 4-2 below.

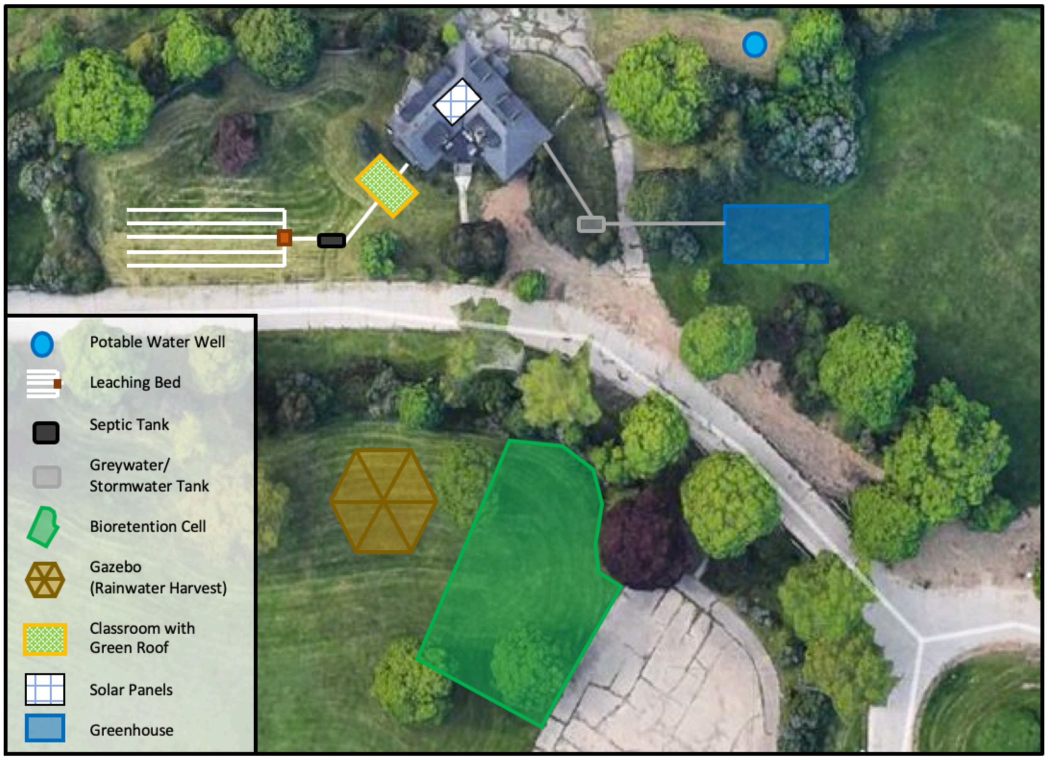


Figure 4-2: Proposed site layout from an aerial view.

The placement of the components follows the requirements set out in the Ontario Building Code Act. Furthermore, an illustration depicting the flow of water through the system is illustrated in Figure 4-3 below. It is seen from this figure how the 'One Water' cycle closely mimics the natural hydrologic cycle at the Site.

Overall, the final design of the complete 'One Water' system consists of the following components:

- Stormwater collection and treatment completed by the following LID's:
  - A bioretention cell capturing runoff from the parking lot
  - A green roof capturing rainwater on the portable classroom building
  - Rainwater harvesting from the rooftops of the gazebo, greenhouse and the new education Centre
- Greywater collection and treatment system (not illustrated on the figures because this is located within the new Centre building). The greywater is collected from the sinks, showers and drinking water fountains, is treated by flocculation, sedimentation, filtration and chlorine disinfection and is then reused to supply the toilets only.
- Underground storage tank to store the collected stormwater and greywater, with the greywater kept in a separate compartment.
- A private potable water well to supply the kitchen, drinking water fountains, sinks and showers within the building and to supplement the storm/greywater reuse system as needed.
- A decentralized wastewater treatment system consisting of an underground septic tank and leaching bed to treat the effluent wastewater from the new Centre.

- A renewable energy system consisting of solar panels placed on the new Centre rooftop to power the 'One Water' system. The system requires power for the shallow well pump, submersible effluent pump and sump pump to service the potable water well, septic tank and underground storage tank, respectively.

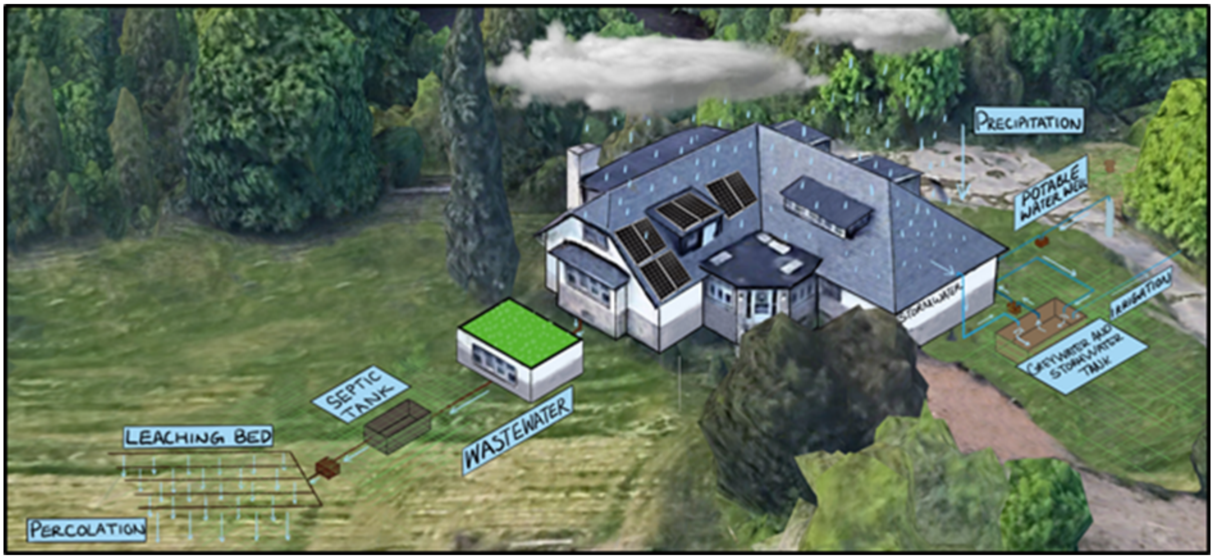


Figure 4-3: Proposed 'One Water' system layout including water flow pathways.

4.2.2 Water Reuse System

The water reuse component of the 'One Water' system is made up of both stormwater capture and greywater recycling. The tank is divided into two chambers to separate these sources. The tank was sized to hold twelve days' worth of reuse water based on the average daily demand for greywater and stormwater reuse purposes. With 231 L/d of greywater available for toilet flushing and a total stormwater reuse demand of 387 L/d for crop irrigation, landscaping, and toilet flushing, the tank was sized at 7.5m^3. Of this total, 4.8m^3 is dedicated to stormwater collection and 2.7m^3 to greywater collection. The detailed tank sizing procedure is included in Appendix G. The design of the two reuse water sources is discussed below and a suggested outline on maintenance is included.

Stormwater Capture

The capture and treatment of stormwater uses rooftop collection, a green roof on the expanded classroom section of the visitor centre, and a bioretention cell for the parking lot. These LID features provide treatment for removal of pollutants such as salts and sand from winter maintenance of the parking lot and other common pollutants such as phosphorous or nitrogen. The green roof and bioretention cell were sized to effectively capture 90% of average annual rainfall, following guidance of the Credit Valley Conservation LID Manual and the Stormwater Management Planning and Design Manual [11], [29].

Given the variability in system performance from a stormwater capture perspective, PCSWMM modelling was performed to analyze the system's water collection ability. This modelling measured the ability of the stormwater reservoir to meet the associated site application demands. Upon applying the final optimization phase, incorporation of greywater reuse and seasonal changes in flow demand, the following results were observed under the 2014 to 2020 climate and precipitation data.

Table 4-1: Summary of stormwater capture results from final design PCSWMM model.

General Model Results	
Average Annual Precipitation (mm)	761
Average Annual Impervious Catchment Runoff (mm)	67
Average Annual Impervious Catchment Infiltration and LID Drainage (mm)	625
Average Annual Impervious Catchment Evaporation (mm)	68
Average Annual Impervious Catchment Runoff (m^3)	520
Average Annual Impervious Catchment Infiltration and LID Drainage (m^3)	4,760
Average Annual Impervious Catchment Evaporation (m^3)	3,110
Scenario 1	
Average Annual Stormwater Reuse System Capturability (m^3)	521
Average annual Stormwater Reuse (m^3)	138
Average Storage Tank Depth (m)	0.90
Average Annual Days of Inoperable System (hours)	15
Percent Exceedance of reuse tank depth greater than 0 m (%)	96.5
Average Annual Days of Pump Operation (days)	364.4

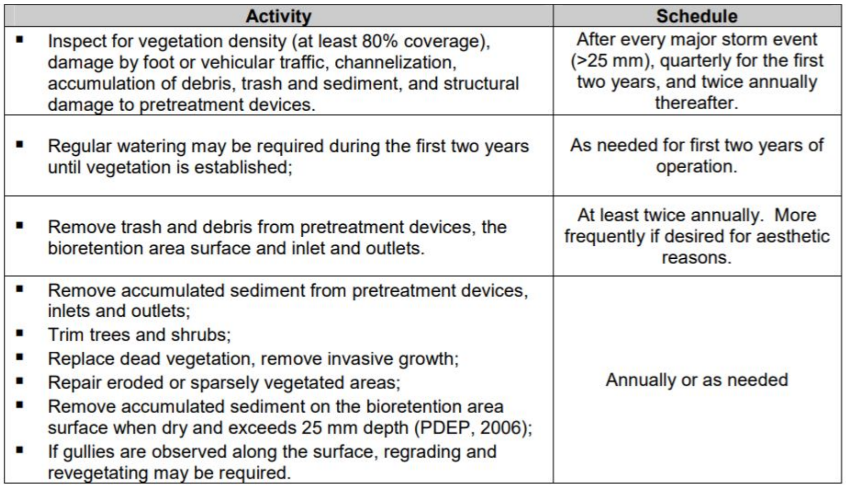
These results yield an average annual volume of 138m^3 used by the aforementioned stormwater reuse applications and an average supply of the reusable stormwater for over 364 days per year. The general hydrological results remained the same as in previous model versions given no change in catchments or LID feature sizing. The total annual stormwater volume that can be supplied to the tank is much greater, at 521m^3. This means an overflow system should be devised for directing the excess runoff into a surface swale or infiltration trench to prevent the backup of stormwater around the tank or in the green roof, for example. Additionally, if the client determines more stormwater collection is required the tank volume can be increased to allow for greater capture volumes. The quality of the collected stormwater will be suitable for the specified reuse purposes, however if higher quality reuse water is of interest, a pre-treatment filter system may be installed prior to collection of the stormwater in the tank.

Operation and maintenance of the LID features and collection system is vital for the system's performance. A standard sized manhole opening should be provided with the underground storage tank for maintenance purposes [11]. The rooftop rain harvesting system should be inspected at least bi-annually in the spring and fall [11]. The eavestrough and downspouts should be checked weekly for clogging from debris such as leaves [11].

Green roof maintenance is typically most demanding in the first two years with frequent monitoring of plant establishment [11]. An electronic leak detection system is recommended to ensure proper function of the impermeable liner, particularly in the first few months of operation [11]. General maintenance should occur twice a year, including weeding for removal of excessive plant growth and debris or dead vegetation removal to avoid clogging of the overflow conveyance system [11].

Like the green roof, the bioretention cell's performance is strongly related to the use of effective maintenance practices. General weeding, pruning and litter removal is required as with any landscaped garden [11]. A list of common maintenance needs and a recommended schedule is provided in the following table as an excerpt from the CVC LID design manual [11].

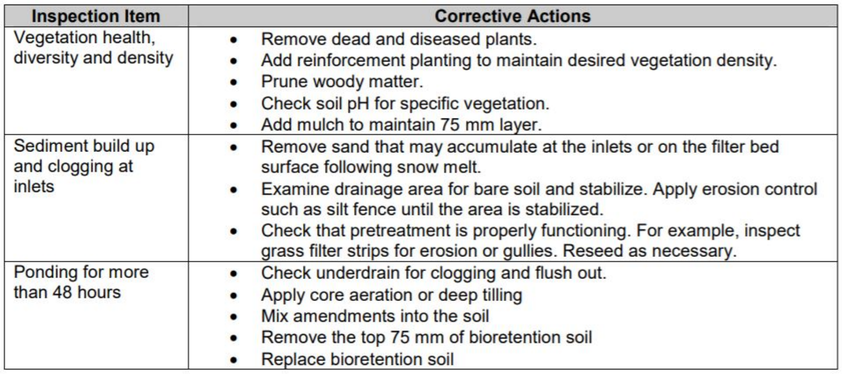
Table 4-2: Summary of maintenance activities and suggested schedule, from CVC.



Activity	Schedule
▪ Inspect for vegetation density (at least 80% coverage), damage by foot or vehicular traffic, channelization, accumulation of debris, trash and sediment, and structural damage to pretreatment devices.	After every major storm event (>25 mm), quarterly for the first two years, and twice annually thereafter.
▪ Regular watering may be required during the first two years until vegetation is established;	As needed for first two years of operation.
▪ Remove trash and debris from pretreatment devices, the bioretention area surface and inlet and outlets.	At least twice annually. More frequently if desired for aesthetic reasons.
▪ Remove accumulated sediment from pretreatment devices, inlets and outlets; ▪ Trim trees and shrubs; ▪ Replace dead vegetation, remove invasive growth; ▪ Repair eroded or sparsely vegetated areas; ▪ Remove accumulated sediment on the bioretention area surface when dry and exceeds 25 mm depth (PDEP, 2006); ▪ If gullies are observed along the surface, regrading and revegetating may be required.	Annually or as needed

An annual spring inspection should also be performed on the bioretention cell, and the following table describes common concerns and corrective actions that can be taken [11].

Table 4-3: Summary of common inspection items and corrective actions during annual inspection.



Inspection Item	Corrective Actions
Vegetation health, diversity and density	• Remove dead and diseased plants. • Add reinforcement planting to maintain desired vegetation density. • Prune woody matter. • Check soil pH for specific vegetation. • Add mulch to maintain 75 mm layer.
Sediment build up and clogging at inlets	• Remove sand that may accumulate at the inlets or on the filter bed surface following snow melt. • Examine drainage area for bare soil and stabilize. Apply erosion control such as silt fence until the area is stabilized. • Check that pretreatment is properly functioning. For example, inspect grass filter strips for erosion or gullies. Reseed as necessary.
Ponding for more than 48 hours	• Check underdrain for clogging and flush out. • Apply core aeration or deep tilling • Mix amendments into the soil • Remove the top 75 mm of bioretention soil • Replace bioretention soil

These maintenance measures can help optimize the stormwater collection ability of the system, avoid larger costs for complete rehabilitation of LID features, and extend the overall service life [13].

Greywater Reuse

The greywater reuse system includes a collection system to divert the effluent water from the sinks, showers and drinking water fountains in the new education Centre building to the underground storage tank to supply the building's toilets. The specific design of the greywater collection piping system is not included in the scope of this project because access to the architectural plans or layout of the inside of the old Superintendent's building could not be obtained at this time. Based on the water demand calculations in Appendix F, it is estimated that an average of about 270.6 L of greywater/day could be collected to supply the toilets. A maximum of 201.0 L/d of supplemental water from the stormwater collection or the potable well is required to meet toilet flushing water demands.

Prior to entering the underground storage tank, greywater will pass through a treatment system in order to ensure the water meets required quality standards set out in the Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing (Reclaimed Water Guideline). The collected greywater can therefore only be used for toilet flushing as use for irrigation would require higher levels of treatment. The greywater is therefore stored in a compartment separate from the collected stormwater in the undergone storage tank to prevent cross contamination.

The treatment system follows the guidelines required in the Reclaimed Water Guideline. The main concern in the raw greywater is the presence of pathogenic microorganisms (i.e., viruses, bacteria or protozoa) or chemicals which may pose a risk to human health. The treatment system is required to meet the water quality standards provided in Table 1 of the guideline document which includes parameters of biological oxygen demand (BOD), total suspended solids (TSS), turbidity, E. Coli, thermotolerant coliforms and residual chlorine [16]. The system must meet the values at the point of discharge or at other points in the system as indicated in the footnotes of Table 1 in the document.

The treatment system is designed with primary and secondary treatment components followed by disinfection. The primary treatment is a flocculation and sedimentation basin. Flocculation is the agglomeration of destabilized particles by chemical joining and binding for subsequent removal by sedimentation or filtration [33]. The sedimentation tank will allow for the settling of the non-dissolved particles in the water. The removal of these particles in the primary process treats the BOD, TSS and turbidity in the water. The design of the flocculation basin and sedimentation tank is provided in Appendix F. The tank dimensions are estimated to be 0.3 m by 0.189 m by 0.6 m to treat a daily volume of 0.343 m^3/day.

The secondary treatment is a sand filter (biofiltration process). This process removes soluble organic components such as the remaining particles and pathogens attached to them, effectively treating the remaining BOD, TSS, turbidity and coliforms [16]. The disinfection process is completed by chlorine disinfection to remove microorganisms that are pathogenic and to ensure the residual chlorine standards are met [16]. The specific design of the secondary and disinfection treatment processes (i.e., sizing of the filter bed and estimation of the required chlorine dosage) could not be completed for this project due to lack of site-specific information such as water quality data.

An outline of the system components is illustrated in Figure 4-4 below.

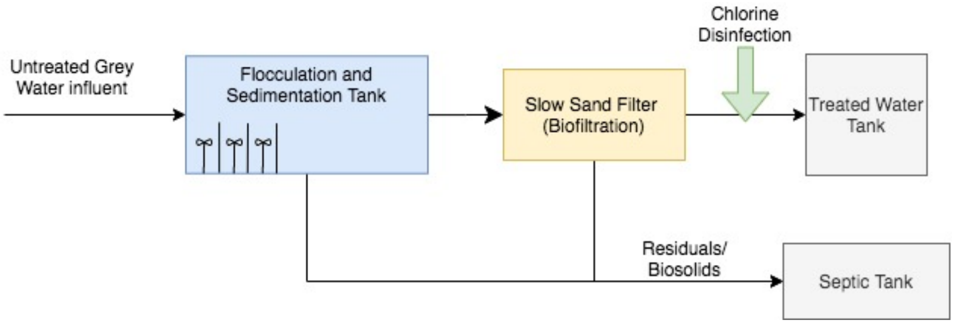


Figure 4-4: Greywater treatment system flow diagram.

It should be noted that several commercial greywater treatment systems are available for residential purposes which would be suitable for implementation of this design at the new education Centre. One of these systems is the Greyter HOME Residential Water Recycling System by Greyter Water Systems [36]. This system meets the water quality requirements set out by NSF 350 which complies the Canadian guidelines. This type of treatment system is likely the most cost effective and reliable option to accompany the implementation of the YGH 'One Water' design.

A detailed maintenance and monitoring plan is outlined in the document to ensure proper operation of whichever system is implemented.

4.2.3 Wastewater System

The final decentralized wastewater treatment system consists of two main components; a septic tank and gravity fed leaching bed (conventional absorption trench). The two-chamber, 500 gallon polypropylene septic tank was sized to store two days' worth volume of wastewater and includes an effluent filter on the tank outlet to prevent clogging. The leaching bed design consists of a total of 125 meters of four-inch perforated PVC piping, which is divided into five 25 meter segments. The two main system components are to be connected to each other and the Centre with solid PVC piping, while an HDPE distribution box ensures wastewater is divided equally among the leaching bed segments. Additionally, the system is to be located south-west of the Centre, which allows for required clearances from the potable water well and pond to be met. Figure 4-5 outlines the wastewater treatment system layout and location at the Site.

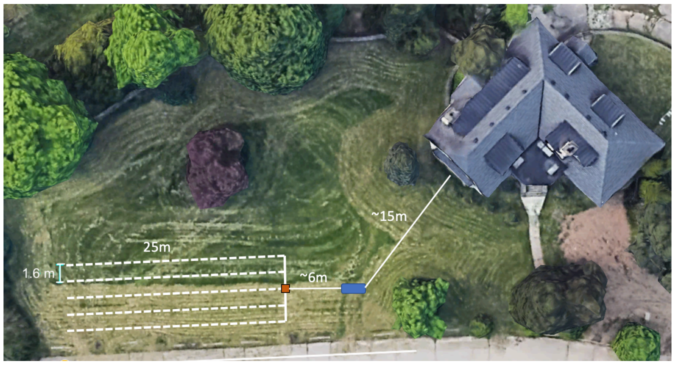


Figure 4-5: Septic tank and leaching bed design schematic

The wastewater system was designed in compliance with Section 8 of the Ontario Building Code Act. A leaching bed is Class 4 sewage system which must achieve an effluent water quality criteria of no greater than 10 TSS and 10 $CBOD_5$ [19]. Given that the effluent water quality cannot be tested for a leached bed system, it is assumed that water quality criteria is met if the system is designed in accordance with specifications outlined in the Ontario Building and is maintained appropriately [19].

The design calculations and specifications for the decentralized wastewater system is included in Appendix F. Designing the system involved determining the design flow which is twice the daily sanitary flow [19]. This flow was used to size the septic tank and length of perforated piping required for the leaching bed. The piping length also required using the soil percolation time (T), which can accurately be determined with a percolation test. Our team estimated this value by using three nearby water well records from the Government of Ontario to classify the soil and determine a suitable hydraulic conductivity, which can be correlated to a percolation time. The site's percolation time was 15 min/cm, thus the native material was suitable to use as a bed and fill material and a mantle was not needed. Leaching bed installation requirements include adding a stone layer and geotextile prior to backfilling, as outlined in Figure 4-6.

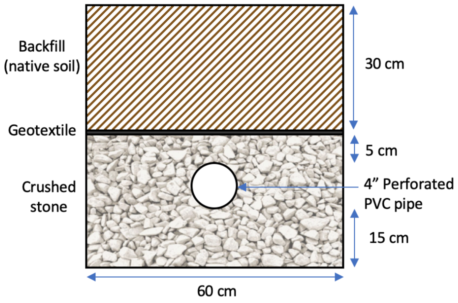


Figure 4-6: Leaching bed installation requirements [19].

The performance of the decentralized wastewater system depends greatly on operation and maintenance. Common problems such as clogging and fouling stem from flushing of chemicals and items which belong in the garbage [37]. Therefore, it would be crucial that YGH ensures the system is operated appropriately. Regular maintenance for the system involves septic tank inspection every three to five years by a licensed professional and pumping out solids and scum when required [17]. The effluent filter on the tank should be inspected annually and replaced when needed. Additionally, well water testing three times a year for indicator bacteria ensures that the system is intact and treating wastewater as designed [17]. Completing regular maintenance and operating the system appropriately is integral for ensuring the wastewater system performs safely and effectively.

4.2.4 Renewable Energy Generation

The renewable energy generation system designed for the 'One Water' system consists of 8, 400W mono-crystalline solar panels, a 17.6 kWh solar battery storage unit, and 48V/110V power inverter.

To design the solar energy system for the pumping components of the 'One Water' system, solar PV energy production and pump energy requirement calculations were performed using Excel. Using the calculated potable water, wastewater effluent, and stormwater flowrates, hours of usage generated from PCSWMM, and estimated pumping distances, the amount of power per day, kWh/day, required by the YGH 'One Water' system [38]. Pumps were selected based on the 'One Water' systems pumping requirements. A Burcam Shallow well jet pump was selected for the potable well pump [39]. For the wastewater effluent pump, a Liberty septic submersible effluent pump with a mechanical float switch was chosen [40]. A Master Class cast iron sump pump was selected for pumping the greywater to be reused [41]. Each pump was selected through matching the flowrate requirements and power requirements for each application. The power requirements for each pump was calculated using the amps and voltages provided by the manufactures [42]. The power requirements for the pumps were summed to give a kWh/day power requirement for the system, calculated to be 11.65 kWh/day. Using the selected solar panel wattage, and solar irradiation estimated for the site, found from Natural Resource Canada, the number of solar panels were calculated and a battery storage system and inverter were selected [34]. To ensure year-round energy supply with no reliance on the grid, the solar panels and battery storage were sized with 30% larger generating power and storage ability, generating 15.15 kWh/day or 4 MWh per year. An inverter is needed as solar panels generate direct current (DC) electricity while the pumps and most other electrical appliances require alternating current electricity (AC).

The renewable energy system does not require the government of Ontario's Renewable Energy Approvals as the generation capacity does not exceed 10kW [43]. There are no other known regulations that need to be referenced for this renewable energy system.

It is suggested that the 8 solar panels be mounted on the south facing roof of the new Centre. Solar panels are able to achieve the highest operational efficiency when oriented facing south [44]. Roof mounting is also suggested over ground mounting as it saves on required space for installation as they make use of otherwise non-useful roof space. Downsides to a roof mounted system is potentially more difficult installation and maintenance. Due to the nature of roof structures, installation costs could be higher and would require more time for installation. It is suggested that solar panels are given a cleaning every 4 months to achieve maximum energy generation [45]. During cleanings it is also beneficial to inspect the panels for damages, such as cracked glass caused by hail or fallen objects. It is important to catch damages early on to minimize replacements required. To sustain optimal pump operations, routine maintenance should be performed. Pressure, temperature, noise, flow rate, values, speed and strain should all be checked. Clogging of pumps can occur frequently, therefore preventative routine maintenance is vital. The selected pumps have warranties ranging from 5-8 years. As the service life was found to be 12.5 years, one replacement for each pump was accounted for in the total system cost.

4.3 Design Life Cycle Considerations

To determine the impact the system will have over its life cycle, a life cycle assessment (LCA) was developed using the open source software tool, OpenLCA. These assessments typically involve attempting to quantify the impacts of raw material acquisition, manufacturing, transportation, operation, maintenance, recycling and disposal of a product or system [46]. OpenLCA is a software that uses a bank of materials and processes such as transportation methods with a quantified breakdown of environmental impacts by chemicals and residues on a unit basis. Flows and processes are created to mimic the lifecycle stages described above. System life cycle flow charts were developed for each major component of the design. The flow diagram for the septic tank is provided in Figure 4-7 below, with the remaining charts provided under Appendix I.

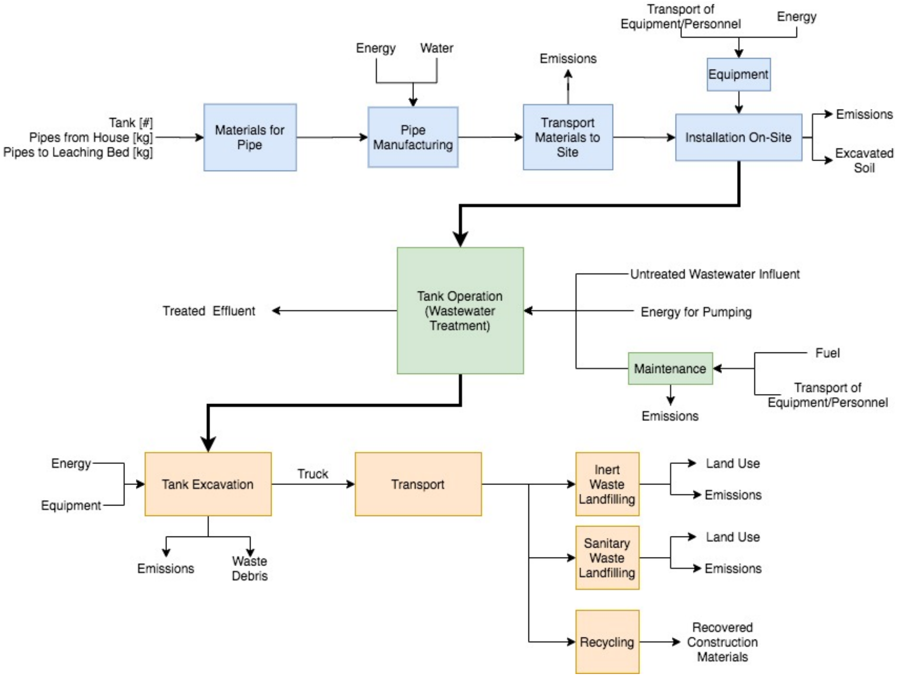


Figure 4-7: Flowchart summarizing the major inputs and outputs through the life cycle of the septic tank.

Due to software database limitations, the operation and maintenance procedures were not considered in this assessment. The assessment was focused on investigating the environmental impacts of the construction and disposal of the 'One Water' system, including manufacturing, transportation, and general construction equipment processes where applicable. A detailed analysis of materials and quantities required was performed for all components of the system to act as inputs for the LCA model. Transportation assumptions were also made, assigning a distance of 20km for all resources that could be locally sourced, and a distance of 70km for resources or products sourced from larger metropolitan areas such as Toronto. Where exact materials or processes were not provided in the database of OpenLCA, the next most appropriate option was selected. Tables of the material quantities for each system component are provided in Appendix I.

Upon consultation with Akul Bhatt, a University of Guelph Ph.D candidate, the TRACI 2.1 Impact Analysis method was selected due to its well-established use in life cycle assessment, environmental impact, and sustainable design models [47]. The analysis method considers environmental impacts in up to ten different categories, including global warming contributions, ecotoxicity, smog, and eutrophication [47]. The TRACI software has been used in applications including the US Green Building's LEED Certification and the US Marine Corps' Environmental Knowledge and Assessment Tool [47].

Analyses were completed for the system installation considering the impacts produced to install the components to full scale, and for the impacts produced per kilogram of each system component. The full scale analysis captures the total impacts of each component and allows for simple comparisons to be made. The per kilogram analysis removes the influence of material quantities in the measured impacts to see which components are more environmentally intensive on a per mass basis. In both analyses, comparisons were made between system components and between the materials used for the whole system to determine how environmental impacts can be minimized in terms of material selection within each system component.

The global warming contribution impact assessment category was used from TRACI given the ease in which its results may be interpreted. The results of the first analysis for contribution to global warming are presented collectively below as Figure 4-8.

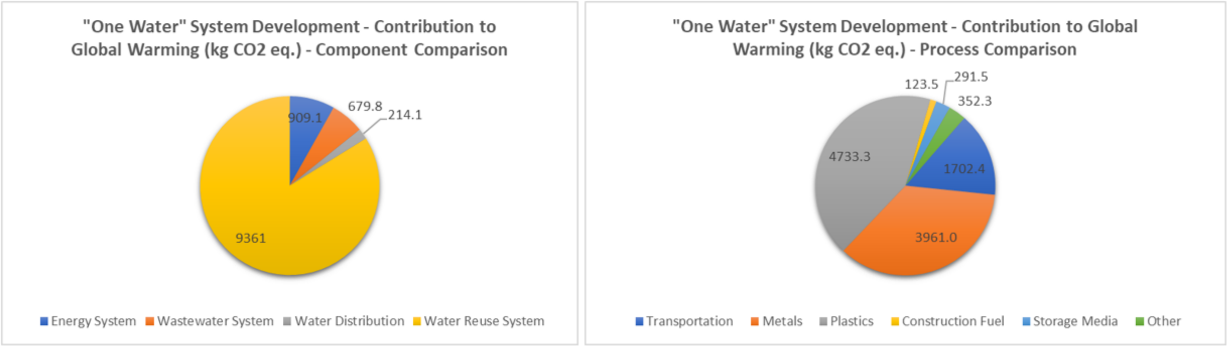


Figure 4-8: Lifecycle analysis outputs for the installation of the 'One Water' system at full scale.

The results show the water reuse system (includes the reuse tank and LID collection components) makes up most emissions contributions out of all the system components, while plastics, metals and transportation make up the top three greatest material contributions respectively. This stems from the amount of plastic needed in the green roof, the large quantities of materials transported to the site for the bioretention cell, and the steel used in creating the reuse water storage tank. Figure 4-9 is provided to understand the impacts of each system excluding variations in the component sizes.

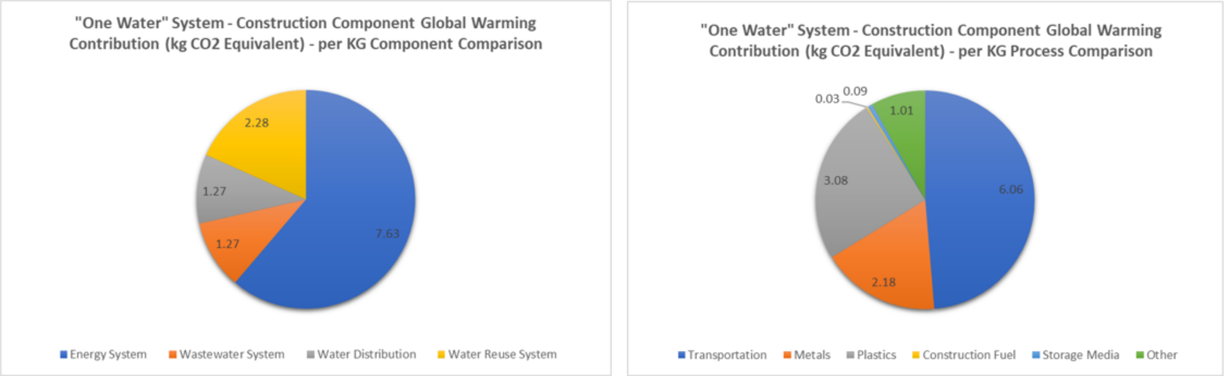


Figure 4-9: Lifecycle analysis outputs for installation of the 'One Water' system on a per Kg basis.

From the analysis on a per kilogram basis, the renewable energy system becomes the dominant system component in terms of CO_2 emissions with the remaining components in relatively similar amounts. The transportation process accounts for almost half of the CO_2 contributions, while the metals and plastics also make up significant portions in the process comparison chart. These sharp increases in the energy system and transportation process are contributed to the shipment of the system's battery used to store the energy generated by the solar panels for consistent pump operation on-site. The storage battery was sourced from a Chinese manufacturer and thus had to be transported by airplane as part of this analysis. Air transportation is a high impact process in CO_2 emissions, and thus dominates in these findings. Plastic and metal production are also still relatively intensive processes within this second analysis.

Many opportunities exist to help minimize the global warming contributions and other environmental impacts of the system's installation process. One strategy is using local suppliers of the materials needed. The battery sourced from China, for example, is produced and sold within Canada but at a higher price. Similarly, suppliers of plastic piping and solar panels are available within the City of Guelph, at slightly higher prices on average. If the client is willing to pay a premium, these products should be selected to minimize environmental impacts.

Opportunities also exist in the material selection to reduce the negative environmental effects of the system's installation. It is still vital to ensure the materials selected can last for at least the minimum expected lifespan of the design. Some material substitutes include use of coconut husk fragments instead of gravel in the trenches of the leaching bed [48]. The husks are effective at nutrient removal and are a biodegradable waste upon the design's end of life [48]. Additionally, the PVC pipes needed for distribution of water throughout the system can be supplied using recycled plastics. The production process to create a pipe from recycled plastic may have similar environmental effects, but it saves other plastic products from landfill or incineration. Many companies exist that supply recycled plastics, such as the Florida-founded Dixie Septic [49]. Similarly, the metal water reuse storage tank may be made from recycled metals.

The other component considered is disposal of the system at the end of its service life. Materials may be sent to landfill, incinerated, or potentially recycled and repurposed. For this life cycle assessment, the product was assumed to be sent to landfill due to the typically lower costs, simpler disposal process, and less energy intensive processes [50]. It was assumed the gravel, filter media and storage media of the LIDs and leaching bed could remain on-site and were thus excluded from the disposal analysis. A travel distance of 175km was used as a conservative estimate with the City of Guelph currently sending some landfill waste to the Twin Creek's Landfill in Waterford Ontario [51]. The following figures show the effects of these disposal processes in with the design.

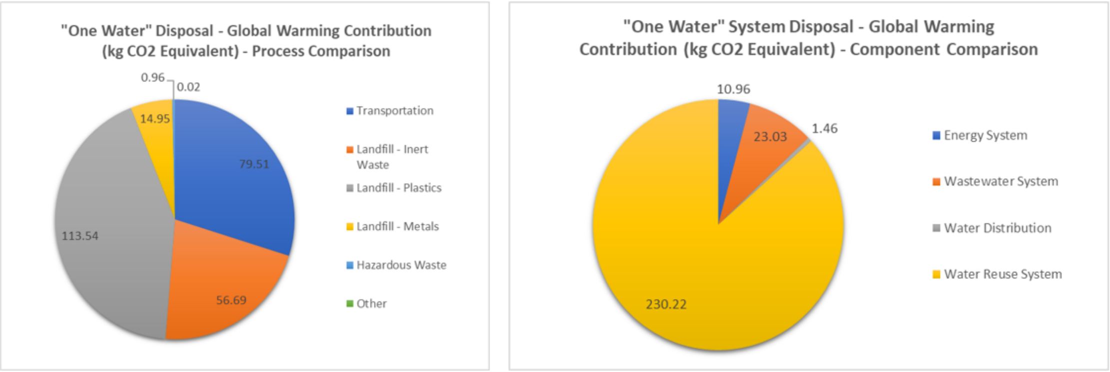


Figure 4-10: Lifecycle analysis outputs for the disposal of the 'One Water' system.

Again, the water reuse system is most impactful from its material quantities, and the impactful processes are landfilling of plastic, inert waste such as glass or concrete, and transportation. These processes can be eliminated however if the products are to be reused or recycled. Components such as distribution pipes, the green roof layers, and the reuse tank all have approximate lifespans of 50 years and up to 100 years for some of the plastics used [52]. The reuse tank may be used in another storage application such as industrial water storage or municipal salt and sand storage for winter road maintenance. The PVC piping and other plastics can be accepted by plastic recycling plants such as the Canadian company, Blue Planet Recycling, that convert a variety of plastics back into pellets for reuse in other manufacturing processes [53].

Using reuse and recycle opportunities such as these can help the client maintain its sustainability goals through limiting the environmental impacts caused by disposal of the system. By adopting these recycling and reuse measures, the carbon dioxide emissions due to disposal could be reduced to roughly 1/3 of the base scenario's 266 kg depending on the transportation requirements to access the recycling centres.

5 DESIGN DEFENSE

The following sections provide a detailed overview of how the 'One Water' design solution is robust and effectively considers the environmental, social, safety, and economic interests of the Yorklands Green Hub.

5.1 Primary Function

When analysing the 'One Water' design, the problem is effectively addressed in several different aspects. The most critical analysis involves reviewing the solution in contrast to the initial project constraints and criteria. The following table highlights the key entries and provides a description of how the design solution was able to achieve each.

Table 5-1: Summary of design solution performance in comparison to key constraints and criteria.

#	Constraints	Achievement
2	Any design aspects requiring energy (e.g., water supply system pumps, etc.) will be satisfied via sustainable on-site energy sources.	The implementation of eight 400W solar panels and a storage battery provides sufficient energy production for the various water distribution pumps of the design.
3	As opposed to municipal water servicing, a local drinking water source is requested by the client Yorklands Green Hub.	The design solution incorporates a drinking water well, spatially placed to comply with required OBC setbacks from storage tanks and septic tanks.
5	Mixing of the reused greywater and stormwater supply with the potable water supply to the building must be prevented.	The greywater reuse system will be isolated to a separate chamber in the storage tank, with about 2.1m^3 of the 7.5m^3 tank designated for greywater reuse storage. Distribution pipes will be separated between potable, grey, and stormwater systems.
6	Wastewater System Design must meet the design, effluent quality, and setback requirements set out under Section 8 of the Ontario Building Code Act [19].	The septic tank and leaching bed were selected and designed based upon requirements of the Ontario Building Code and in consultation with Dr. Abbassi for additional expert opinion. Setbacks and design geometries were followed using a conservative process.
7	The Stormwater Management System must be designed to capture 90% of average annual rainfall as per the CVC Low Impact Development Guidelines [11].	Hydrologic design process was completed following the requirements set out in relevant guidelines and adopted necessary filling and drainage time checks for the bioretention cell and green roof.
9	Reclaimed greywater must satisfy the applicable water quality standards for non-potable uses [16].	A detailed overview of the general treatment components and sizing is outlined in Section 4.2.3 and referenced Canadian guidelines to ensure

		removal rates and reusable greywater quality standards were met.

#	Applicability	Criteria	Achievement
1	Common Criteria	Minimize capital cost	Design was optimized and adjusted to reduce capital cost. For example, a leaching bed system was selected due to its simple design/installation and low energy demand.
4		Site and environmental cost/disruption	The 'One Water' design will incorporate recycled plastics for piping and septic tank, metal storage tanks, and locally sourced construction materials to ensure long-lasting products are used that can be reused or recycled at the end of the design life, and construction transportation is minimized.
6	Wastewater System	Minimize energy requirements	Selection of a passive septic tank and leaching bed was made to help address this criterion. A gravity pump for moving wastewater to the bed is included in the design but may not be required upon detailed site topographical analysis.
7		Maximize treatment quantity per area	The large open spaces provided on-site allowed for this criterion to be less important, however leaching beds fall in the middle when compared to other treatment in this space requirement category.
9	Stormwater System	Maximize water treatment ability per unit area (Footprint)	A bioretention cell and green roof were chosen due to their flexibility in treating certain pollutants and relatively small footprint requirements. Other green infrastructure such as infiltration chambers may have a smaller footprint, but the treatment ability is reduced.
10	Energy	Maximize output per unit	A detailed comparison was performed between the different renewable energy sources. Solar panels were found to be the most productive energy producer per unit and did not detract from the natural aesthetic of the site.

Beyond this comparison with the project constraints and criteria, the 'One Water' design was also checked for its performance under future climate change scenarios in which site hydrology shifts considerably. The PCSWMM model was run under two additional scenarios. These scenarios were developed using data from the Ontario Climate Change Data Portal with RCP 4.5 and RCP 8.5 scenarios for the years between 2040 and 2070 [31].

RCP stands for Representative Concentration Pathway, and four pathways ranging from 8.5 to 2.6 are used in climate change modelling studies. These pathways are measures of future fossil fuel emissions levels, first introduced by the Intergovernmental Panel on Climate Change in 2014 as part of their fifth assessment report [54]. The RCP 2.6 scenario represents the lowest emissions levels, where emissions begin to drop significantly around 2020, and would be achieved by aggressive transition to renewable energy sources [54]. RCP 8.5 is a "business as usual" scenario in which no changes are made to fossil fuel reliance across the globe, and emissions continue to rise [54]. The functionality analysis for the system under future climate change used the RCP 8.5 and 4.5 scenarios as a worst-case and optimistic approach respectively. No hourly predictive precipitation or climate data could be obtained for this analysis. To resolve this, the model input data was adjusted by comparing historical monthly precipitation and temperature data from the Government of Canada's Historical Climate data portal to the climate change data [30]. The model's hourly rainfall data and climatic data was then adjusted based on the percent change in those monthly values. An overview of the shifts in precipitation and temperature data between the base (design solution under current climate conditions) and the two future climate scenarios is provided in Figure 5-1.

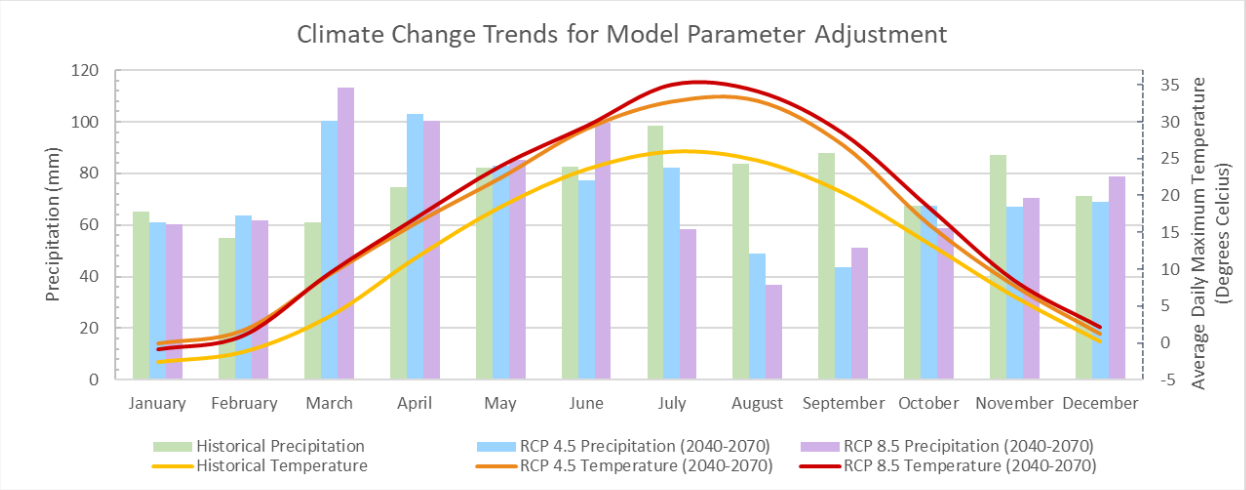
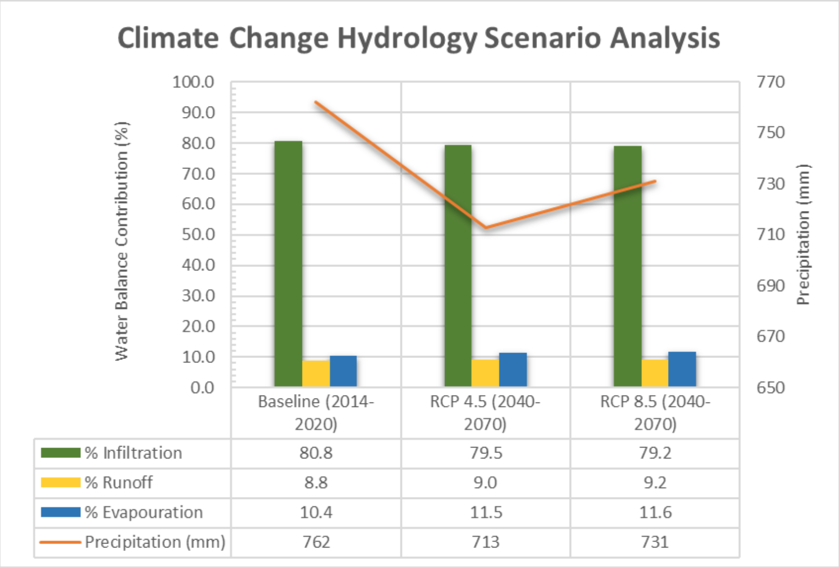


Figure 5-1: Summary of Precipitation and Temperature shifts in the three scenarios.

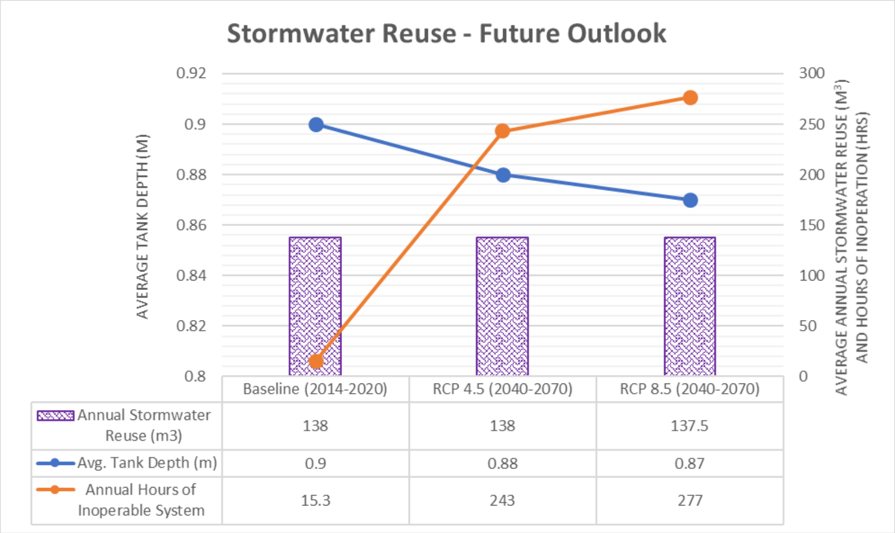
Running these future climate change scenarios yielded notable trends in the system's performance ability. An overview of the hydrologic patterns of the site across each climate scenario is provided in Figure 5-2.



	Baseline (2014-2020)	RCP 4.5 (2040-2070)	RCP 8.5 (2040-2070)
🟩 % Infiltration	80.8	79.5	79.2
🟨 % Runoff	8.8	9.0	9.2
🟦 % Evapouration	10.4	11.5	11.6
— Precipitation (mm)	762	713	731

Figure 5-2: Summary of hydrologic functions of the site under the three model scenarios.

Additionally, the results of these scenario analyses in the stormwater capture system performance is provided in Figure 5-3 below.



	Baseline (2014-2020)	RCP 4.5 (2040-2070)	RCP 8.5 (2040-2070)
▨ Annual Stormwater Reuse (m3)	138	138	137.5
● Avg. Tank Depth (m)	0.9	0.88	0.87
● Annual Hours of Inoperable System	15.3	243	277

Figure 5-3: Summary of stormwater capture system performance under the three model scenarios.

Figure 5-2 shows a small, consistent change in hydrologic function of the site. Relative amounts of infiltration slowly decrease, while runoff and evaporation slowly increase. This is likely a function of both the more intense rain events in months with increased precipitation and from an increase in average daily temperatures of the model. Overall precipitation varies but not in a consistent pattern.

Figure 5-3 indicates that while the average storage levels and volumes in the reuse tank only decrease slightly, the average annual hours with an empty tank increase significantly in both climate change scenarios. The system goes from less than one non-operable day a year to 10 and 11.5 days in the RCP 4.5 and 8.5 scenarios respectively. The discrepancy results from the increased seasonality of rainfall shown in Figure 5-1, as the tank system is often filled from the beginning of winter to early summer, then experiences prolonged dry periods in summer and fall. The volume of water remains similar, but the availability throughout the year significantly changes. A plot of the tank level in the 2017 modelling data year under the RCP 8.5 scenario captures this effect and is shown below.

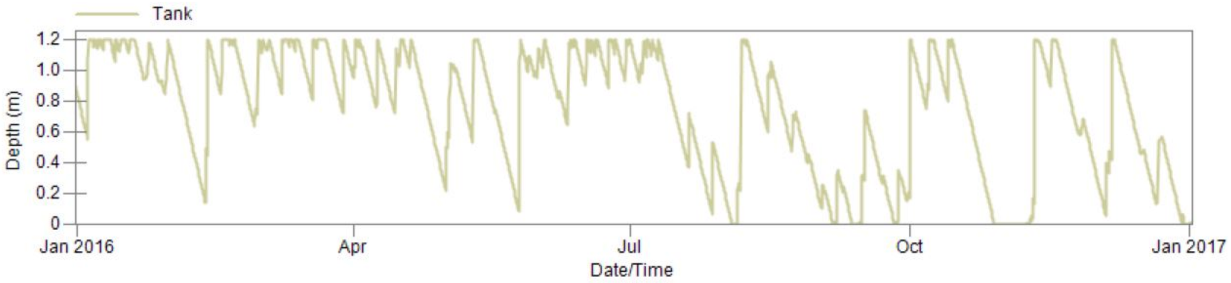


Figure 5-4: Sample output from PCSWMM of reuse tank levels for 2017 precipitation data under the RCP 8.5 (2040-2070) scenario.

The robust design solution does however manage to combat this to still deliver the required water demands. The potable water well pump is sized to handle the total water usage requirements of the site, and the energy requirement of the pumps in any given condition remains relatively unchanged. The similar pump sizes and their collective need to pump the same volume of water through the system regardless of the source (well or reuse tank) results in no additional energy requirements in these prolonged dry periods.

The 'One Water' design is also an effective solution through its flexibility to be modified or scaled up to suit changing water demands. Changes in demand may be from future climate conditions, expansion of the Centre itself, or increased visitor traffic. Expansion of the centre's infrastructure may include additional greenhouses, increased parking space, or sleep cabins for overnight style kids' camps. These additional spaces will require connection to the 'One Water' system and increase the site's water demands. Conveniently, the new impervious surfaces can be incorporated into the system through simple rooftop capture or new green infrastructure features. Where new structures are far from the reuse tank, or storage capacity in the tank cannot support more water collection, rain barrels are an effective solution to support reuse water opportunities at new buildings. For example, rain barrels could be installed for a new greenhouse to support its irrigation or landscaping needs.

Expansion of the centre may also occur in terms of the number of visitors. If the frequency of school groups or large public event gatherings occurring at the centre increase in future years, water demands will also increase. To increase water collection ability without new impervious surfaces, the design can easily be modified by adding a liner and an outlet drain to the bioretention cell that would direct parking lot runoff into the reuse tank. In the current conditions model the 540m^2 of bioretention cell used to capture and treat parking lot runoff infiltrates over 4,100m^3 of water a year. This is much greater than the approximately 140m^3 of stormwater required for reuse under current site demands, and so just a small fraction of this water would need to be directed to the system if demands increased significantly.

Finally, in any case where water use increases, the wastewater and energy systems must also be adjusted to ensure full function of the 'One Water' system. Solar panels are ideal energy production units given their small size and easily scalable design. When pump electricity demands increase beyond the 16 kWh/d rate supplied by the panels, additional panels can be added to the Sustainable Environment Centre's visitor centre to increase energy supply. To account for greater wastewater flows, the leaching bed can be easily extended or widened given the large open space selected and its proximity to the entrance road for straightforward construction. If flows expand beyond the capacity of the septic tank, it can be easily replaced for a larger volume tank and re-installed in the same location for a relatively small cost and minimal disruption to the system.

5.2 Safety

One of the highest safety risks of the water reuse system with respect to the protection of public health is the possibility of insufficient water treatment or water contamination. With respect to insufficient water treatment, the greywater recycling system is of highest concern because raw greywater may contain pathogenic microorganisms or chemicals which would be hazardous to human health if you are exposed. To ensure protection from these organisms, a treatment system is included in the design prior to storing the water for reuse which effectively removes these organisms and chemicals. A maintenance and water sampling program for the treatment system is provided in the applicable guideline document to ensure that the system operates as designed. Additionally, the reuse applications for the greywater were limited to toilet flushing only to reduce the risk for human exposure.

With respect to water contamination, cross contamination of the wastewater or greywater with the potable water or stormwater is of the highest concern because of health hazards associated with the raw wastewater and greywater. To ensure cross contamination does not occur, each of the water types should be designed to have sperate distribution pipe systems that are colour coded and labelled according to the Ontario Building Code Act requirements [19]. Additionally, the collected greywater will be stored in a sperate compartment from the collected stormwater in the underground storage tank. Prevention of water contamination is one of the main reasons why proper and effective maintenance of the system components is very important.

Finally, function of the bioretention cell and leaching bed may be disrupted by heavy foot traffic. Vegetation in the cell may die, or exposed ground around the septic system may lead to sewage leaking to the surface and posing a contamination risk to children especially. To mitigate these risks, natural barricades such as stones or wood fencing will be incorporated to prevent the access of public onto these features.

5.3 Economic

The economic analysis for the 'One Water' system was conducted through analyzing the system's capital costs, operation and maintenance costs, potential revenue from the YGH Sustainable environments centre, and savings on municipal water use. As YGH is a not-for-profit organization, all revenue earned by the organization should be used towards covering the initial costs of the system and operations. Thus, the payback period method was used to estimate the cost recovery for the project.

The system's capital costs, and operation and maintenance costs are summarized in Table 5-2. The total 'One Water' system capital cost was found to be $172,000 with an annual operational and maintenance cost of $4,900. The net present value of the system was found to be $268,700 with a service life of 25 years.

Table 5-2: System capital cost, operation and maintenance cost summary

System Costs				
Component	Capital Cost (2020 CAD$)	Annual O&M Cost (2020 CAD$)	Service Life (years)	Net Present Value (25 years)
Bioretention	$79,000.00	$1,100.00	25	$100,500.00
Green Roof	$40,000.00	$2,350.00	40	$85,900.00
Storm and Greywater Reuse Tank	$17,000.00	$860.00	50	$33,800.00
Pumps	$1,300.00	$100.00	12.5	$4,800.00
Septic Leaching Bed	$10,600.00	$50.00	25	$11,600.00
Solar Panels	$23,100.00	$160.00	25	$26,200.00
Septic Tank	$1,000.00	$250.00	25	$5,900.00
Sum:	**$172,000.00**	**$4,900.00**	-	**$268,700.00**

To cover the capital costs and operation and maintenance costs, the Sustainable Environments Centre revenue and water savings revenue was needed. It was assumed that the Centre operates to the general public 360 days a year and to school groups 300 days a year with 3 groups of 25 students per week. Low cost day fees were chosen to make the Centre more accessible to the public. The day fee cost $2.00 and $5.00, for the general public and school groups respectively. The annual revenue from the Sustainable Environments Centre is $26,900. As the 'One Water' system does not rely on municipal water or city wastewater services, water savings revenue was determined. The annual savings were found to be $766. All values are summarized in Table 5-3 and Table 5-4.

Table 5-3: Summary of Sustainable Environments Centre revenue

Sustainable Environments Centre Revenues				
Visitor Type	Number per Day	Operating Days Per Year	Day Fee	Annual Revenue
General Public	15	360	$2.00	$10,800
School Groups	3 per week of 25 students	300	$5.00	$16,100
			Total:	**$26,900**

Table 5-4: Summary of water savings revenues

Water Savings Revenues				
Water Type	Daily Flows (m3/d)	Price Rate	Unit	Annual Savings
Municpal Water Charges	0.531	$1.77	per m^3	$343
Wastewater Charges	0.603	$1.92	per m^3	$423
		Total:		**$766**

Using the annual total Sustainable Environments Centre revenue and water savings revenue and the systems total cost, the payback period of the system was determined to be 7.5 years. After the 7.5 years, earned revenue can be used towards future programming and new modifications or additions to the centre. The payback period analysis is provided in Appendix B. The Calculations are summarized in Appendix B.

5.4 Social and Environmental

The 'One Water' system design provides significant environmental and social benefits compared to a conventional urban water and wastewater system. Environmental benefits include preservation of the local water balance by sourcing and returning water on-site – water and wastewater is managed holistically through the 'One Water' system. Other benefits include reduced greenhouse gas emissions through using renewable energy at the site to power the system components and adoption of recycled plastics for the piping materials. Additionally, the design requires less infrastructure as the system is not connected to municipal services, resulting in reduced emissions and resource requirements for the production and transportation of the design components. Lastly, the LIDs used for stormwater capture have additional benefits including water treatment and provide habitat for wildlife, which is especially beneficial in Guelph's urban setting. The property will also act as a new greenspace for the several new developments planned in the area as outlined in the Guelph Innovation District Secondary Plan.

Social benefits of the 'One Water' system include educational opportunities on sustainability and water conservation for school groups and the public. Therefore, the design aligns with the YGH mission which includes providing educational demonstrations to "help citizens and businesses choose low impact and carbon neutral energy alternatives", and to increase "engagement of citizens in building strong, resilient, safe and inclusive communities" [2]. The 'One Water' system also protects greenspace, maintains the current natural site aesthetic and supports community-based programs and events at the Site. Furthermore, the design allows for the preservation and re-purposing of the heritage site in an innovative manner, which supports the City's vision for sustainable growth. The system can also act as a great example for future developers in and around Guelph who are interested in adopting such a system or applying similar sustainability measures.

6 DESIGN RISKS AND UNCERTAINTIES

The following section identifies the sources of error, bias and uncertainty which may impact the effectiveness of the design and the potential risks associated with the design. Recommendations for improving the design or reducing the risks are also presented.

6.1 Design Assumptions

The following section outlines the key general assumptions for the overall design. The more specific technical assumptions which impact the accuracy of the modelling and calculations are also outlined.

6.1.1 General Limiting Assumptions

Several general assumptions were developed to ensure the feasibility of the design. The main assumption that the entire project depends upon is the securement of Parcel 2 of the previous GCC property by YGH and that they will have sufficient budget for implementation of the design. The property dictates many of the limitations of the design and several components will be sized based on the features located on-site (such as the sizing of the LIDs based on the parking lot size). Additionally, the system will be designed based on water requirements, which will be estimated on the plans described by YGH for the first year of the centre operation; Although scalability of the design will be considered when evaluating the alternatives, it should be noted that if the centre is expanded, the water requirements would need to be adjusted.

Additionally, the implementation of the design requires that the building at YGH be disconnecting from municipal water and wastewater services. It is assumed for this project that the client will be in agreement with this change.

Other site-specific limiting assumptions were also discovered during the research stage of the project. It was discovered during a document review that potential groundwater contamination was mentioned in an Infrastructure Ontario presentation from 2016. The G360 Institute for Groundwater Research was contacted by the team to confirm if contamination concerns were addressed. As no definitive information could be found on any remediations, it was assumed that there is no longer contamination to allow for feasibility of the private on-site well required for this design.

Additionally, information on the soil conditions and the water table elevation at the Site is required for the design. Although the well record for wells within the Site area may not be directly located where the system will be, it is assumed the soil conditions in these records are uniform within the Site area. It is also assumed that although the well records are not current that the water table elevations have not changed significantly since the date of the records.

6.1.2 Technical Assumptions

Several key assumptions were made to obtain necessary parameters as part of the design process. When such assumptions were needed, decisions were made in reference to literature review findings, expert opinion, and technical design guidelines. This section briefly outlines such key assumptions made.

Several key technical assumptions were made in the development of the design solution, and the following table outlines these assumptions while providing a brief justification for each.

Table 6-1: Design assumptions and associated justification for the PCSWMM model.

Assumption	Justification
Hydrologic Modelling	
Hourly precipitation data from Pine Grove Station in Vaughan, Ontario suitable for use in model.	Gauges with precipitation data have become less common with time. For hourly data that can better capture storm intensity than daily data, the longest running data set with fewest data gaps was the Pine Grove Station and determined most suitable upon consultation with the project advisor.
Precipitation data is assumed to fall in the form of rain during all months of the year.	PCSWMM can adopt snow pack functions, however for the preliminary design it was recommended through expert opinion of the project advisor to assume all precipitation to fall as rain.
Precipitation data from 1998/01/01 to 2006/12/31 will be adopted in the model simulation period of 2012/01/01 to 2019/12/31.	Daily climate data from Guelph Turfgrass monitoring station is available from 2007 to present, and thus the outdated precipitation will be translated to the 2012 to 2020 time frame to most accurately reflect current air temperature trends.
The simulation period will cover at least three full years and may be up to eight years.	Simulation of hourly precipitation data for at least three years will allow for an appropriate estimation of average annual stormwater collection in the system such that water savings estimates, energy requirements, and cost savings can all be accurately determined upon the detailed design stage of the project.
Determination of catchment parameters including runoff coefficients and soil infiltration.	Catchment parameters shall be assumed based upon appropriate technical guidance documents including the Ministry of Transportation Drainage Management Manual [10] and the Minnesota Stormwater Manual [55].
Wastewater Treatment System Design	
Subsoil percolation rates estimated from nearby well records.	Due to lack of access to site and required infiltration testing equipment, best estimates of the subsurface soil material and its percolation rate was developed based on composition records found in three well records on or near the site.
Groundwater levels were taken from well record data.	The leaching bed design must be a minimum distance from the seasonal high groundwater table. With lack of current data close

	to the site, the same well records were referenced for information on groundwater levels on-site as part of this check.
Life Cycle Assessment	
Operation and Maintenance not included.	Quantifying removal efficiencies of pollutants and other functions of the system is highly varied based on the literature review
Materials were selected using most applicable database source.	The ELCD Greendelta database used had a limited number of processes, and thus where the exact material required did not exist in the
Construction and disposal process accounted for via estimate of machinery fuel consumption.	Without exact numbers of equipment, types of equipment, and personnel required for installation or disposal of the system, these processes were estimated through a volume of gas burned by all machinery based on an average daily rate multiplied by the expected number of days worked.
Transportation distances based on average source or destination location.	Research into suppliers or landfill sites was performed and applied as a typical average distance within the LCA model.

6.2 Design Risks and Uncertainties

As with any design project, the 'One Water' System design for the future YGH Centre has important risks, uncertainties, and limitations tied to it that can affect the accuracy or applicability of the claims made with this design.

The main risks and uncertainties associated with the design are as follows:

- Leaching bed failure caused by issues such as blockage in the pipes could result in environmental damage due to groundwater, surface water or soil contamination from the release of insufficiently treated wastewater.
- Poor maintenance may have effects on other parts of the system as well (e.g. unacceptable greywater quality if system is not monitored) and therefore must be prioritized.
- The quality of the captured stormwater is not monitored. It is unknown if the quality will always be suitable for greenhouse irrigation (e.g. if the water is affected by salt in the winter).
- Greenhouse irrigation may have more stringent requirements in comparison to landscape irrigation as the greenhouse contains food for human consumption.
- The system performance during winter months is not well-known. The modelling during the winter months was completed assuming that all precipitation in the winter was rain and therefore the effects of snow melting rates were not accounted for.
- It is possible that the client will change the site layout (e.g., not construct the greenhouse). Therefore, the amount of impervious surface area could decrease which may decrease the feasibility of rainwater harvesting.

- Since this is a retrofit of an existing heritage building, there may be existing infrastructure which will need to be removed (e.g. old sewer pipes may need to be removed to prevent contamination). It is possible that the cost for the evaluation/removal of existing infrastructure will not be feasible for YGH's budget.

The main limitations to the design are as follows:

- The feasibility of the design implementation depends on YGH securing the site that the system was designed for and YGH having sufficient budget. Therefore, it depends on the ability of YGH to secure the site and charge sufficient admission rates.
- A lack of on-site soil characteristics, water table depth, groundwater quality and topographic grading information forced many assumptions in the design of the system based on the best available data (e.g. leaching bed infiltration capacity was based on old well records). Additional assessment of the site may be required (i.e., geotechnical investigation and site assessment) for a more accurate design solution.
- Water demand for the system was estimated based on conversations with YGH on their plans for operations at the site which may change. Additionally, at the time of the Site visit for this project, entrance to the old Superintendent's building was not permitted and therefore an evaluation of available space for the design was based on a site visit to 10 Carden Shared Space, which is a similar operation to that described by YGH.
- The project life cycle analysis was completed using a the most complete dataset available, however, the dataset used is specific to Europe. The LCA would be more accurate if Canadian data was available.
- The project life cycle analysis could also be improved by expanding the system boundary of analysis to be more detailed (i.e., include more processes and resources involved in the creation of the design as well as operational phases).

7 PROJECT MANAGEMENT

This section provides a summary of the project schedule and costs incurred during the entire project period. Due to unanticipated impacts of the COVID-19 pandemic, minor modifications were made to these project management components, which are explain in the following sections.

7.1 Scheduling

The project schedule was minimally altered throughout the term and was only recently updated to reflect a one week extension resulting from the University's response to COVID-19. A detailed GANTT chart is included in Appendix E. All identified tasks have been completed in accordance with the schedule and there are no outstanding items remaining. The total project duration was 23 weeks and consisted of four primary tasks including general meetings, data collection and analysis, design development and a final presentation and report. In considering project phases, Fall 2019 focused on data collection and analysis, December to February 2020 focused on preliminary design development and March to April 2020 focused on design optimization, lifecycle assessment and the preparation of final design deliverables. Due to the University of Guelph's closure as a result of COVID-19, the Design Day presentation was cancelled and instead consisted of a poster submission with questions answered in writing. Additionally, weekly team and advisor meetings continued in a virtual format. Ultimately, the project was completed in a timely manner with no significant impacts to the Client.

7.2 Updated Project Fees

The project cost breakdown for spending incurred during the project period is included in Appendix E. The work completed consisted of a total of 685 hours which amounts to $67,900 with disbursements included. Therefore, 90% of the total project budget has been spent during the project period from September 1st, 2019 to April 11th, 2020. The portion of the total budget spent is lower than anticipated primarily due to the cancellation of Design Day and reduced time required to prepare detailed design drawings for Task 3. Completion of the final design report exceeded the allocated budget; however, this is not a concern given the large number of underbudget items. Overall, the project was completed successfully within the initially allocated budget of $75,000.

8 DESIGN CONCLUSIONS AND RECOMMENDATIONS

The following section summarizes findings from the system's feasibility and functionality analyses and makes recommendations regarding opportunities to further improve the system's design.

8.1 Conclusion

The 'One Water' system designed for Yorklands Green Hub has been shown to effectively meet the project constraints and criteria while effectively considering the sustainability and environmental protection objectives of YGH. The system disconnects the site from municipal supply while providing well water for potable needs, stormwater and greywater for certain non-potable uses, and a septic tank to leaching bed wastewater treatment system that returns collected water back to the site. Reuse water is unavailable for just 15 hours a year on average and supplies a total volume of 138m^3. The system's distribution pumps are supplied by renewable energy from solar panels on the visitor centre, making this an off-the-grid system.

The design is shown to be effective under future climate change scenarios and can be easily scaled up for increased water demands. Use of recycled plastics for piping and green roof materials, and recycling or repurposing of all components will be prioritized to minimize the environmental footprint of the system throughout its life cycle.

The 'One Water' system respects and benefits the local environment mainly by maintaining the natural hydrologic balance of the site. Water that is drawn from the site is used in a variety of purposes but ultimately returned into the ground through the leaching bed. To protect the local environment, the Ontario Building Code Act was followed for sizing, depth and location of the leaching bed to ensure proper pollutant or nutrient removal. Additionally, setbacks from the code were checked to minimize contamination of any nearby surface water features. The green roof and bioretention cell will also be landscaped to help diversify the local ecosystems and educate visitors on the benefits of a naturalized property.

Safety of visitors is considered using natural barricades and educational signage directing people from staying off the features. Inside the building, distribution systems for greywater, stormwater, and potable water will be labelled and colour coded. To minimize cross contamination risk, the different water systems are kept separate including the use of a chambered storage tank. Finally, recycled greywater is treated to meet Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing, and water quality tests will be performed daily by staff [16].

Social benefits of this system are considerable. In combination with the YGH Sustainable Environments centre, the 'One Water' program can be taught to school groups to encourage water conservation and reuse while the general public can tour the information centre to learn about the system. Live monitors of the system's use and components in operation can help enhance this learning opportunity. The use of green infrastructure and an underground wastewater treatment system also holds the existing natural aesthetic of the site, helping to attract visitors.

The system is projected to have an initial capital investment cost of $172,000 with annual operation and maintenance fees of $4,900. These costs can be recovered by YGH in less than 8 years with savings on municipal water bills as well as reasonable admission charges for visiting the centre. With a minimum design life of 25 years, limited only by poor upkeep of the green roof and bioretention cell, the costs can be recovered quickly. Additionally, these costs can be significantly lowered by reducing the size of the bioretention cell, an optional site feature currently with the highest capital cost of all components.

8.2 Recommendations

To further improve the 'One Water' system solution, several recommendations have been identified by the project team and are listed below.

- Further investigate stormwater collection ability in winter for improved system performance estimate under sub-zero conditions
- Perform on-site soils and subsurface materials investigation to optimize the design of the leaching bed and bioretention cell
- Perform detailed investigation of topography to refine site layout and placement of 'One Water' system components for maximizing water flow by gravity
- Investigate system performance in winter under future climate change scenarios
- Provide detailed costing for greywater treatment infrastructure as well as costs for plumbing system required for distribution of the different water sources throughout site
- Analyze the future Sustainable Environment Centre's expansion scenarios to determine upscaling requirements and new stormwater capture opportunities
- Identify opportunities for greater renewable energy generation and consumption sources that can use the excess energy currently not used by the pumping system

8.3 Closing Remarks

The 'One Water' system solution for YGH's Sustainable Environments centre is an innovative solution to water management that provides immense educational opportunity and acts as a premium demonstrational tool for future developments looking to value sustainability and environmental responsibility.

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APPENDICES

APPENDIX A. SUPPORTING FIGURES

Figure A-1: Existing Conditions Site Map Prepared on Google Earth.

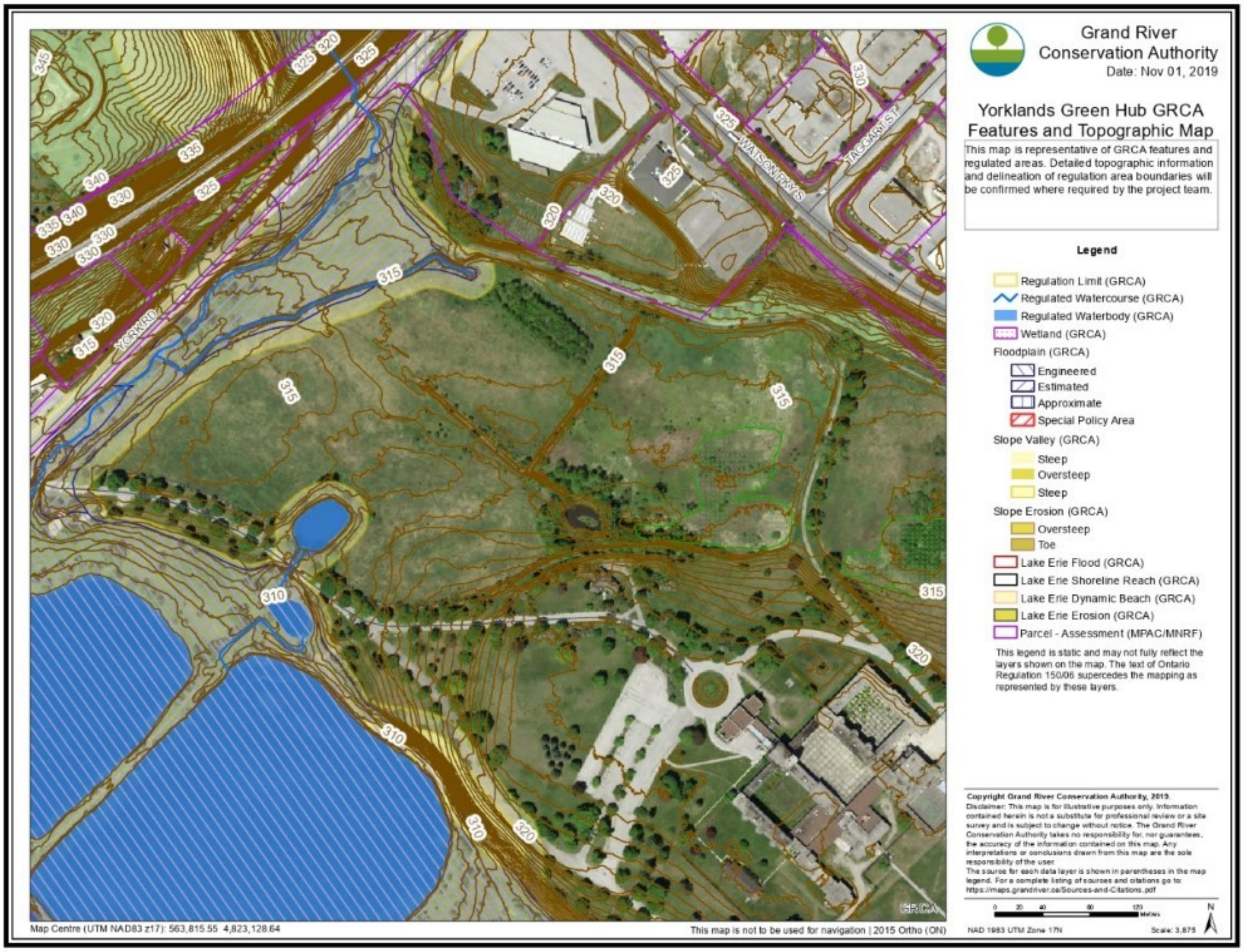


Figure A-2: Grand River Conservation Authority Regulated Areas and Site Features Map.

APPENDIX B. SYSTEM COST ESTIMATES

Stormwater Infrastructure:

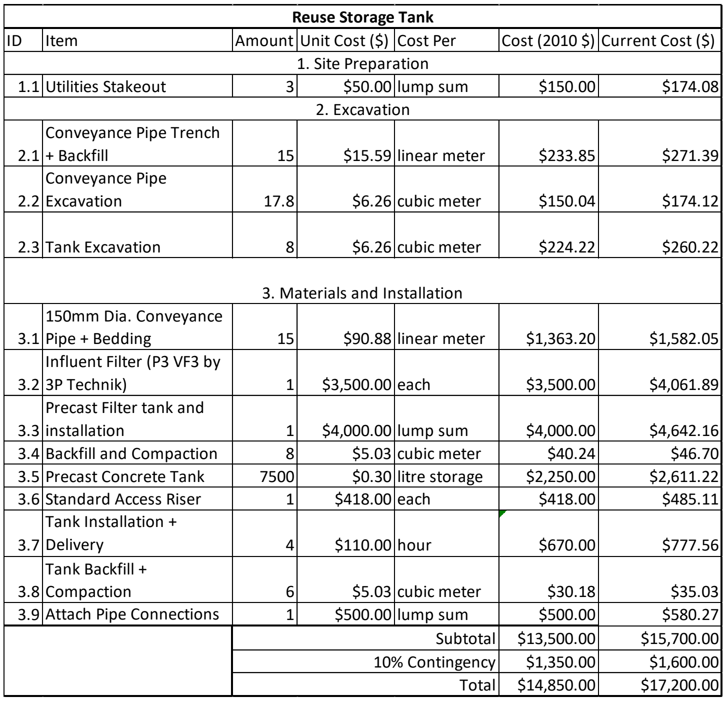
Table B-1: Cost summary for bioretention cell.

Bioretention						
ID	Item	Amount	Unit Cost ($)	Cost Per	Cost (2010 $)	Current Cost ($)
	1. Site Preparation					
1.1	Test Pits	3	$74.46	each	$223.38	$259.24
1.2	Infiltration Tests	2	$608.85	each	$1,217.70	$1,413.19
1.3	Utilities Stakeout	1	$500.00	lump sum	$500.00	$580.27
1.4	Erosion & Sediment Control Measures	1	$383.09	lump sum	$383.09	$444.59
	2. Excavation					
2.1	Topsoil Removal and Stockpile	162	$3.13	cubic meter	$507.06	$588.46
2.2	Subsoils Excavation	540	$4.04	cubic meter	$2,181.60	$2,531.84
2.3	Subsoil Removal	13	$172.92	per hour per dump truck	$2,247.96	$2,608.85
2.4	Construction Fencing	1	$800.00	per week	$800.00	$928.43
	3. Materials and Installation					
3.1	Stone Base Fill	162	$39.13	cubic meter	$6,339.06	$7,356.74
3.2	Pea Gravel	23	$59.23	cubic meter	$1,362.29	$1,580.99
3.3	Filter Media (Sand Mix)	486	$44.53	cubic meter	$21,641.58	$25,115.94
3.4	Concrete Curb Addition	30	$114.61	linear meter	$3,438.30	$3,990.29
3.5	Wood Mulch	54	$7.90	cubic meter	$426.60	$495.09
3.6	Vegetation	405	$50.20	square meter	$20,331.00	$23,594.96
				Subtotal	$61,600.00	$71,500.00
				10% Contingency	$6,160.00	$7,150.00
				Total	$67,760.00	$78,650.00

Table B-2: Cost summary for green roof.

Green Roof						
ID	Item	Amount	Unit Cost ($)	Cost Per	Cost (2010 $)	Current Cost ($)
	1. Site Preparation					
1.1	Crane Mobilization	1	$316.00	lump sum	$316.00	$366.73
1.2	Infiltration Tests	2	$608.85	each	$1,217.70	$1,413.19
	2. Materials and Installation					
2.1	Crane Operation	3	$4,632.68	days	$13,898.04	$16,129.24
2.2	Waterproof Membrane	66	$40.67	square meter	$2,684.22	$3,115.15
2.3	Water Leakage Test	1	$3,000.00	lump sum	$3,000.00	$3,481.62
2.4	Root Barrier	66	$8.46	square meter	$558.36	$648.00
2.5	Drainage Layer + Filter Cloth	66	$15.25	square meter	$1,006.50	$1,168.08
2.6	Aluminum Edging	34	$39.59	linear meter	$1,346.06	$1,562.16
2.7	Stone Perimeter	17	70.06	square meter	$1,191.02	$1,382.23
2.8	Growing Media	162	$20.95	square meter	$3,393.90	$3,938.76
2.9	Plant Cutlings	66	$2.54	square meter	$167.64	$194.55
2.10	Seed Mat	66	$35.85	cubic meter	$2,366.10	$2,745.96
				Subtotal	$31,100.00	$36,100.00
				10% Contingency	$3,110.00	$3,600.00
				Total	$34,210.00	$39,700.00

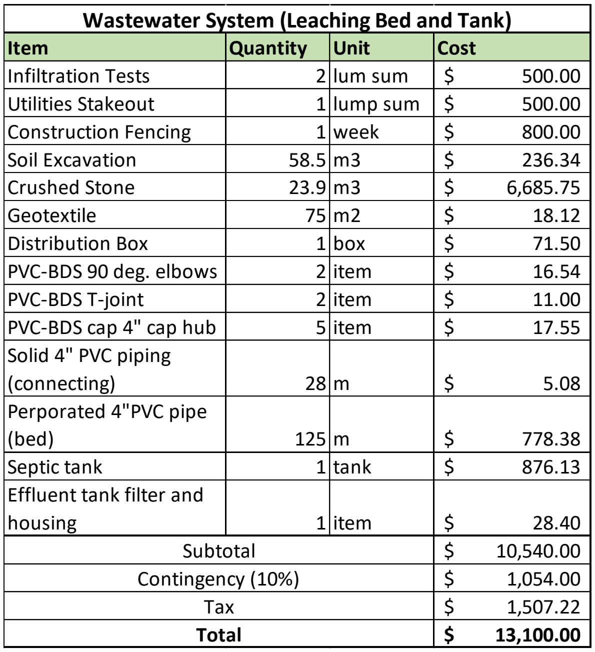
Table B-3: Cost summary for water reuse tank.



Reuse Storage Tank						
ID	Item	Amount	Unit Cost ($)	Cost Per	Cost (2010 $)	Current Cost ($)
1. Site Preparation						
1.1	Utilities Stakeout	3	$50.00	lump sum	$150.00	$174.08
2. Excavation						
2.1	Conveyance Pipe Trench + Backfill	15	$15.59	linear meter	$233.85	$271.39
2.2	Conveyance Pipe Excavation	17.8	$6.26	cubic meter	$150.04	$174.12
2.3	Tank Excavation	8	$6.26	cubic meter	$224.22	$260.22
3. Materials and Installation						
3.1	150mm Dia. Conveyance Pipe + Bedding	15	$90.88	linear meter	$1,363.20	$1,582.05
3.2	Influent Filter (P3 VF3 by 3P Technik)	1	$3,500.00	each	$3,500.00	$4,061.89
3.3	Precast Filter tank and installation	1	$4,000.00	lump sum	$4,000.00	$4,642.16
3.4	Backfill and Compaction	8	$5.03	cubic meter	$40.24	$46.70
3.5	Precast Concrete Tank	7500	$0.30	litre storage	$2,250.00	$2,611.22
3.6	Standard Access Riser	1	$418.00	each	$418.00	$485.11
3.7	Tank Installation + Delivery	4	$110.00	hour	$670.00	$777.56
3.8	Tank Backfill + Compaction	6	$5.03	cubic meter	$30.18	$35.03
3.9	Attach Pipe Connections	1	$500.00	lump sum	$500.00	$580.27
				Subtotal	$13,500.00	$15,700.00
				10% Contingency	$1,350.00	$1,600.00
				Total	$14,850.00	$17,200.00

Wastewater Treatment System:

Table B-4: Cost summary for wastewater system.



Wastewater System (Leaching Bed and Tank)			
Item	**Quantity**	**Unit**	**Cost**
Infiltration Tests	2	lum sum	$ 500.00
Utilities Stakeout	1	lump sum	$ 500.00
Construction Fencing	1	week	$ 800.00
Soil Excavation	58.5	m3	$ 236.34
Crushed Stone	23.9	m3	$ 6,685.75
Geotextile	75	m2	$ 18.12
Distribution Box	1	box	$ 71.50
PVC-BDS 90 deg. elbows	2	item	$ 16.54
PVC-BDS T-joint	2	item	$ 11.00
PVC-BDS cap 4" cap hub	5	item	$ 17.55
Solid 4" PVC piping (connecting)	28	m	$ 5.08
Perporated 4"PVC pipe (bed)	125	m	$ 778.38
Septic tank	1	tank	$ 876.13
Effluent tank filter and housing	1	item	$ 28.40
Subtotal			$ 10,540.00
Contingency (10%)			$ 1,054.00
Tax			$ 1,507.22
Total			**$ 13,100.00**

Renewable Energy System:

Table B-5: Cost summary for renewable energy system.

Renewable Energy System			
Item	**Quantity**	**Unit**	**Cost**
Solar Panels	8	lump sum	$ 4,960.00
Battery	1	lump sum	$ 9,150.58
Inverter Charger	1	lump sum	$ 4,437.00
Subtotal			$ 18,500.00
Contingency (10%)			$ 1,850.00
Tax			$ 2,645.50
Total			**$ 23,000.00**

Water Distribution System:

Table B-7: Cost summary for pumping system.

Pumping System			
Item	**Quantity**	**Unit**	**Cost**
Shallow Well Pump	1	lump sum	$ 391.99
Submersible Effluent Pump	1	lump sum	$ 501.19
Cast Iron Sump Pump	1	lump sum	$ 159.99
Subtotal			$ 1,050.00
Contingency (10%)			$ 105.00
Tax			$ 150.15
Total			**$ 1,300.00**

System Payback Period

Table B-9: Summary of project payback period calculation.

Yorklands Green Hub "One Water" System Component	Capital Cost (2020 CAD$)	Annual O&M Cost (2020 CAD$)	Minimum Service Life (years)	Annual Savings + Visitor Revenue (2020 CAD$)	Payback Period (years)
Stormwater Infrastructure	$136,000.00	$4,310.00	25	**$27,700.00**	**7.5**
Wastewater Infrastructure	$11,600.00	$300.00	25		
Renewable Energy Infrastructure	$23,100.00	$160.00	25		
Water Distribution Infrastructure	$1,300.00	$100.00	12.5		
Total System	**$172,000.00**	**$4,900.00**	**25**		

APPENDIX C. DESIGN ALTERNATIVES AND EVALUATION

C.1.1 Stormwater Collection System

The designed stormwater collection system for the YGH will incorporate the use various LIDs. Descriptions of how each LID could be implemented on the site are outlined as follows and further details of each LID can be found in Appendix D.

Roof top rain harvesting for the YGH would be designed to collect rainwater from the roofs of various structures. An underground cistern would be sized to collect stormwater from the superintendent's house and the connected classroom expansion. Rain barrels would be implemented for the gazebo and other smaller structures on the site.

Green roofs require greater structural requirements and cannot be installed on roofs with slopes greater than 10%, thus green roofs would only be applicable to the classroom expansion. While green roofs are not accommodating for all roof types, they can achieve up to 75% energy reductions for the building they are installed on.

Bioretention cells would be placed close to the parking lot area of YGH to capture its stormwater runoff. An impermeable lining would be placed under the cell to allow for capture and storage of the stormwater prior to reuse.

Infiltration chambers can be installed under paved surfaces including the parking lot, and road areas in the YGH. The runoff collected from infiltration chambers will infiltrate back into the native soil. Low traffic areas would be favorable as chlorine and sodium from road salt can promote the mobilization of heavy metals into groundwater. The implementation of infiltration chambers at YGH would involve excavating the current pavement prior to installation. New pavement would also need to be laid after the installation.

To install permeable surfaces at YGH, all current pavement and impermeable surfaces would need to be excavated and replaced. Replacement material could include pervious concrete, porous asphalt, and interlocking pavement. All of which would allow for stormwater to permeate and infiltrate into the native soil.

C.1.2 Wastewater Treatment System

A septic tank and leaching bed system is a possible solution for the on-site wastewater treatment at the YGH. As the calculated wastewater flowrate for the YGH is less than 10,000 litres per day, the septic tank and leaching bed wastewater treatment capacity would be suitable for the needs of the YGH. To be implemented on the site, the system would require both a primary treatment tank and secondary bed, which would need to meet the minimum set back requirements outlined in the Ontario Building Code as discussed in Section 2.3.3. As the system can fully function as a passive gravity fed system through relying on changes in elevation, no additional energy requirements are needed. The system would be placed north east of the superintendent's house, to take advantage of the elevation change of the site, with the leaching bed placed downstream of the septic tank.

A bioreactor system for the wastewater treatment at the YGH would consist of an aerobic membrane bioreactor. MBRs are favorable for the YGH site as they have a compact footprint and are very efficient. However, they also have drawbacks. The most significant downside is its very high energy demand which makes it vulnerable to power shortages. Others include high maintenance and capital costs as discussed in Section 2.3.3.

A constructed wetland system for wastewater treatment would allow for a larger treatment capacity, treating up to one thousand cubic meters of wastewater per day. However, the system requires much larger land requirements, around two square metres per one cubic metre of wastewater treatment. For the YGH, a constructed wetland system would be placed in a similar location to the septic tank and leaching bed system. Stringent operating conditions make cold weather climates sub optimal for the system, as discussed in Section 2.3.3. To sustain its optimal operating conditions, substantial maintenance would be required, resulting in much higher operating costs for the YGH.

C.1.3 Sustainable Energy Sources

Solar energy is a potential solution for sustainable energy production for the YGH. Solar panels have relatively high energy production abilities with low capital costs. As individual panels are cost effective, it is relatively easy to scale up the energy production capacity. For the YGH high wattage panels would be chosen for their increased energy production capacity. They would be designed to mount on the superintendent's house as the sloped roofs allow for high energy production. See Section 2.3.5 for further details. Solar panels also have high education value as they can easily be observed from the exterior of the building. Low seasonal variation in energy production is also favorable for the YGH site.

Wind energy is another potential design solution for the YGH's energy production, as wind turbines have very high energy generation abilities. The downside to wind energy is the high capital costs, scalability, and seasonal variations, more details are provided in Section 2.3.5. For the YGH small scale wind turbines would be used, up to 5kW energy generation capacity. This is preferable to large scale turbines as they would have lower capital costs, and do not need set back requirements.

Renewable biogas generation has the potential to be a sustainable energy system design for the YGH. Food waste from the kitchen/café would provide the necessary biomass for the system. As the café and kitchen are not in use daily, it may be difficult to generate enough biomass to produce sufficient amounts of biogas for the energy needs of the YGH. Stringent operating temperatures could be difficult to achieve during Canadian winters and so the system may need additional heating to be operational.

C.2 Design Alternatives Evaluation Process

The design alternatives were evaluated utilizing the multi-criteria decision matrix (MCDM) method, specifically the weighted sum model. This decision-making technique involves a numerical method of evaluation by determining the relevant criteria and alternatives, attaching numerical values relevant to the importance of these criteria and to the impacts of the alternatives on the criteria, and finally processing the numerical value to determine a ranking of the alternatives [56]. The numerical ranking for each alternative is calculated as the summation of the numerical values assigned for each criterion multiplied by the respective assigned criterion weightings. The alternative which receives the highest ranking is determined to be the most favourable option. Essentially, this method provides a means to determining which alternatives satisfy the most criteria. [56]. The numerical ranking for each alternative is calculated as the summation of the numerical values assigned for each criterion multiplied by the respective assigned criterion weightings. The alternative which receives the highest ranking is determined to be the most favourable option. Essentially, this method provides a means to determining which alternatives satisfy the most criteria.

For this design project, a MCDM was applied for each of the three components of the design – the stormwater collection system, the wastewater treatment system and the renewable energy generation – to determine which of the options for each component will be favourable for the project criteria. The MCDM for each of three components utilized the applicable criteria discussed previously in Section 2.4. A breakdown of the numerical scale developed by the team for each of the criteria is presented in Table C 1, below. This scale is used in the evaluation of each of the MCDM, with each alternative being assigned a value from the scale based on its ability to satisfy each of the applicable criteria.

Table C 1: Matrix Scale

Scale Value	Common Criteria					Wastewater		Stormwater		Energy Output/unit
	Capital Cost	Operation & Maintenance	Other Benefits	Site & Environmental Cost/Disruption	Scalability	System Energy Requirements	Footprint	Capture Ability	Treatment Ability	
1 (Worst)	Complex manufacturing and high material costs	High operating and maintenance cost, very frequent operator visits	No educational value, no aesthetic value, does not align with YGH vision, provides no ecological benefits	High quantity of non-recyclable by-products, system disrupts wildlife and public, very short lifecycle	No ability to increase capacity/output to accommodate YGH growth	Permanent pump power required for operation.	Large area required per treated volume (>1m^2 land/ m^3 effluent)	No ability to capture and collect stormwater runoff for on-site reuse	Does not improve concentrations of any parameters in the applicable guidelines	Low energy output, stringent operating conditions for energy production
2	Complex manufacturing and moderate material costs	High operating and maintenance cost, medium operator visits	Minimal educational value, inconvenient appearance, does not align with YGH vision, provides minimal ecological benefits	Medium quantity of non-recyclable by-products, minimal wildlife and public disruption, short lifecycle	Limited ability to increase capacity/output to accommodate YGH growth	-	-	Poor ability to capture and collect stormwater runoff for on-site reuse	Slightly improves concentrations of very minimal parameters in the applicable guidelines	Low-moderate energy output, stringent operating conditions for energy production
3 (Good)	Moderate manufacturing with low material cost	Medium operating and maintenance cost, frequent operator visits	Moderate educational value, inconvenient appearance, aligns well with YGH vision. provides some ecological benefits	Low quantity of non-recyclable by-products, minimal wildlife and public disruption, moderate lifecycle	Moderate ability to increase capacity/output to accommodate YGH growth	Intermittent pump power required for operation.	Moderate area required per treated volume (about 1m^2 land/ m^3 effluent)	Moderate ability to capture and collect stormwater runoff for on-site reuse	Slightly improves concentrations of some parameters in the applicable guidelines	Moderate energy output, able to operate under some conditions (seasonal energy production)

Scale Value	Common Criteria					Wastewater		Stormwater		Energy Output/unit
	Capital Cost	Operation & Maintenance	Other Benefits	Site & Environmental Cost/Disruption	Scalability	System Energy Requirements	Footprint	Capture Ability	Treatment Ability	
4	Simple manufacturing with moderate material costs	Medium operation and maintenance costs, infrequent operator visits	High educational value, good appearance, aligns well with YGH vision, provides many ecological benefits.	Low quantity of non-recyclable by-products, no impact on wildlife and public, long lifecycle	Good ability to increase capacity/output to accommodate YGH growth	-	-	Good ability to capture and collect stormwater runoff for on-site reuse	Moderately improves concentration of some parameters in the applicable guidelines	High energy output, able to operate under some conditions (seasonal energy production)
5 (Best)	Simple manufacturing with low material cost	Low operating and maintenance cost, infrequent operator visits	Very high educational value, pleasing appearance, aligns great with YGH vision, provides exceptional ecological benefits.	Treatment uses renewable materials and has no impact on wildlife and public, very long lifecycle	Extremely suitable for increasing capacity output to accommodate YGH growth	No energy inputs required and completely passive system.	Minimal area required per treated volume (<1m^2 land/ m^3 effluent)	High ability to capture and collect stormwater runoff for on-site reuse	Improves concentrations of many parameters in the applicable guidelines	High energy output/unit, energy production occurs under various conditions (suitable for year-round production)

C.3 Design Alternatives Evaluation

The following section presents the MCDM evaluation for each of the design components, utilizing the numerical scale described above. The evaluation matrix and resulting rankings of the alternatives for the stormwater collection system, the wastewater treatment system and the energy sources are presented in Table C 2, Table C 3 and Table C 4, respectively. The alternative that was awarded the highest ranking is indicated by the bolded total values; for the stormwater collection system, the three highest ranked alternatives will be incorporated in the design.

Table C 2 : Stormwater Collection System Decision Matrix

Alternatives	Criteria							Total Score
	Weighting							
	Minimize Capital Cost	Minimize Maintenance Requirements	Minimize Environmental Cost/Disruption	Maximize Other Benefits	Maximize Scalablity Potential	Maximize Stormwater Treatment Ability	Maximize Stormwater Capture Ability	
	10%	*10%*	*10%*	*15%*	*20%*	*5%*	*30%*	*100%*
Rooftop Rain Harvesting	5	5	5	2	4	4	5	**4.3**
Green roof	1	2	3	5	3	5	5	**3.7**
Bioretention Cells	4	4	4	5	5	5	4	**4.4**
Infiltration Chambers	3	3	2	2	2	3	4	2.9
Pavement Surface Collection	3	4	2	1	3	1	4	2.9

Table C 3: Wastewater Treatment System Decision Matrix

Alternatives	Criteria							Total Score
	Weighting							
	Minimize Capital Cost	Minimize Maintenance Requirements	Minimize Environmental Cost/Disruption	Maximize Other Benefits	Maximize Scalability Potential	Minimize Energy Requirements	Maximize Treatment Quantity per Unit Area	
	15%	*15%*	*10%*	*5%*	*20%*	*30%*	*5%*	*100%*
Wetland Flow System	3	2	4	5	4	3	3	3.3
Bioreactor	1	3	2	3	2	1	5	1.9
Septic Tank and Leaching Bed	5	5	4	3	4	5	2	**4.5**

Table C 4: Energy Source Decision Matrix

Alternatives	Criteria						Total Score
	Weighting						
	Minimize Capital Cost	Maximize Other Benefits	Minimize Maintenance Requirements	Minimize Site and Environmental Cost/Disruption	Maximize Energy Production/ Unit	Maximize Scalability Potential	
	10%	*15%*	*20%*	*15%*	*15%*	*25%*	*100%*
Solar Energy	3	4	3	3	3	5	**3.7**
Wind Energy	2	3	2	5	5	2	3.1
Renewable Biogas Generation	4	4	2	2	3	1	2.4

Based on the results of the matrices above, the preferred design alternatives were determined to be rooftop rain harvesting, green roofs and bioretention cells for the stormwater collection system, a septic tank and leaching bed for the wastewater system and solar energy for the renewable energy source.

C.3.1 Sensitivity Analysis

To create confidence in the chosen design, a sensitivity analysis was conducted by adjusting the weightings for the criteria for two alternate situations. The original weightings as presented above were decided based on the values and goals expressed by YGH and the team's interpretation of what is important to the success of the design. The alternate scenarios for this analysis and the respective weightings were determined based on adjusting the importance of the YGH values and goals.

For the first scenario, the criteria were adjusted for a situation where it is assumed that the costs and maintenance requirements are not considered an important aspect for YGH. This scenario assumes that YGH is mainly focused on achieving their goals for the site, regardless of the cost in capital or maintenance, therefore those two criteria have been given very low weightings in comparison to other criteria. Additionally, in this scenario it is assumed that the minimal environmental disruption/cost and minimal energy requirements criteria are of high importance to YGH to achieve their goals for environmental sustainability.

For the second scenario, the criteria were adjusted for a situation where it is assumed that YGH has decided that they will not be expanding the Site in the future. Therefore, YGH would not consider the scalability of the various components of the design to be an important aspect and is given the lowest rating in comparison to other criteria. Alternatively, in this scenario it is also assumed that YGH has a tight budget and therefore considers the costs and maintenance to be of high importance.

Some of the weightings remain the same between all the scenarios due to the interpretation that either the value of these criteria cannot be adjusted due to its importance for the design success or the adjustment of the criteria would not cause significant changes to the overall results. The criteria of stormwater capture ability for the stormwater collection system and of energy production per unit for the energy source were not adjusted as it is necessary that these criteria be of the highest importance in order for the design to be successful and meet the necessary water and energy requirements for the Site. The criteria of treatment ability for the stormwater collection was not adjusted and was consistently valued the lowest since the treatment ability of all the options is similar and therefore would not impact the decision. Finally, the criteria for treatment quantity per unit area for the wastewater system was not adjusted from its low weighting since there is sufficient area available at the Site and therefore this aspect should be present too big of an issue for the design regardless of which alternative is chosen.

The different weighting scenarios are summarised in Table C 5 below.

Table C 5: Weightings for Alternate Scenarios

Criteria	Stormwater Matrix			Wastewater Matrix			Energy Matrix		
	Previous Weighting	Scenario 1	Scenario 2	Previous Weighting	Scenario 1	Scenario 2	Previous Weighting	Scenario 1	Scenario 2
Minimize Capital Cost	10%	5%	20%	15%	5%	25%	10%	5%	20%
Minimize Maintenance Requirements	10%	5%	20%	15%	5%	25%	20%	5%	20%
Minimize Environmental Cost/Disruption	10%	20%	10%	10%	30%	15%	15%	30%	15%
Maximize Other Benefits	15%	15%	10%	5%	5%	15%	15%	15%	25%
Maximize Scalability Potential	20%	20%	5%	20%	20%	5%	25%	20%	5%
Minimize Energy Requirements				30%	30%	10%			
Maximize Treatment Quantity per Unit Area				5%	5%	5%			
Maximize Stormwater Treatment Ability	5%	5%	5%						
Maximize Stormwater Capture Ability	30%	30%	30%						
Maximize Energy Production/Unit							15%	25%	15%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

The results of the MCDM evaluation for each of the two alternate scenarios for each of the three design components is provided in Appendix C-1. The results of the sensitivity analysis are presented in the following graphs for the stormwater collection system, the wastewater treatment system and the energy sources, respectively. It is clearly illustrated on the graphs that the results of the sensitivity analysis confirm that the results determined in the previous design alternatives evaluation are the preferred options to proceed with for this project.

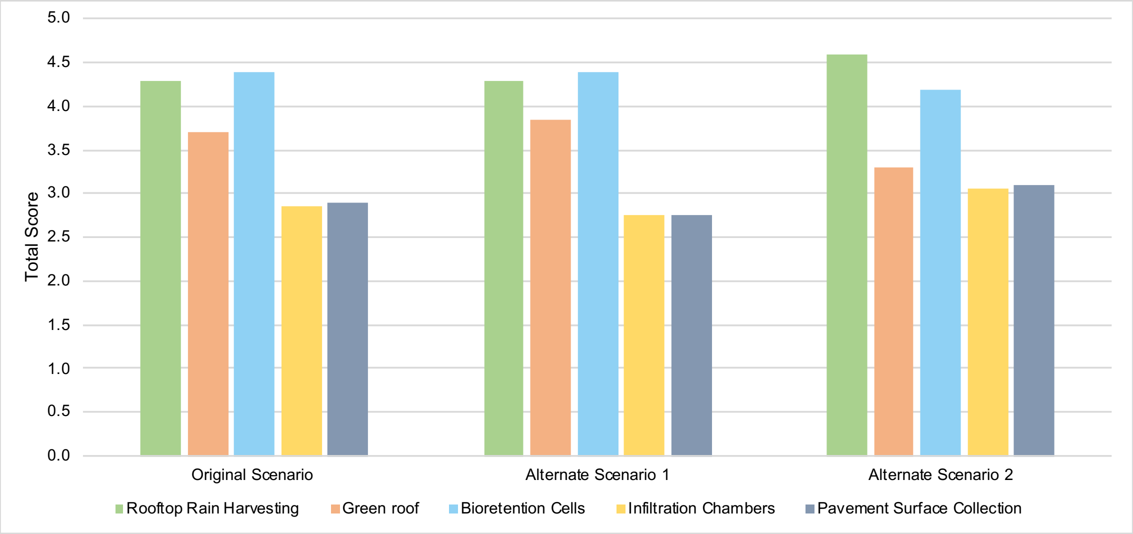


Figure C 1: Sensitivity Analysis Results for Stormwater Collection System

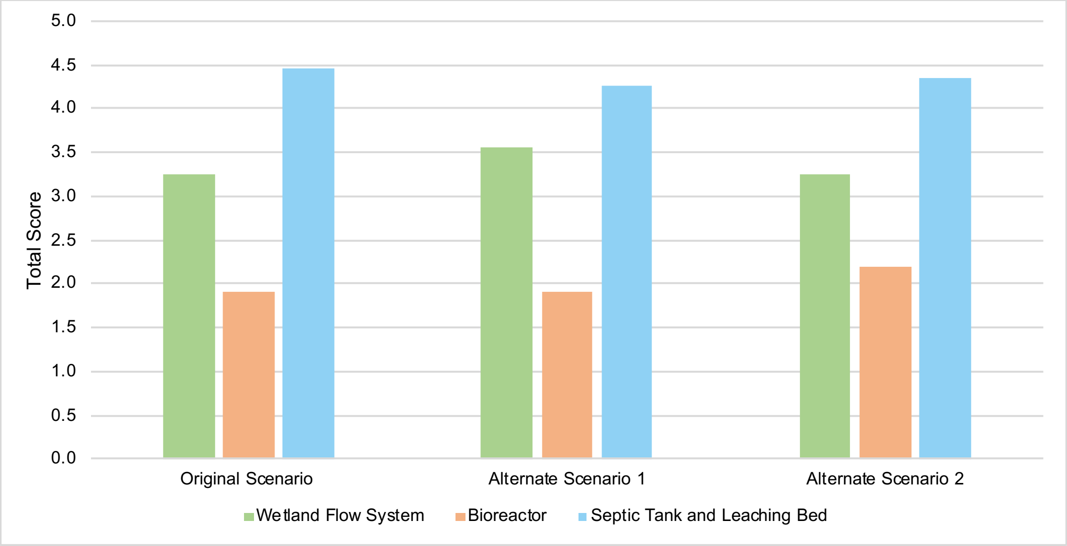


Figure C 2: Sensitivity Analysis Results for Wastewater Treatment System

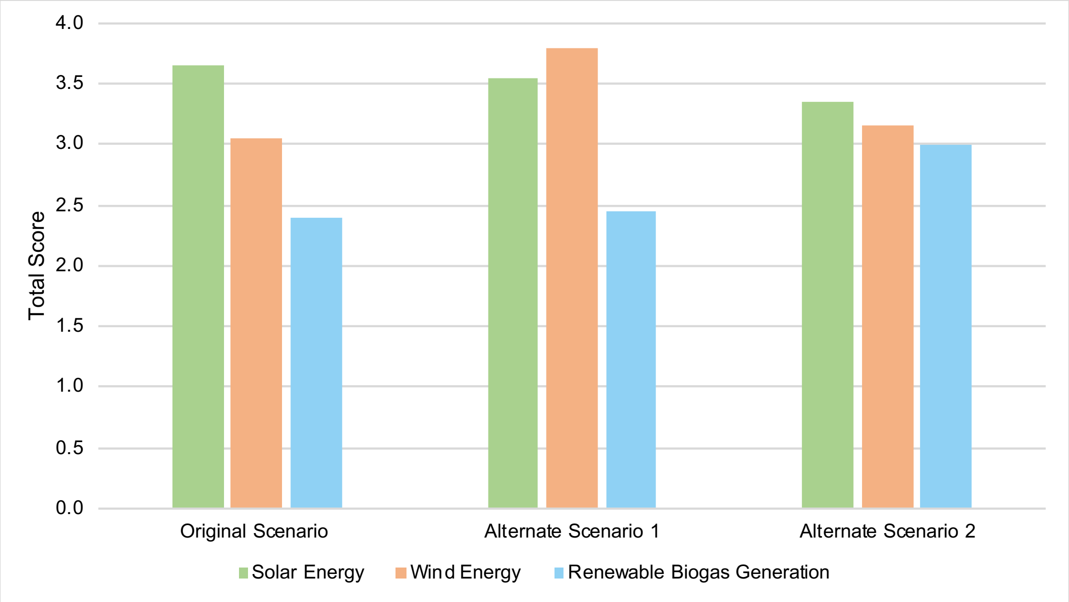


Figure C 3: Sensitivity Analysis Results for Energy Sources

Appendix C-1: Sensitivity Analysis Tables

Wastewater Treatment Alternatives	**Criteria**							**Total Score**
	Weighting - Scenario 1							
	Minimize Capital Cost	**Minimize Maintenance Requirements**	**Minimize Environmental Cost/Disruption**	**Maximize Other Benefits**	**Maximize Scalability Potential**	**Minimize Energy Requirements**	**Maximize Treatment Quantity per Unit Area**	
	5%	*5%*	*30%*	*5%*	*20%*	*30%*	*5%*	*100%*
Wetland Flow System	3	2	4	5	4	3	3	3.6
Bioreactor	1	3	2	3	2	1	5	1.9
Septic Tank and Leaching Bed	5	5	4	3	4	5	2	**4.3**

Wastewater Treatment Alternatives	**Criteria**							**Total Score**
	Weighting - Scenario 2							
	Minimize Capital Cost	**Minimize Maintenance Requirements**	**Minimize Environmental Cost/Disruption**	**Maximize Other Benefits**	**Maximize Scalability Potential**	**Minimize Energy Requirements**	**Maximize Treatment Quantity per Unit Area**	
	25%	*25%*	*15%*	*15%*	*5%*	*10%*	*5%*	*100%*
Wetland Flow System	3	2	4	5	4	3	3	3.3
Bioreactor	1	3	2	3	2	1	5	2.2
Septic Tank and Leaching Bed	5	5	4	3	4	5	2	**4.4**

Stormwater Collection Alternatives	**Criteria**							**Total Score**
	Weighting - Scenario 1							
	Minimize Capital Cost	**Minimize Maintenance Requirements**	**Minimize Environmental Cost/Disruption**	**Maximize Other Benefits**	**Maximize Scalablity Potential**	**Maximize Stormwater Treatment Ability**	**Maximize Stormwater Capture Ability**	
	5%	*5%*	*20%*	*15%*	*20%*	*5%*	*30%*	*100%*
Rooftop Rain Harvesting	5	5	5	2	4	4	5	**4.3**
Green roof	1	2	3	5	3	5	5	**3.9**
Bioretention Cells	4	4	4	5	5	5	4	**4.4**
Infiltration Chambers	3	3	2	2	2	3	4	2.8
Pavement Surface Collection	3	4	2	1	3	1	4	2.8

Stormwater Collection Alternatives	**Criteria**							**Total Score**
	Weighting - Scenario 2							
	Minimize Capital Cost	**Minimize Maintenance Requirements**	**Minimize Environmental Cost/Disruption**	**Maximize Other Benefits**	**Maximize Scalablity Potential**	**Maximize Stormwater Treatment Ability**	**Maximize Stormwater Capture Ability**	
	20%	*20%*	*10%*	*10%*	*5%*	*5%*	*30%*	*100%*
Rooftop Rain Harvesting	5	5	5	2	4	4	5	**4.6**
Green roof	1	2	3	5	3	5	5	**3.3**
Bioretention Cells	4	4	4	5	5	5	4	**4.2**
Infiltration Chambers	3	3	2	2	2	3	4	3.1
Pavement Surface Collection	3	4	2	1	3	1	4	3.1

Energy Alternatives	**Criteria**						**Total Score**
	Weighting - Scenario 1						
	Minimize Capital Cost	**Maximize Other Benefits**	**Minimize Maintenance Requirements**	**Minimize Site and Environmental Cost/Disruption**	**Maximize Energy Production/ Unit**	**Maximize Scalability Potential**	
	5%	*15%*	*5%*	*30%*	*25%*	*20%*	*100%*
Solar Energy	3	4	3	3	3	5	3.6
Wind Energy	2	3	2	5	5	2	**3.8**
Renewable Biogas Generation	4	4	2	2	3	1	2.5

Energy Alternatives	**Criteria**						**Total Score**
	Weighting - Scenario 2						
	Minimize Capital Cost	**Maximize Other Benefits**	**Minimize Maintenance Requirements**	**Minimize Site and Environmental Cost/Disruption**	**Maximize Energy Production/ Unit**	**Maximize Scalability Potential**	
	20%	*25%*	*20%*	*15%*	*15%*	*5%*	*100%*
Solar Energy	3	4	3	3	3	5	**3.4**
Wind Energy	2	3	2	5	5	2	3.2
Renewable Biogas Generation	4	4	2	2	3	1	3.0

APPENDIX D. LOW IMPACT DEVELOPMENT SUMMARY TABLE

Table D-10: Summary of Typical Low Impact Development infrastructure, including design considerations and potential treatment ability.

Low Impact Development Features Overview			
Feature	Description	Design and Site Considerations	Effectiveness
Bioretention Cells	Excavated area filled with a filter bed media (mix of sand, fines and organic material) and mulch ground cover for plant growth. Cell temporarily stores, treats and infiltrates runoff. Variations include addition of underdrain and impermeable liner if collection of water important. Designed for capturing water quality storage requirement or small event flows.	Require pre-treatment feature such as stone diaphragm to remove particles that may clog the cell. Overflow bypass also necessary for larger storm events. Should not accept runoff from high traffic areas where salt and pollution levels are high.	Reductions Include: • Runoff (45% with underdrain) • TSS (76%) • Phosphorous (47%) • Nitrogen (40%) • Lead (80%) • CFU (71%)
Cisterns	An underground or above ground tank that collects and stores stormwater for various non-potable water reuse applications. Can also have variations such as rain barrels for smaller, residential uses.	Vary in size (190 to 40,000 litres) depending on application requirements. Minor pre-treatment required such as gravity filtration or first flush diversion. Operates year round if located indoors or underground.	Runoff reduction estimate of 40%. No significant pollutant reductions.
Dry Swales	Type of enhanced swale incorporating engineered soil bed and optional perforated underdrain. Similar to enhanced swales in terms of design of their surface geometry, slope, check dams, and pre-treatment devices, but similar to bioretention cells in terms of the filter bed media. Open channels designed to convey, treat, and attenuate stormwater runoff.	Bottom of swale separated from seasonal high groundwater table by 1m. Longitudinal slopes between 0.5-4% with a maximum of 6%. Areas with potential for highly contaminated runoff not suitable for treatment via swales. Setback at least 4m from building foundations.	Reductions Include: • Runoff with underdrain (45%) • Runoff without underdrain (85%) • Pollutant removal varies, function of design parameters
Green Roofs	Layer of vegetation and growing medium installed on flat or sloping roof. System initially stores rainfall in the medium, then acts as filter in events where excess rain falls than what can be stored. Can be intensive (depth greater than 15cm and allows for deeply rooted plants) or extensive	Greater structural requirements are often necessary to support green roofs. Vital to ensure effective waterproofing of the roof to avoid future water damage. While they are an additional cost to install, energy reductions of as much as 75% for the building can	Reductions Include: • Runoff (45-55%) • TSS (85-90%) • Nitrate (90%) • Metals (70-85%) • CFU (10%) • Posphorous

	(less than 15cm depth and allows shallow rooting). Connected to cistern or downspout.	be achieved. Cannot effectively operate on roofs with greater than 10% slope.	(-250%). *Varies based on media used, fertilizer, etc
Infiltration Facilities	Rectangular trenches lined with geotextile fabric and filled with granular stone or other void forming material that receive runoff from an inlet pipe that allow it to infiltrate into the native soil below. Can be installed under paved surfaces or open space such as a recreational field. Other variations, soakaway pits, are installed at the ground surface.	Suited for sites with limited surface area for SWM features. Facilities are not suitable for winter use in high traffic areas where chlorine and sodium pollution from road salt is likely (can increase mobilization of heavy metals into groundwater). Should be set back at least 4 meters from building foundations	Reductions Include: • Runoff (85%) • TSS (70-90%) • Phosphorous (80%) • Nitrogen (76%) • Lead (90%) • Copper (85%) • Zinc (83%)
Permeable Surfaces	Includes pervious concrete, porous asphalt, and interlocking pavers. Allows stormwater to drain through the surface and into a stone reservoir below for infiltration into underlying native soil. Suitable in low traffic areas such as local roads, parking lots, and pedestrian walkways. Suitable for use on-sites where space for surface LID features is very limited. Can include an underdrain and impermeable liner for no or partial infiltration.	Not suitable for placement in areas with high road salt application. Clogging is main concern as sediments build up at interface with underlying media. 2.5mm clear stone or gravel used rather than sand to limit clogging. Must conform to design standards for expected loading capacity to ensure structural stability maintained. Surface slope between 1- 5%, and 4m setback to building foundations.	Reductions Include: • Runoff with subdrain (45%) • Runoff without subdrain (85%) • TSS (>50%) • Metals (>50%) • Hydrocarbons (>50%)

APPENDIX E. PROJECT MANAGEMENT

Project Schedule

No.	**Task Description**	**Duration**	**November**				**December**				**January**					**February**				**March**				**April**	
			W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W5	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2
Task 1	**General Tasks**																								
1.1	Group Meetings	21 days	■		■		■		■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
1.2	Client Meetings	4 days										■					■				■				
1.3	Advisor Meetings	7 days										■		■		■		■		■	■		■	■	
Task 2	**Data Collection and Analysis**																								
2.1	Literature Review	9 weeks	■	■	■	■	■	■	■	■	■						■								
2.2	Correspondence with client	2 days		■				■											■						■
2.3	Correspondence with external groups	8 weeks	■	■	■	■	■	■	■	■									■						
2.4	Review of site documents	4 weeks					■	■	■	■															
2.5	Site data compilation	3 weeks								■	■	■													
2.6	Field Condition Assessment	1 day		■																					
Task 3	**Design Development**																								
3.1	Conceptual design alternatives	3 weeks									■	■	■	■											
3.2	Advisor consultation	1 day													■										
3.3	Preliminary Site Plan Refinement	2 weeks														■	■								
3.4	Preliminary Flow Calculations	2 weeks														■	■								
3.5	Hydrologic Model Development	5 weeks													■	■	■	■	■						
3.6	Preliminary Wastewater Design Development	2 weeks																■	■						
3.7	Detailed Design Drawings	3 weeks																		■	■	■			
3.8	Design specifications	3 weeks																		■	■	■			
Task 4	**Final Report and Presentation**																								
4.1	Design Refinement	1 weeks																			■		■		
4.2	Design Specifications Refinement	1 weeks																			■		■		
4.3	Final Cost Estimate	2 weeks																			■	■			
4.4	Life Cycle Analysis	3 weeks																			■	■	■		
4.5	Presentation Development	2 weeks																					■	■	
4.6	Design Day Presentation	1 day																							■ X
4.7	Final Report Writing	5 weeks																			■	■	■	■	■ X

Figure E-3: Overview of up-to-date project schedule.

Table E-11: Overview of updated project budget.

Team Member		Jacob Martin	Alana Valle	Elli Shanen	Ana Brankovan	Period Spending			Original Budget	
Task		**$ 90.00**	**$ 90.00**	**$ 90.00**	**$ 90.00**	**Total Hours**	**Total Rate**	**% of Budget**	**Total Hours**	**Total Rate**
Task 1: General Tasks										
1.1	Group Meetings	18	18	18	18	**72**	**$ 6,480.00**	**100%**	72	$ 6,480.00
1.2	Client Meetings	2	4	6	2	**14**	**$ 1,260.00**	**70%**	20	$ 1,800.00
1.3	Advisor Meetings	10	10	10	10	**40**	**$ 3,600.00**	**100%**	40	$ 3,600.00
1.4	Project Feedback Revisions	8	8	8	8	**32**	**$ 2,880.00**	**100%**	32	$ 2,880.00
Task 2: Data Collection and Analysis										
2.1	Literature Review	5	6	6	5	**22**	**$ 1,980.00**	**100%**	22	$ 1,980.00
2.2	Correspondence with client	1	0	3	0	**4**	**$ 360.00**	**100%**	4	$ 360.00
2.3	Correspondence with external groups	2	2	5	3	**12**	**$ 1,080.00**	**80%**	15	$ 1,350.00
2.4	Review of site documents	1	1	4	2	**8**	**$ 720.00**	**100%**	8	$ 720.00
2.5	Site data compilation	3	2	4	3	**12**	**$ 1,080.00**	**86%**	14	$ 1,260.00
2.6	Field Condition Assessment	1	1	1	1	**4**	**$ 360.00**	**67%**	6	$ 540.00
Task 3: Design Development										
3.1	Conceptual design alternatives	17	20	18	17	**72**	**$ 6,480.00**	**100%**	72	$ 6,480.00
3.2	Advisor consultation	1	1	1	1	**4**	**$ 360.00**	**100%**	4	$ 360.00
3.3	Preliminary Site Plan Development	5	7	7	6	**25**	**$ 2,250.00**	**96%**	26	$ 2,340.00
3.4	Preliminary Flow Calculations	2	11	0	11	**24**	**$ 2,160.00**	**100%**	24	$ 2,160.00
3.5	Hydrologic Model Development	40	2	2	2	**46**	**$ 4,140.00**	**82%**	56	$ 5,040.00
3.6	Preliminary Wastewater Design Development	2	10	15	22	**49**	**$ 4,410.00**	**98%**	50	$ 4,500.00
3.7	Detailed Design Drawings	10	12	15	12	**49**	**$ 4,410.00**	**67%**	73	$ 6,570.00
3.8	Design Specifications	7	7	7	7	**28**	**$ 2,520.00**	**78%**	36	$ 3,240.00
Task 4: Final Report and Presentation										
4.1	Design Refinement	8	8	8	8	**32**	**$ 2,880.00**	**62%**	52	$ 4,680.00
4.2	Design Specifications Refinement	4	4	4	4	**16**	**$ 1,440.00**	**100%**	16	$ 1,440.00
4.3	Final Cost Estimate	4	3	3	3	**13**	**$ 1,170.00**	**81%**	16	$ 1,440.00
4.4	Life Cycle Analysis	12	0	4	4	**20**	**$ 1,800.00**	**100%**	20	$ 1,800.00
4.5	Presentation Development	2	5	2	3	**12**	**$ 1,080.00**	**100%**	12	$ 1,080.00
4.6	Design Day Presentation	1	1	1	1	**4**	**$ 360.00**	**33%**	12	$ 1,080.00
4.7	Final Report Writing	15	26	15	15	**71**	**$ 6,390.00**	**118%**	60	$ 5,400.00
Total Hours		181	169	167	168					
Total Fees		$ 16,290.00	$ 15,210.00	$15,030.00	$ 15,120.00					
Period:	**September 1, 2019 to April 11, 2020**				**Total Hours**		**685**	**90%**		**762**
					Total Fees		**$ 61,700.00**	**90%**		**$ 68,600.00**
					Disbursments (10%)		**$ 6,170.00**	**90%**		**$ 6,860.00**
					Total Fees including disbursments		**$ 67,900.00**	**90%**		**$ 75,500.00**

APPENDIX F. DESIGN CALCULATIONS

Table F-12: Design Calculations Literature Values.

Parameter	Source	Reference
Toilet Flow	WaterSense	[57]
Shower Flow	WaterSense	[57]
Washroom Sink Flow	WaterSense	[57]
# of Washroom Uses Per Person	Bladder and Bowel Community	[58]
Time to Wash Hands	Centres for Disease Control and Prevention	[59]
Drinking Water Fountain Flow	Commercial Water Concious Drinking Water Fountain Specifications	[60]
Greenhouse Area	Paul Neeland's Proposed Greenhouse Design	[61]
Water Required for Tomato and Bell Pepper Crops	Journal Article – Crop Study	[62]
Water Required for Flower Bed	Gardening Website	[63]
# of Watering Days Per Week	Gardening Website	[63]
Dishwasher Flow	Commercial Dishwasher Model Specificatons	[64]
Regular Sink Taps Flow	WaterSense	[57]
Pre-Rinse Spray Valve Sink Taps Flow	WaterSense	[57]

Washroom Demand Calculations

ASSUMPTIONS:

1) Winter period is 10 months from September to June (i.e., during the school year)
2) Summer period is 2 months from July to August (i.e., when school is out)
3) The building is in operation 7 days a week for the entire year
4) There is one full time staff living at the centre
5) There is one part time staff there during the day
6) The # of student visits is 4/week in the winter and 2/week in the summer
7) There are 25 students each for each visit
8) The # of public visitors is 5/day in the winter and 20/day in the summer
9) Each visitor (public and students) and part time staff uses the washroom 4 times/day
10) Each full time staff living there uses the washroom 10 times/day
11) The sink used once per washroom use
12) It takes a person 0.5 minutes to wash their hands
13) Each full time staff uses the shower 7 times/week (i.e., 1 time/day)
14) It takes a person 10 minutes to take a shower
15) Every person uses the drinking water fountains for 0.5 minutes/day

Note: These assumptions are based on conversations with YGH, literature values and personal estimates.

PARAMETERS:

Parameter	Winter	Summer	Units
Length of Period	10	2	Months / Year
Days of Building Operation	7	7	Days / Week
# of Full Time Staff	1	1	People / Day
# of Part Time Staff	1	1	People / Day
# of Student Visits	4	2	Vists / Week
# of Normal Days	3	5	Days / Week
# of Student Each Visit	25	25	People / Visit
# of Public Visitors	5	20	People / Day
# of Washroom Uses - Visitors &PT	4	4	Uses / Day
# of Washroom Uses - FT	10	10	Uses / Day
# of Shower Uses	1	1	Uses / Day
Time to Shower	10	10	Minutes / Shower
Time to Wash Hands	0.5	0.5	Minutes / Wash
WaterSense Product Flows:			
Toilet	4.85	4.85	L / Flush
Shower	7.57	7.57	L / Minute
Washroom Sink	5.68	5.68	L / Minute

CALCULATIONS:

	Equation	Calculation		
Daily Uses		Winter	Summer	Units
During a Normal Day:				
Toilet Flushes	((PT Staff + Public Visitors) * # of Washroom Uses Visitors &PT) + (FT Staff * # of Washroom Uses FT)	34	94	Flushes / Day
Shower Minutes	FT Staff * Shower Uses * Time to Shower	10	10	Minutes / Day
Washroom Sink Minutes	(((PT Staff + Public Visitors) * # of Washroom Uses Visitors &PT) + (FT Staff * # of Washroom Uses FT)) * Time to Wash Hands	17	47	Minutes / Day
During a School Vist Day:				
Toilet Flushes	Students * # of Washroom Uses Visitors &PT	100	100	Flushes / Day
Washroom Sink Minutes	Students * # of Washroom Uses Visitors &PT * Time to Wash Hands	50	50	Minutes / Day
Daily Water Demand Flows				
During a Normal Day:				
Toilets	Toilet Flow * Toilet Flushes	**164.9**	**455.9**	L / Day
Showers	Shower Flow * Shower Minutes	75.7	75.7	L / Day
Washroom Sinks	Washroom Sink Flow * Washroom Sink Minutes	96.6	267.0	L / Day
Showers and Sinks	Shower Demand + Washroom Sinks Demand	**172.3**	**342.7**	L / Day
During a School Day:				
Toilets	Toilet Flow * Toilet Flushes	**485.0**	**485.0**	L / Day
Washroom Sinks	Washroom Sink Flow * Washroom Sink Minutes	**284.0**	**284.0**	L / Day
Weekly Water Demand Flows				
Toilets	(Daily Normal Influent * # of Normal Days/Week) + (Daily School Influent * # School Visits/Week)	**2,434.7**	**3,249.5**	L/ Week
Showers and Sinks	(Daily Normal Influent * # of Normal Days/Week) + (Daily School Influent * # School Visits/Week)	**1,652.8**	**2,281.3**	L/ Week
Annual Water Demand Flows				
Toilets	((Weekly Winter Influent * Length of Winter Period) + (Weekly Summer Influent * Length of Summer Period)) * 4 Weeks / Month	**123,384.0**		L / Year
Showers and Sinks	((Weekly Winter Influent * Length of Winter Period) + (Weekly Summer Influent * Length of Summer Period)) * 4 Weeks / Month	**84,361.6**		L / Year

Drinking Water Fountain Demand Calculations

ASSUMPTIONS:

1) Winter period is 10 months from September to June (i.e., during the school year)
2) Summer period is 2 months from July to August (i.e., when school is out)
3) The building is in operation 7 days a week for the entire year
4) There is one full time staff living at the centre
5) There is one part time staff there during the day
6) The # of student visits is 4/week in the winter and 2/week in the summer
7) There are 25 students each for each visit
8) The # of public visitors is 5/day in the winter and 20/day in the summer
9) Every person uses the drinking water fountains for 0.5 minutes/day
10) 75% of the water dispensed at a fountain is consumed, 25% is collected grey water

Note: These assumptions are based on conversations with YGH, literature values and personal estimates.

PARAMETERS:

Parameter	Winter	Summer	Units
Length of Period	10	2	Months / Year
Days of Building Operation	7	7	Days / Week
# of Full Time Staff	1	1	People / Day
# of Part Time Staff	1	1	People / Day
# of Student Visits	4	2	Vists / Week
# of Normal Days	3	5	Days / Week
# of Student Each Visit	25	25	People / Visit
# of Public Visitors	5	20	People / Day
Time at Fountain	0.5	0.5	Minutes / Day
WaterSense Product Flows:			
DW Fountain	4.16	4.16	L / Minute

CALCULATIONS:

	Equation	Calculation		
Daily Uses		Winter	Summer	Units
During a Normal Day:				
DW Fountain Minutes	(PT Staff + Public Visitors + FT Staff) * (Time at Fountain)	3.5	11	Minutes / Day
During a School Vist Day:				
DW Fountain Minutes	(Students) * (Time at Fountain)	12.5	12.5	Minutes / Day
Daily Water Demand Flows				
During a Normal Day:				
Influent Potable Water	(Fountain Flow) * (DW Fountain Minutes)	**14.6**	**45.8**	L / Day
Effluent Grey Water	(Influent Potable Water) * 0.25	**3.6**	**11.4**	L / Day
During a School Vist Day:				
Influent Potable Water	(Fountain Flow) * (DW Fountain Minutes)	**52.0**	**52.0**	L / Day
Effluent Grey Water	(Influent Potable Water) * 0.25	**13.0**	**13.0**	L / Day
Weekly Water Demand Flows				
Influent Potable Water	(Daily Normal Influent * # of Normal Days/Week) + (Daily School Influent * # School Visits/Week)	**251.7**	**332.8**	L / Week
Effluent Grey Water	(Influent Potable Water) * 0.25	**62.9**	**83.2**	L / Week
Annual Water Demand Flows				
Influent Potable Water	((Weekly Winter Influent * Length of Winter Period) + (Weekly Summer Influent * Length of Summer Period)) * 4 Weeks/Mont	**12,729.6**		L / Year
Effluent Grey Water	(Influent Potable Water) * 0.25	**3,182.4**		L / Year

Irrigation Demand Calculations

ASSUMPTIONS:

1) The greenhouse on-site will be similar in size and operationto the design proposed to YGH by Paul Neelands (i.e., the greenhouse wil have a footprint of 26X30 ft or 7.92x9.15m)
2) The greenhouse will have 90% productive space
3) The types of crops grown in the greenhouse will be similar to tomatoes and bell peppers
4) It is assumed that the greenhouse crops will consist of 50% tomatoes and %50 bell peppers
5) Landscaping requirements consists of flower beds, year round
6) Flower beds require about 1 millimeter (mm) of water per week
7) Each flower bed has dimensions of about 1 m x 3 m
8) There will be about 10 flower beds in total across the whole Site

Note: These assumptions are based on conversations with YGH, literature values and personal estimates.

PARAMETERS:

Parameter	Value	Units
Greenhouse Area (Total)	72.5	m^2
Greenhouse Area (Productive Space)	65.2	m^2
Tomato Crop Percentage	0.5	
Bell Pepper Crop Percentage	0.5	
Water Required for Tomato Crops	3.2	L / m^2 / Day
Water Required for Bell Pepper Crops	4.1	L / m^2 / Day
Flower Bed Area	3	m^2 / Bed
# of Flower Beds	10	Beds
Water Required for Flower Bed	0.005	m / Watering Day
# of Watering Days Per Week	2	Days
m3 to L Conversion Factor	1000	L / m^3

CALCULATIONS:

Greenhouse Demand	**Equation**	**Calculated Value**	**Units**
Area for Tomato Crop	Productive Greenhouse Area * Tomato Percentage	32.6	m^2
Area for Bell Peppers	Productive Greenhouse Area * Bell Pepper Percentage	32.6	m^2
WATER DEMAND			
Tomato Crops	Area for Tomato Crop * Water Required for Tomatoes	104.4	L / Day
Bell Pepper Crops	Area for Bell Pepper Crop * Water Required for Bell Peppers	133.7	L / Day
Daily Greenhouse Irrigation	Summation of All Crop Demands	**238.1**	L / Day
Weekly Greenhouse Irrigation	Daily Demand * 7 Days/ Week	**1,666.4**	L / Week
Landscape Demand			
Total Flower Bed Area	Flower Bed Area * # of Flower Beds	30.0	m^2
WATER DEMAND			
Daily Landscaping Irrigation	Total Flower Bed Area * Water Required for Flower Bed * m3 to L Conversion Factor	**150.0**	L / Day
Weekly Landscaping Irrigation	Daily Flower Beds * # of Watering Days Per Week	**300.0**	L / Week
Total Daily and Weekly Irrigation Demand			
Daily Influent Irrigation Water	Daily Greenhouse Demand + Daily Landscaping Demand	**388.1**	L / Day
Weekly Influent Irrigation Water	Weekly Greenhouse Demand + Weekly Landscaping Demand	**1,966.4**	L / Week
Annual Influent Irrigation Water	Total Weekly Demand * 52 Weeks / Year	**102,252.9**	L / Year

Kitchen Demand Calculations

ASSUMPTIONS:

1) Winter and Summer conditions are the same
2) The kitchen is in operation 7 days a week
3) There are 4 workshops per week
4) The kitchen runs the dishwasher once per day on normal days and twice per day on workshop days
5) The kitchen at YGH will be very simialr to the community kitchen at 10C Shared Space in Guelph, Ontario
6) There are 4 sink taps in the kitchen similar to the washroom sink taps
7) There are 2 sinks taps with pre-rinse spray valves
8) There is one dishwasher
9) The dishwasher is run once every normal day and twice every workshop day
10) Each regular tap and pre-rinse spray valve tap runs for a total of 5 minutes ona normal day and 10 minutes on a workshop day.

Note: These assumptions are based on conversations with YGH, literature values and personal estimates.

PARAMETERS:

Parameter	Normal Day	Workshop Day	Units
# of Dishwashers	1	1	Dishwashers
# of Regular Taps	4	4	Taps
# of Spray Valve Taps	2	2	Taps
Dishwasher Cycles	1	2	Cycles / Dishwasher / Day
Regular Tap Minutes (Per One Tap)	5	10	Min / Day
Spray Valve Tap Minutes (Per One Tap)	5	10	Min / Day
# of Workshop Days	0	4	Days / Week
# of Normal Days	7	3	Days / Week
Flows:			
Dishwasher	6.81	6.81	L / Cycle
Regular Sink Taps	5.68	5.68	L / Min
Pre-Rinse Spray Valve Sink Taps	4.85	4.85	L / Min

CALCULATIONS:

Daily Water Demand Flows	Equation	Calculated Value	Units
During a Normal Day:			
Dishwasher	# of Dishwashers * Dishwasher Cycles *Dishwasher Flow	6.8	L / Day
Regular Taps	# of Regular Taps * Regular Tap Minutes *Regular Taps Flow	113.6	L / Day
Spray Valve Taps	# of Spray Valve Taps * Spray Valve Tap Minutes * Spray Valve Taps Flow	48.5	L / Day
During a Workshop Day:			
Dishwasher	# of Dishwashers * Dishwasher Cycles *Dishwasher Flow	13.6	L / Day
Regular Taps	# of Regular Taps * Regular Tap Minutes *Regular Taps Flow	227.2	L / Day
Spray Valve Taps	# of Spray Valve Taps * Spray Valve Tap Minutes * Spray Valve Taps Flow	97.0	L / Day
Daily Influent Water (Normal Day)	Summation of Normal Day Demands	**168.9**	L / Day
Daily Influent Water (Workshop Day)	Summation of Workshop Day Demands	**337.8**	L / Day
Weekly Water Demand Flows			
Weekly Influent Water	(Normal Daily Demand * # of Normal Days) + (Workshop Daily Demand * # of Workshop Days)	**1,858.0**	L / Week
Annual Water Demand Flows			
Annual Influent Water	Total Weekly * 52 Weeks / Year	**96,616.5**	L / Year

Summary and Design Flows Calculations

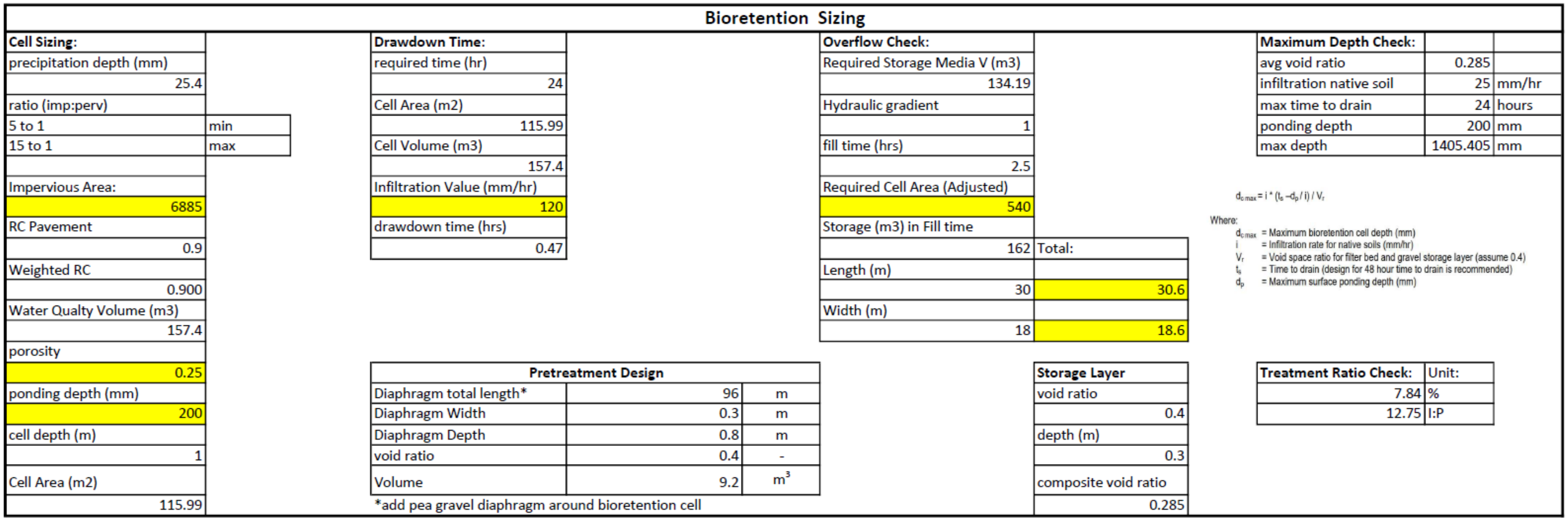
SUMMARY OF CALCULATED VALUES:

	Winter			Summer			Annual (L / Year)
	Daily (L / Day)		Weekly (L / Week)	Daily (L / Day)		Weekly (L / Week)	
	Normal Day	School Visit/Workshop Day		Normal Day	School Visit/Workshop Day		
INFLUENT							
Toilets	164.9	485.0	2,434.7	455.9	485.0	3,249.5	123,384.0
Sinks / Showers	172.3	284.0	1,652.8	342.7	284.0	2,281.3	84,361.6
Drinking Water Fountains	14.6	52.0	251.7	45.8	52.0	332.8	12,729.6
Irrigation (Greenhouse and Landscape)	388.1		1,966.4	388.1		1,966.4	102,252.9
Kitchen	168.9	337.8	1,858.0	168.9	337.8	1,858.0	96,616.5
EFFLUENT							
Toilets	164.9	485.0	2,434.7	455.9	485.0	3,249.5	123,384.0
Sinks / Showers	172.3	284.0	1,652.8	342.7	284.0	2,281.3	84,361.6
Drinking Water Fountains	3.6	13.0	62.9	11.4	13.0	83.2	3,182.4
Irrigation (Greenhouse and Landscape)	None						
Kitchen	168.9	337.8	1,858.0	168.9	337.8	1,858.0	96,616.5

DESIGN FLOWS:

	Equation	Calculated Value						
		Winter			Summer			Annual (L/Year)
		Daily (L/Day)		Weekly (L/Week)	Daily (L/Day)		Weekly (L/Week)	
		Normal Day	School Visit / Workshop Day		Normal Day	School Visit / Workshop Day		
Minimum Water Required from Potable Well	Kitchen Influent + Drinking Water Fountains Influnet + Sinks and Showers Influent	355.7	673.8	3,762.5	557.3	673.8	4,472.1	193,707.7
Minimum Water Required from Stormwater Collection	Irrigation Total Influent	388.1	388.1	1,966.4	388.1	388.1	1,966.4	102,252.9
Grey Water Collected	Sinks and Showers Effluent + Drinking Water Fountains Effluent	172.3	284.0	1,652.8	342.7	284.0	2,281.3	84,361.6
Toilet Water Required from Well or Stormwater	Toilet Water Effluent - Grey Water Collected	-7.4	201.0	781.9	113.2	201.0	968.2	39,022.4
Wastewater Treatment System Influent Flow	Kitchen Effluent + Toilet Effluent	333.8	822.8	4,292.7	624.8	822.8	5,107.5	220,000.5

Table F-13: Sizing calculation process for parking lot bioretention cell [56].



Bioretention Sizing

Cell Sizing:	
precipitation depth (mm)	
25.4	
ratio (imp:perv)	
5 to 1	min
15 to 1	max
Impervious Area:	
6885	
RC Pavement	
0.9	
Weighted RC	
0.900	
Water Qualty Volume (m3)	
157.4	
porosity	
0.25	
ponding depth (mm)	
200	
cell depth (m)	
1	
Cell Area (m2)	
115.99	

Drawdown Time:
required time (hr)
24
Cell Area (m2)
115.99
Cell Volume (m3)
157.4
Infiltration Value (mm/hr)
120
drawdown time (hrs)
0.47

Overflow Check:	
Required Storage Media V (m3)	
134.19	
Hydraulic gradient	
1	
fill time (hrs)	
2.5	
Required Cell Area (Adjusted)	
540	
Storage (m3) in Fill time	
162	Total:
Length (m)	
30	30.6
Width (m)	
18	18.6

Maximum Depth Check:		
avg void ratio	0.285	
infiltration native soil	25	mm/hr
max time to drain	24	hours
ponding depth	200	mm
max depth	1405.405	mm

$d_{c\,max} = i * (t_s - d_p / i) / V_r$

Where:
$d_{c\,max}$ = Maximum bioretention cell depth (mm)
i = Infiltration rate for native soils (mm/hr)
V_r = Void space ratio for filter bed and gravel storage layer (assume 0.4)
t_s = Time to drain (design for 48 hour time to drain is recommended)
d_p = Maximum surface ponding depth (mm)

Pretreatment Design		
Diaphragm total length*	96	m
Diaphragm Width	0.3	m
Diaphragm Depth	0.8	m
void ratio	0.4	-
Volume	9.2	m^3

*add pea gravel diaphragm around bioretention cell

Storage Layer
void ratio
0.4
depth (m)
0.3
composite void ratio
0.285

Treatment Ratio Check:	Unit:
7.84	%
12.75	I:P

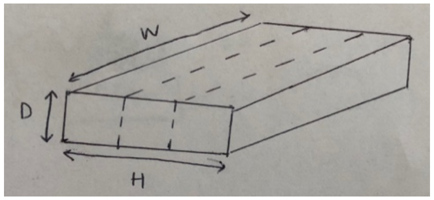
Greywater Treatment System Design

Tank retention time, **t = 45** minutes (estimated based on average required retention time of between 20 minutes to 1 hour)

Flow, **Q =** 0.107 m^2 = 0.3427 m^3/d * 3 (conservative estimate) = **1.0281 m^3/d**

Volume = Q * t = (1.0281 m^3/d)*(45 min)*(1 hr/60min)*(1d/24hr) = **0.0321 m^3**

The flocculation basin will have three compartments of equal depth in series.



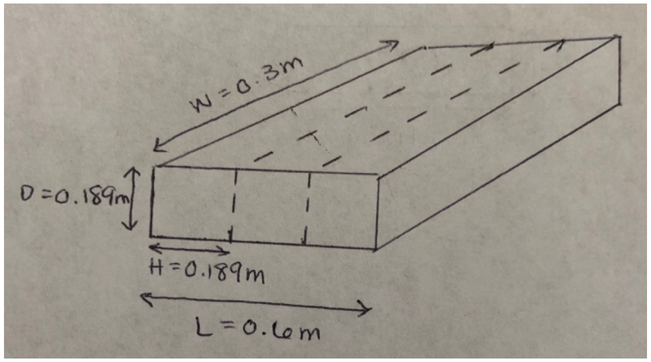
Assume a width of 0.3m for the flocculation basin → **W = 0.3 m**

A = 0.0321m^3 / 0.3 m = 0.107 m^2

Area as square = 0.107 m^2 = $3x^2$ (for all three components) → x = 0.189 m → **D = H = 0.189 m**

Including the sedimentation tank, which is double the size of the flocculation basin:

Total length, **L** = 3*H = 3*0.189 m **= 0.6 m**



Wastewater System Design Calculations

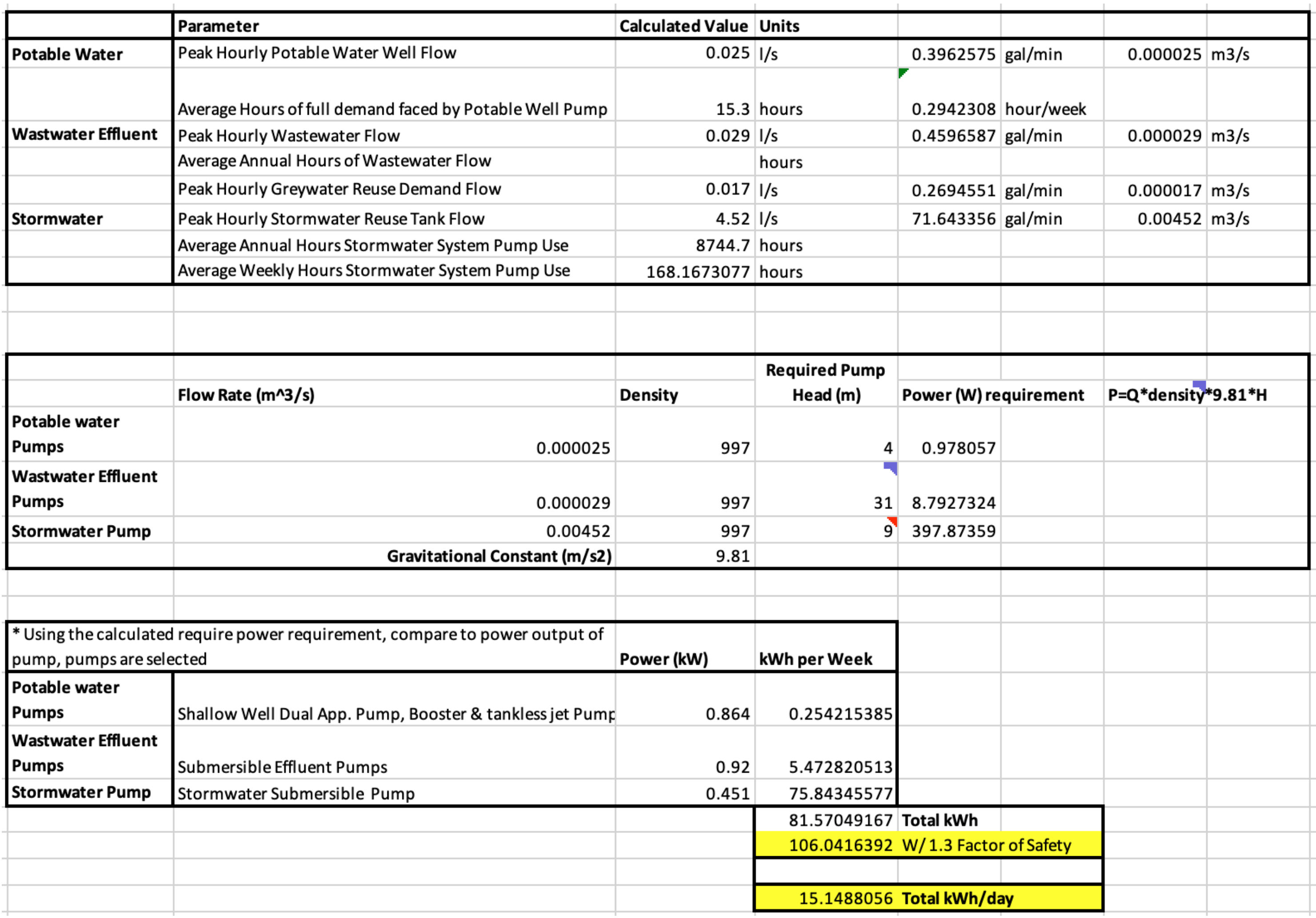
Parameter	Value	Reference
Daily Sanitary Flow (Q_S)	823 L/day	
Soil Hydraulic Conductivity	2.5×10^{-7} m/s	[32][65]
Soil Percolation time (T)	15 min/cm	[66]

Design Calculation using Ontario Building Code Act, Section 8:

Parameter	Equation [19]	Value
Design flow	$Q = Q_S \, x \, 2$	1,646 L/day
Leaching bed total length	$L = QT/200$	123 m
Pipe segment length	(max 30 m)	25 m
Number of pipe segments	$n_{seg} = L/25$	5
Leaching area width	$w = 1.6 \, x \, n_{seg}$	8 m

Construction Requirements:

Parameter	Value
Trench width [19]	0.6 m
Trench depth [19]	0.6 m
Gravel depth [19]	0.3 m
Total excavation	58.5 m^3
Total native fill	31.7 m^3
Soil removal	26.8 m^3
Gravel volume	23.9 m^3
Geotextile cover	75 m^2



	Parameter	Calculated Value	Units				
Potable Water	Peak Hourly Potable Water Well Flow	0.025	l/s	0.3962575	gal/min	0.000025	m3/s
	Average Hours of full demand faced by Potable Well Pump	15.3	hours	0.2942308	hour/week		
Wastwater Effluent	Peak Hourly Wastewater Flow	0.029	l/s	0.4596587	gal/min	0.000029	m3/s
	Average Annual Hours of Wastewater Flow		hours				
	Peak Hourly Greywater Reuse Demand Flow	0.017	l/s	0.2694551	gal/min	0.000017	m3/s
Stormwater	Peak Hourly Stormwater Reuse Tank Flow	4.52	l/s	71.643356	gal/min	0.00452	m3/s
	Average Annual Hours Stormwater System Pump Use	8744.7	hours				
	Average Weekly Hours Stormwater System Pump Use	168.1673077	hours				

	Flow Rate (m^3/s)	Density	Required Pump Head (m)	Power (W) requirement	P=Q*density*9.81*H
Potable water Pumps	0.000025	997	4	0.978057	
Wastwater Effluent Pumps	0.000029	997	31	8.7927324	
Stormwater Pump	0.00452	997	9	397.87359	
	Gravitational Constant (m/s2)	9.81			

* Using the calculated require power requirement, compare to power output of pump, pumps are selected		Power (kW)	kWh per Week	
Potable water Pumps	Shallow Well Dual App. Pump, Booster & tankless jet Pump	0.864	0.254215385	
Wastwater Effluent Pumps	Submersible Effluent Pumps	0.92	5.472820513	
Stormwater Pump	Stormwater Submersible Pump	0.451	75.84345577	
			81.57049167	**Total kWh**
			106.0416392	W/ 1.3 Factor of Safety
			15.1488056	**Total kWh/day**

APPENDIX G. PCSWMM MODEL SETUP

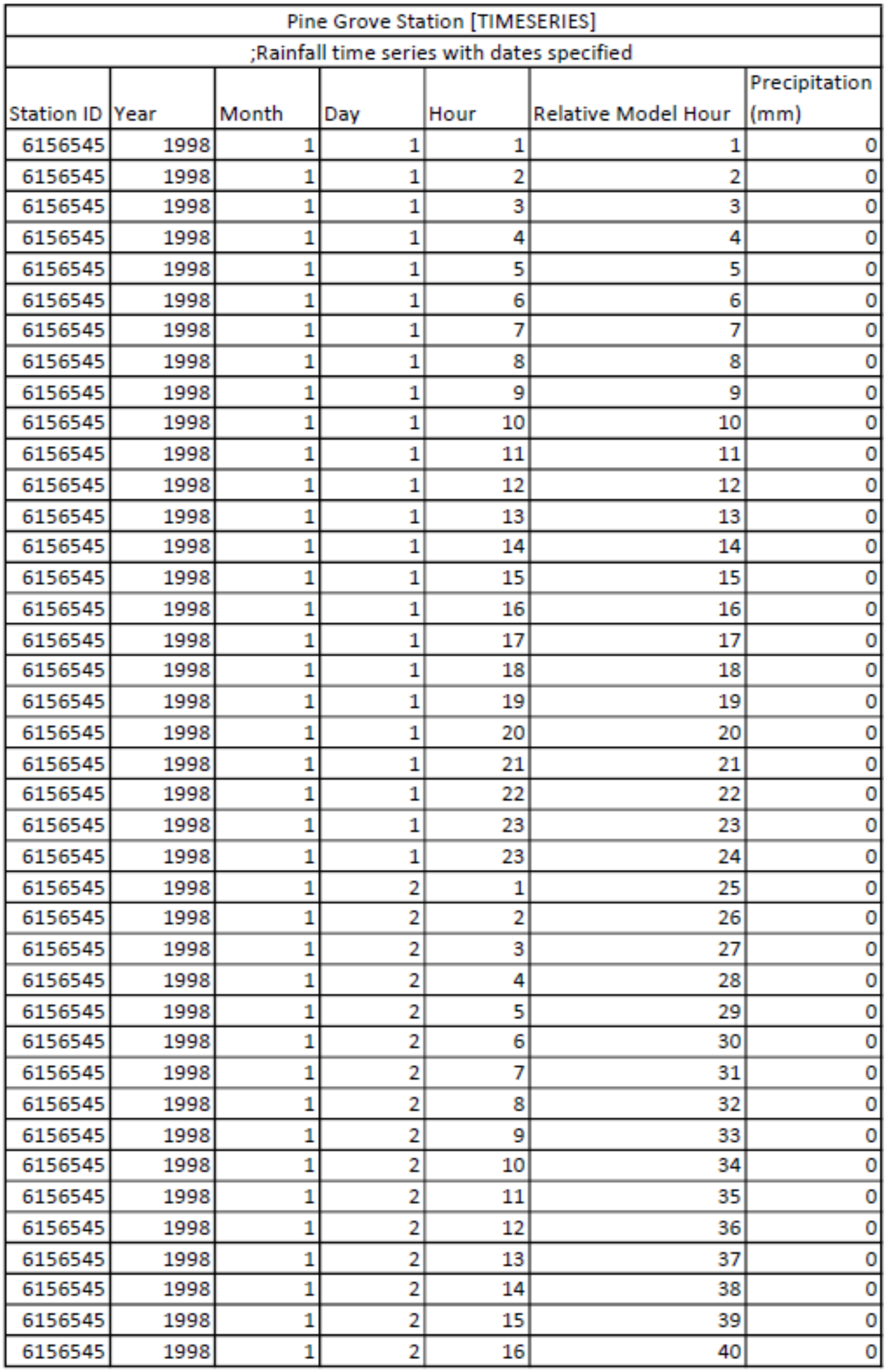
Table G-14: Site soil classification and relevant model parameters. Soil classification from Ontario Soil Survey Complex. [64] Infiltration rates from Minnesota Stormwater Manual. [46]

Site Soil Classification - Hydrologic Modelling		
Classification:	Burford Loam	from Ontario Soil Survey Complex Data
Description:	Gravelly loam	from Ontario Soil Survey Complex Data
Hydrologic Soil Group:	A	from Ontario soils chart for Waterloo County
Max Infiltration Rate (mm/hr):	25	from Minnesota Stormwater Manual
Min. Infiltration Rate (mm/hr)	7	from: https://www.water-research.net/Waterlibrary/runoffeq/soilinfiltrationepa.pdf

Table G-15: Average wind speed calculations from Guelph, Ontario climate data. [65]

Guelph Average Monthly Wind Speeds	
Month	**Speed (km/hr)**
January	17
February	16
March	16
April	16
May	14
June	12
July	11
August	10
September	11
October	13
November	15
December	16

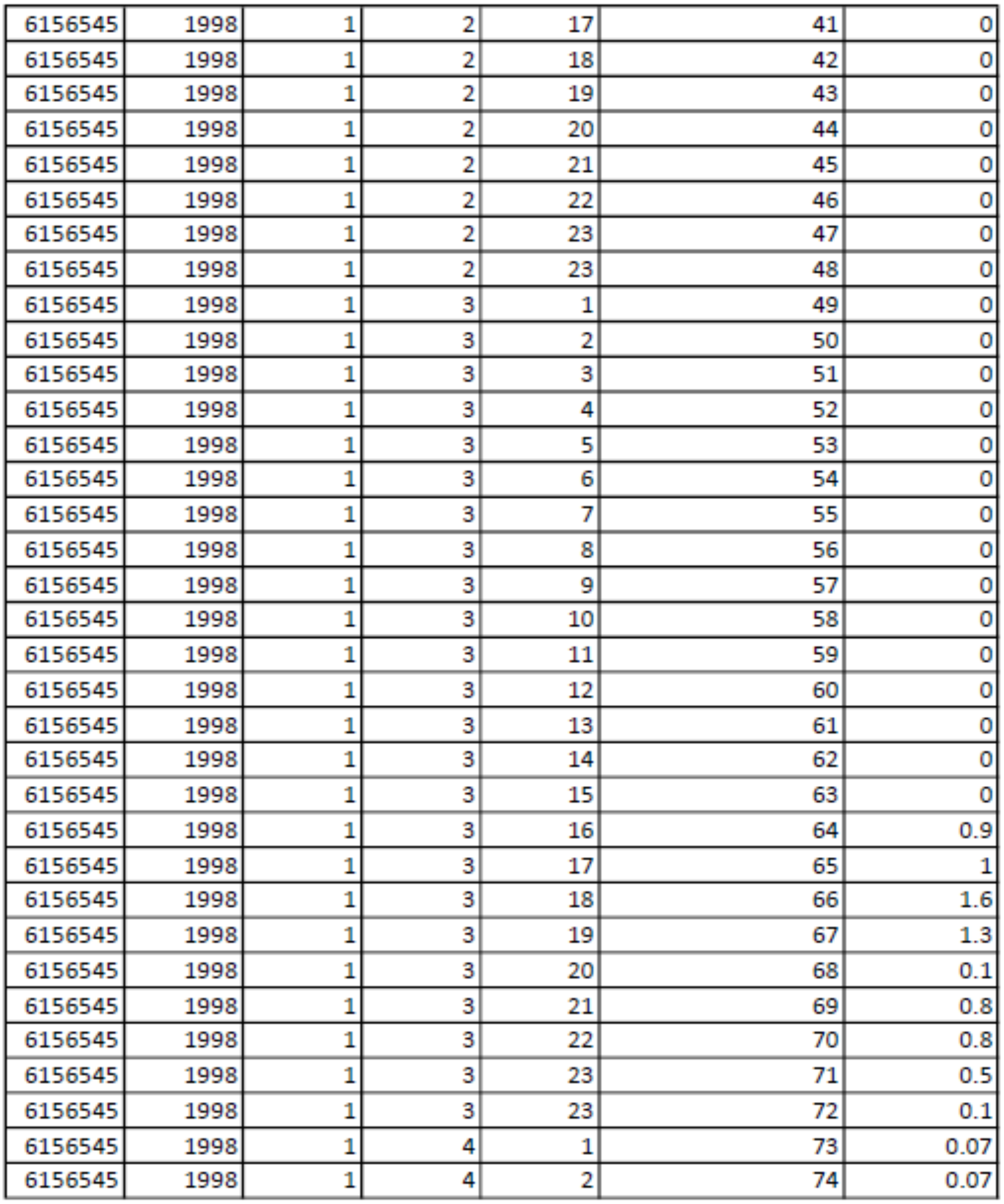
Table G-16: Excerpt from the table of hourly precipitation data used in PCSWMM model. [66]



Pine Grove Station [TIMESERIES]

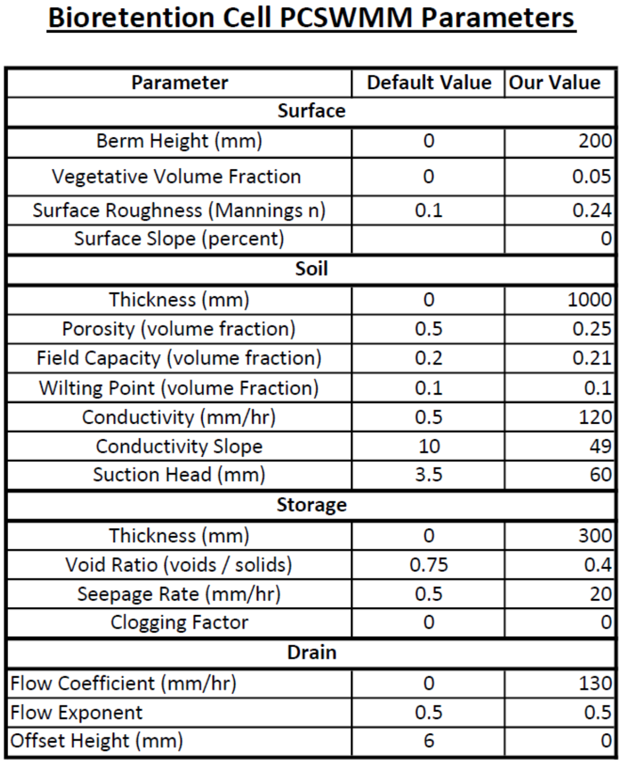
;Rainfall time series with dates specified

Station ID	Year	Month	Day	Hour	Relative Model Hour	Precipitation (mm)
6156545	1998	1	1	1	1	0
6156545	1998	1	1	2	2	0
6156545	1998	1	1	3	3	0
6156545	1998	1	1	4	4	0
6156545	1998	1	1	5	5	0
6156545	1998	1	1	6	6	0
6156545	1998	1	1	7	7	0
6156545	1998	1	1	8	8	0
6156545	1998	1	1	9	9	0
6156545	1998	1	1	10	10	0
6156545	1998	1	1	11	11	0
6156545	1998	1	1	12	12	0
6156545	1998	1	1	13	13	0
6156545	1998	1	1	14	14	0
6156545	1998	1	1	15	15	0
6156545	1998	1	1	16	16	0
6156545	1998	1	1	17	17	0
6156545	1998	1	1	18	18	0
6156545	1998	1	1	19	19	0
6156545	1998	1	1	20	20	0
6156545	1998	1	1	21	21	0
6156545	1998	1	1	22	22	0
6156545	1998	1	1	23	23	0
6156545	1998	1	1	23	24	0
6156545	1998	1	2	1	25	0
6156545	1998	1	2	2	26	0
6156545	1998	1	2	3	27	0
6156545	1998	1	2	4	28	0
6156545	1998	1	2	5	29	0
6156545	1998	1	2	6	30	0
6156545	1998	1	2	7	31	0
6156545	1998	1	2	8	32	0
6156545	1998	1	2	9	33	0
6156545	1998	1	2	10	34	0
6156545	1998	1	2	11	35	0
6156545	1998	1	2	12	36	0
6156545	1998	1	2	13	37	0
6156545	1998	1	2	14	38	0
6156545	1998	1	2	15	39	0
6156545	1998	1	2	16	40	0



6156545	1998	1	2	17	41	0
6156545	1998	1	2	18	42	0
6156545	1998	1	2	19	43	0
6156545	1998	1	2	20	44	0
6156545	1998	1	2	21	45	0
6156545	1998	1	2	22	46	0
6156545	1998	1	2	23	47	0
6156545	1998	1	2	23	48	0
6156545	1998	1	3	1	49	0
6156545	1998	1	3	2	50	0
6156545	1998	1	3	3	51	0
6156545	1998	1	3	4	52	0
6156545	1998	1	3	5	53	0
6156545	1998	1	3	6	54	0
6156545	1998	1	3	7	55	0
6156545	1998	1	3	8	56	0
6156545	1998	1	3	9	57	0
6156545	1998	1	3	10	58	0
6156545	1998	1	3	11	59	0
6156545	1998	1	3	12	60	0
6156545	1998	1	3	13	61	0
6156545	1998	1	3	14	62	0
6156545	1998	1	3	15	63	0
6156545	1998	1	3	16	64	0.9
6156545	1998	1	3	17	65	1
6156545	1998	1	3	18	66	1.6
6156545	1998	1	3	19	67	1.3
6156545	1998	1	3	20	68	0.1
6156545	1998	1	3	21	69	0.8
6156545	1998	1	3	22	70	0.8
6156545	1998	1	3	23	71	0.5
6156545	1998	1	3	23	72	0.1
6156545	1998	1	4	1	73	0.07
6156545	1998	1	4	2	74	0.07

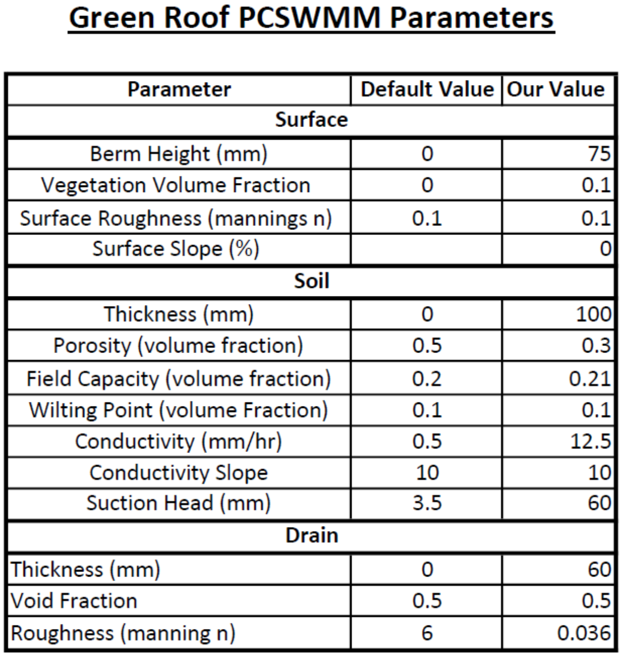
Table G-17: PCSWMM parameter assignments for the bioretention cell.



Bioretention Cell PCSWMM Parameters

Parameter	Default Value	Our Value
Surface		
Berm Height (mm)	0	200
Vegetative Volume Fraction	0	0.05
Surface Roughness (Mannings n)	0.1	0.24
Surface Slope (percent)		0
Soil		
Thickness (mm)	0	1000
Porosity (volume fraction)	0.5	0.25
Field Capacity (volume fraction)	0.2	0.21
Wilting Point (volume Fraction)	0.1	0.1
Conductivity (mm/hr)	0.5	120
Conductivity Slope	10	49
Suction Head (mm)	3.5	60
Storage		
Thickness (mm)	0	300
Void Ratio (voids / solids)	0.75	0.4
Seepage Rate (mm/hr)	0.5	20
Clogging Factor	0	0
Drain		
Flow Coefficient (mm/hr)	0	130
Flow Exponent	0.5	0.5
Offset Height (mm)	6	0

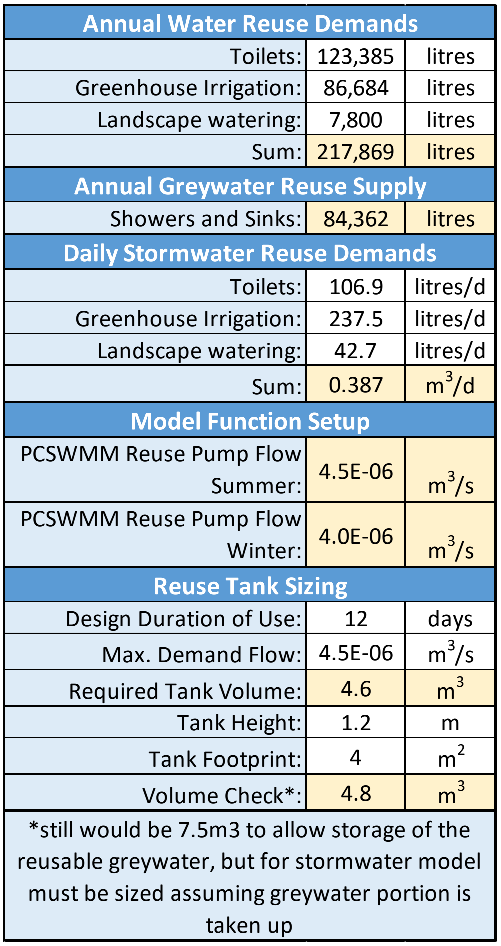
Table G-18: PCSWMM parameter assignments for the green roof.



Green Roof PCSWMM Parameters

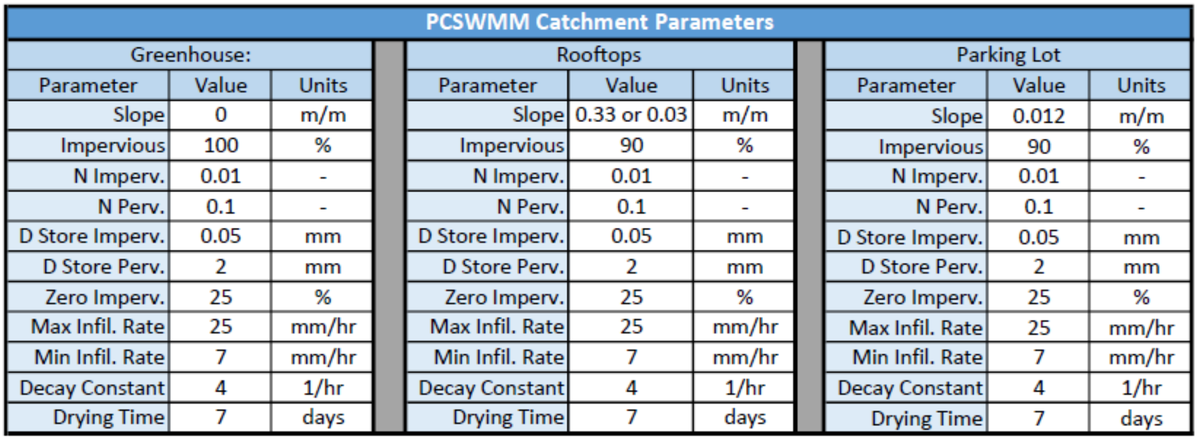
Parameter	Default Value	Our Value
Surface		
Berm Height (mm)	0	75
Vegetation Volume Fraction	0	0.1
Surface Roughness (mannings n)	0.1	0.1
Surface Slope (%)		0
Soil		
Thickness (mm)	0	100
Porosity (volume fraction)	0.5	0.3
Field Capacity (volume fraction)	0.2	0.21
Wilting Point (volume Fraction)	0.1	0.1
Conductivity (mm/hr)	0.5	12.5
Conductivity Slope	10	10
Suction Head (mm)	3.5	60
Drain		
Thickness (mm)	0	60
Void Fraction	0.5	0.5
Roughness (manning n)	6	0.036

Table G-20: Calculation process for water reuse system storage tank sizing.



Annual Water Reuse Demands		
Toilets:	123,385	litres
Greenhouse Irrigation:	86,684	litres
Landscape watering:	7,800	litres
Sum:	217,869	litres
Annual Greywater Reuse Supply		
Showers and Sinks:	84,362	litres
Daily Stormwater Reuse Demands		
Toilets:	106.9	litres/d
Greenhouse Irrigation:	237.5	litres/d
Landscape watering:	42.7	litres/d
Sum:	0.387	m^3/d
Model Function Setup		
PCSWMM Reuse Pump Flow Summer:	4.5E-06	m^3/s
PCSWMM Reuse Pump Flow Winter:	4.0E-06	m^3/s
Reuse Tank Sizing		
Design Duration of Use:	12	days
Max. Demand Flow:	4.5E-06	m^3/s
Required Tank Volume:	4.6	m^3
Tank Height:	1.2	m
Tank Footprint:	4	m^2
Volume Check*:	4.8	m^3
*still would be 7.5m3 to allow storage of the reusable greywater, but for stormwater model must be sized assuming greywater portion is taken up		

Table G-19: Summary of catchment parameters adopted in the PCSWMM model.



PCSWMM Catchment Parameters

Greenhouse:			Rooftops			Parking Lot		
Parameter	Value	Units	Parameter	Value	Units	Parameter	Value	Units
Slope	0	m/m	Slope	0.33 or 0.03	m/m	Slope	0.012	m/m
Impervious	100	%	Impervious	90	%	Impervious	90	%
N Imperv.	0.01	-	N Imperv.	0.01	-	N Imperv.	0.01	-
N Perv.	0.1	-	N Perv.	0.1	-	N Perv.	0.1	-
D Store Imperv.	0.05	mm	D Store Imperv.	0.05	mm	D Store Imperv.	0.05	mm
D Store Perv.	2	mm	D Store Perv.	2	mm	D Store Perv.	2	mm
Zero Imperv.	25	%	Zero Imperv.	25	%	Zero Imperv.	25	%
Max Infil. Rate	25	mm/hr	Max Infil. Rate	25	mm/hr	Max Infil. Rate	25	mm/hr
Min Infil. Rate	7	mm/hr	Min Infil. Rate	7	mm/hr	Min Infil. Rate	7	mm/hr
Decay Constant	4	1/hr	Decay Constant	4	1/hr	Decay Constant	4	1/hr
Drying Time	7	days	Drying Time	7	days	Drying Time	7	days

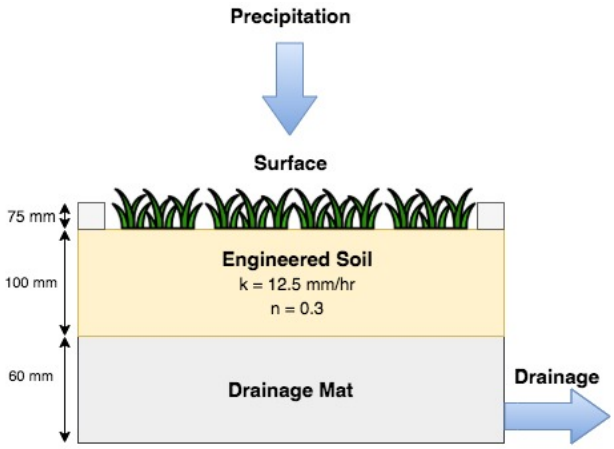


Figure G-4: Green Roof Parameters.

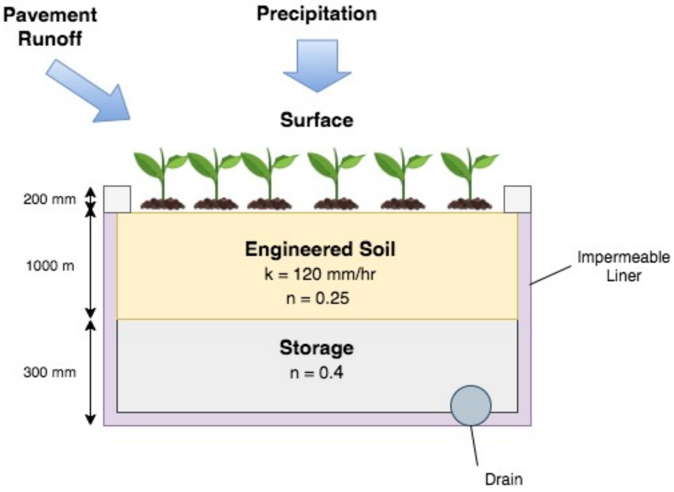


Figure G-5: Bioretention Parameters.

APPENDIX H. FINAL DESIGN MODEL RESULTS

Figure H-6: PCSWMM Model Layout including aerial imagery and DEM overlay where green is lower elevation and red is higher (range 315m to 322m).

Figure H-7: Cropped PCSWMM model layout image showing components around Sustainability Centre.

Objective functions for Depth (m)

From 9/13/2013 12:01:03 PM to 4/18/2020 11:59:57 AM (2409 days)

	Tank
Maximum Depth (m)	1.2
Minimum Depth (m)	0
Mean Depth (m)	0.9014
Duration of Exceedances (h)	52560
Duration of Deficits (h)	1395
Number of Exceedances	1
Number of Deficits	20

Depth (m) Exceedance: 0

Depth (m) Deficit: 0

Figure H-8: Plot of tank levels during model simulation years 2014 to 2020 for the final design scenario.

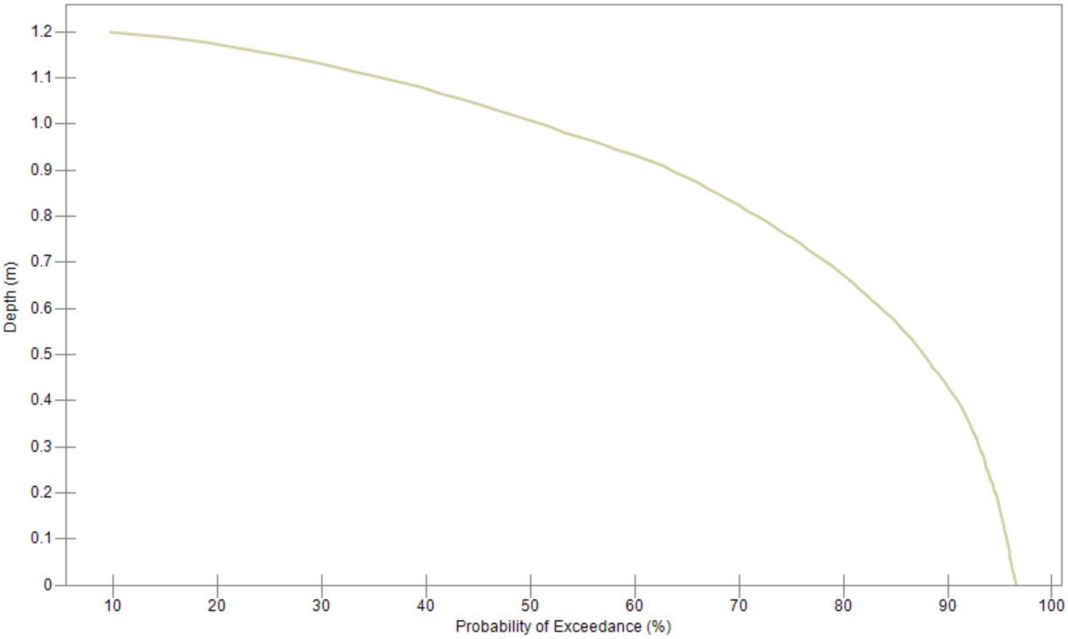


Figure H-9: Probability of exceedance plot for the storage tank water level in the final design scenario.

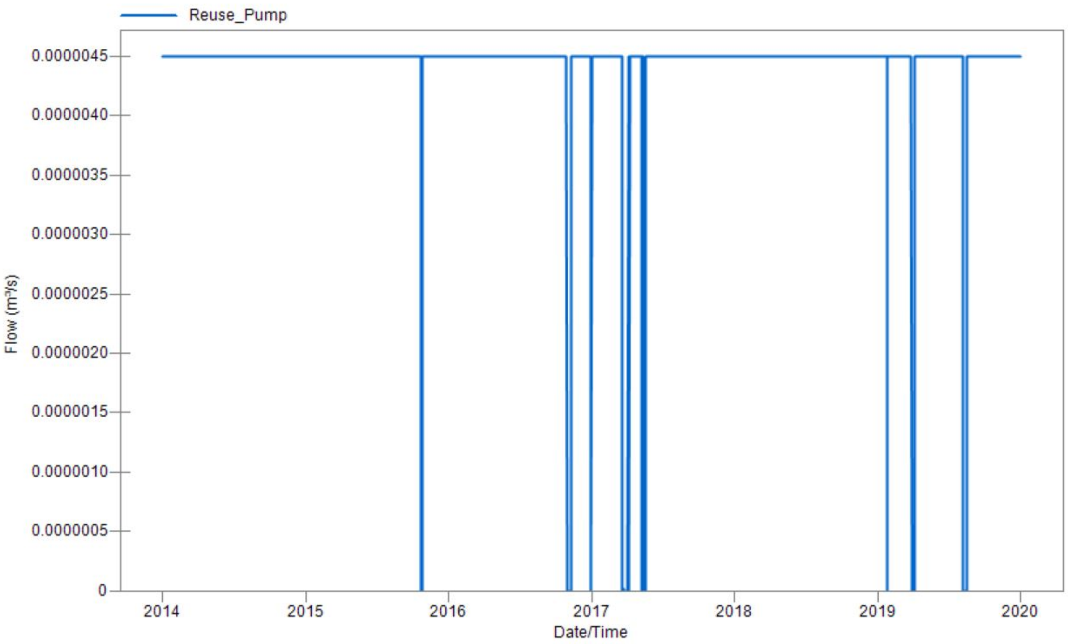


Figure H-11: Pump operation activity in the final design modelling scenario.

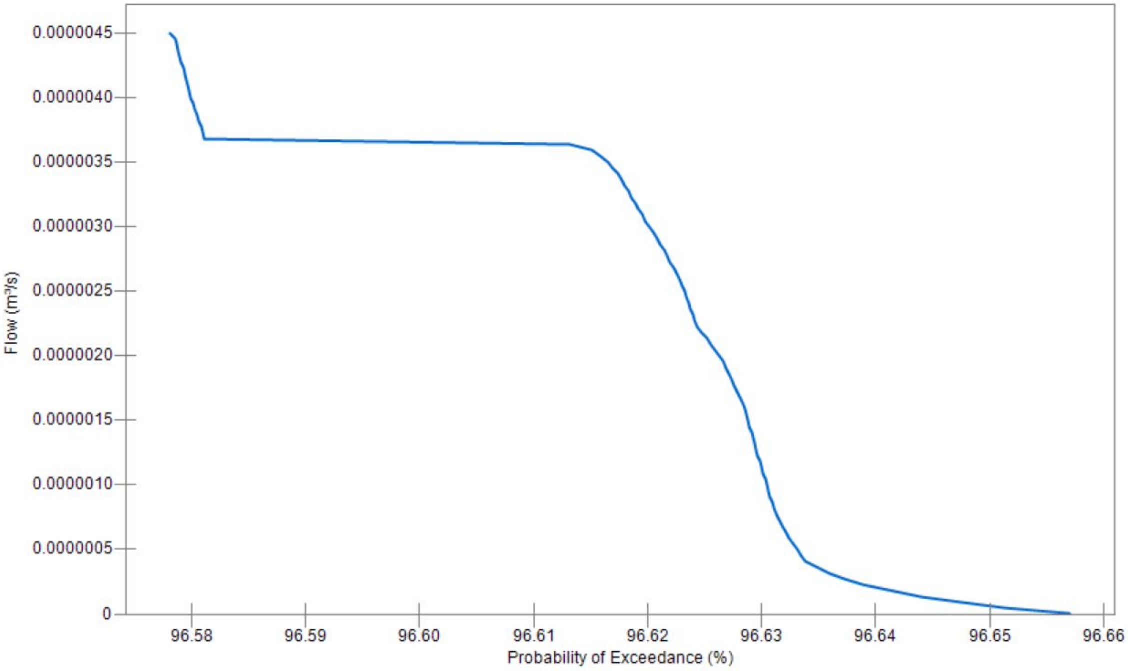


Figure H-10: Probability of exceedance plot for pump operation under the final design modelling scenario.

APPENDIX I. LIFE CYCLE ANALYSIS

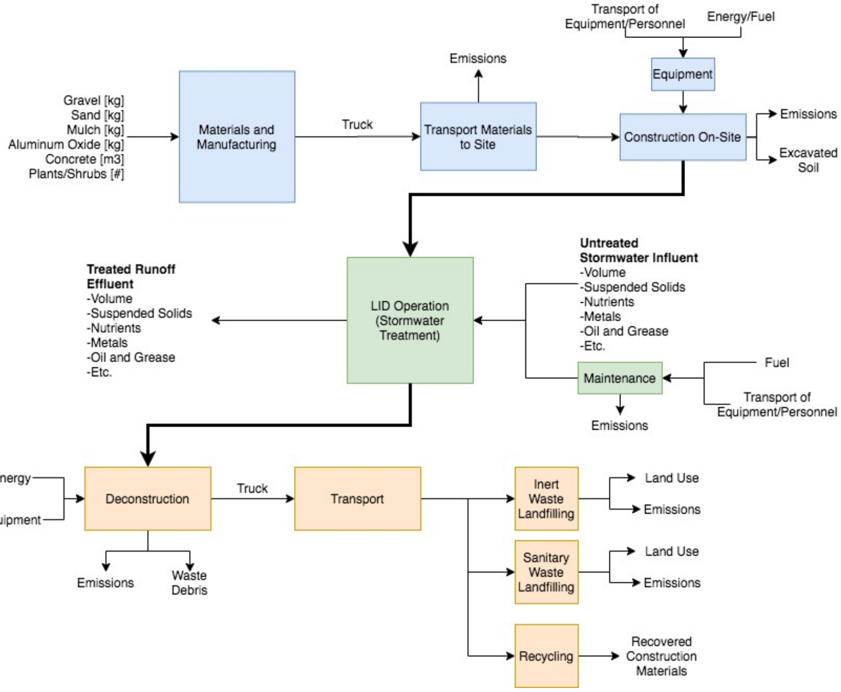


Figure I-13: Process diagram for the life cycle of the bioretention cell.

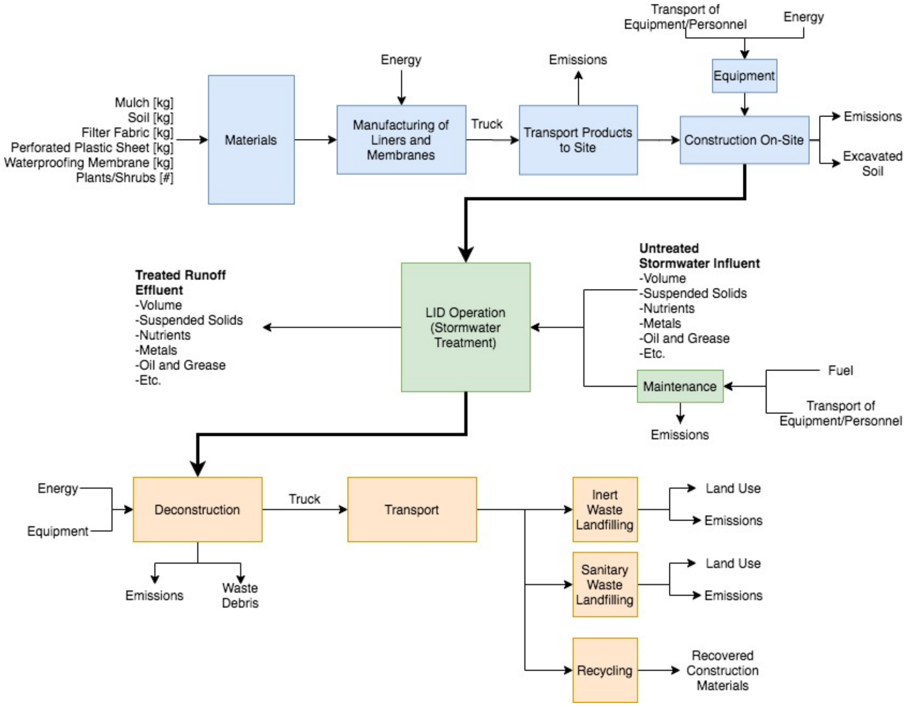


Figure I-12: Process diagram for the life cycle of the green roof.

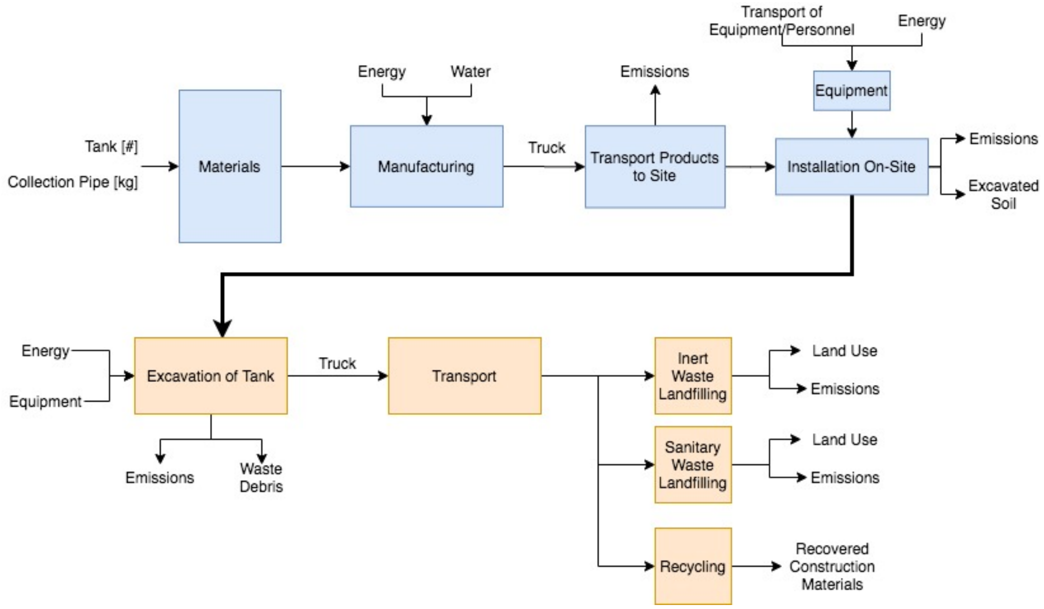


Figure I-15: Process diagram for the life cycle of the water reuse storage tank.

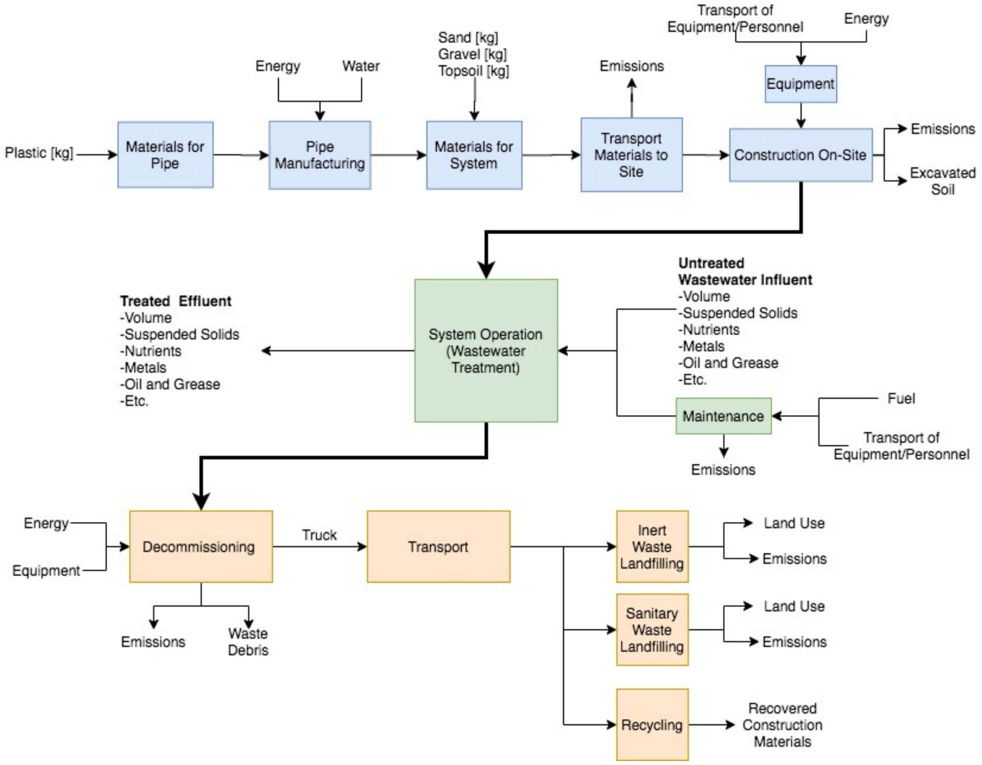
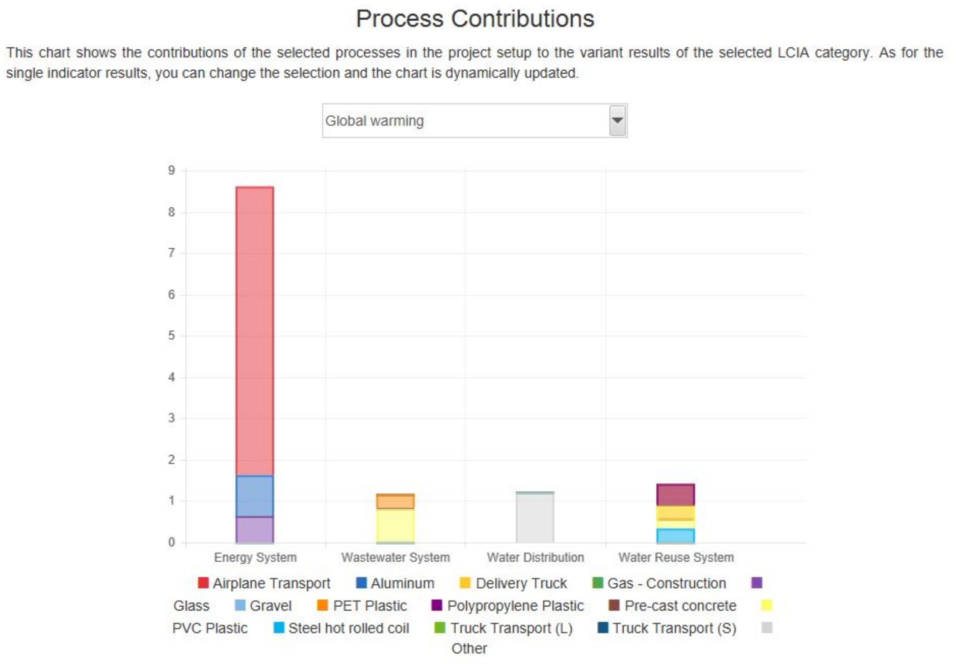


Figure I-14: Process diagram for the life cycle of the leaching bed.

Table I-21: Summaries of materials and quantities for each feature of the 'One Water' system design.

Stormwater Collection System		Wastewater Treatment System	
Bioretention Cell			
Material	*Quantity (kg)*	*Material*	*Quantity (kg)*
Sand	130900	Soil	93600.0
Gravel	59800	stone	36834.1
Clay	22400	polypropylene	1.0
Concrete Curb/drop off parking	5445	HDPE	2.3
Topsoil/Mulch	2289	PVC	0.9
Shrubs/plants	540	PVC	0.4
Green Roof		PVC	1.5
soil media	1902.78	PVC	1.5
Filter Fabric (polyprop)	124.872	PVC	150.1
Storage/Drainage Mat (polypropylene)	275.484	Polyethylene	85.0
impermeable liner (polyurethane or PVC)	330	polypropylene	1.1
Plants/shrubs	198		
Stormwater Capture			
Water Reuse Tank (stainless steel)	1750.176		
Piping to tank (PVC)	859		

Renewable Energy System		Water Distribution Pump System	
Solar Panels		Shallow Well Pump	
Material	*Quantity [kg]*	*Material*	*Quantity [kg]*
Monocrystalline silicon wafer	19.1	510006 Plastic Impeller	0.05
Glass	120.6	Stainless Steel housing, Steel pump head and shaft	10.8
Anodized aluminium alloy frame	47.5	Stainless Steel	2.2
Battery		Steel pump head and shaft	8.7
Lithium ion	72.2	Submerssible Effluent Pump	
aluminum	41	Cast iron	9.2
		Stainless Steel	3.9
		Cast Iron Sump Pump	
		Stainless Steel impeller	0.05
		Cast iron	7.8



Process Contributions

This chart shows the contributions of the selected processes in the project setup to the variant results of the selected LCIA category. As for the single indicator results, you can change the selection and the chart is dynamically updated.

Global warming

Figure I-16: Sample data output from OpenLCA's TRACI 2.1 environmental impact analysis to produce each system component on per kg of material basis.