Water Conservation Project at Trinity College

A Rainwater Harvesting Proposal for the Rooftop Garden at North Munk

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Introduction

The United Nations identifies water security as a significant problem for the global community. To address this concern and curb excessive tap water usage, rainwater collection systems have been implemented across the world. Mitigating excessive water use is an important sustainability goal which rainwater harvesting offers an attainable solution for. At the University of Toronto, Trinity College has committed to developing green projects to reach their sustainability goals. Our client, Dr. Jonathan Steels, approached the class of ENV461 for research on the implementation of a rainwater harvesting (RWH) system for the North Munk building at Trinity College. Dr. Steels had three main objectives: 1) make a more sustainable system which reduces the use of tap water, 2) advance the existing green space for student well-being and, 3) increase food yield from the existing rooftop garden. With these goals in mind, we set out to design a closed-loop rainwater capture, storage, and irrigation system. This proposal will include details on the size and storage of the tank, treatment of the rainwater, methods to pump water onto the rooftop, an automated irrigation system, and a preliminary budget.

Methodology

The project sought review of existing literature, interviews with key informants, and logistical information including weather patterns and building dimensions. The literature review was conducted using a combination of academic sources and grey literature. Current methods of RWH design and implementation were analyzed. This included general information such as system components, as well as more specific information on potential water contaminants. We also identified weather and seasonal patterns in Toronto which provided data on precipitation patterns to calculate for rainwater required. Four interviews with curators of existing green rooftop gardens were conducted to discover firsthand the real-life implications of building RWH systems and to localize findings from the literature review. This included information on system designs and any challenges that they may have encountered (e.g. contaminations and maintenance). Additionally, we interviewed a student volunteer at the North Munk building to determine the existing routine, infrastructure and the types of plants used on the North Munk roof. Lastly, we acquired the building's properties from a student involved with the initial North Munk project and site visits. This was used to examine potential locations for the storage tank and to determine the amount of rainwater that could be collected, given the pitch of the roof.

Client's Requests

Our client had the following requests for the RWH system: (1) reduce tap water usage while providing for a garden with 100 biotops (specialized gardening units) during their growing season from May to October, (2) plants should be watered every 5 to 6 days and, (3) the rainwater storage tank must be buried alongside the building instead of the roof to maintain aesthetics and to keep it under the roof weight capacity.

Benefits of Implementing a RWH System

The rooftop garden requires a total of 36,000L of water for the entire growing season (see Appendix A). RWH is expected to save $0.0046/L or $165.60 per season, assuming 36,000L is collected each season (see Appendix B). Although providing modest savings, the system will have immeasurable benefits for environmental sustainability, food security, and social well-being. For environmental benefits, implementing a RWH system with 100 biotops can sequester up to 40 kg of carbon dioxide and can also absorb up to 60% ambient heat on the rooftop in the summer ("Scientific results", 2018). According to Khan (2014), RWH systems result in reduced pressures for the demand of tap water and consequently, less pressure on our groundwater resources. The slightly acidic pH of rainwater is also considered better for plant growth when compared to Toronto's more basic tap water. (311 Toronto, 2018; Environment and Climate Change Canada, 2013). The added water supply from the RWH system will support the expansion of the North Munk rooftop garden. Expanding the rooftop garden will increase food yield for students and faculty while reducing our carbon footprint from local harvesting. Finally, green space improves students' well-being by reducing anxiety and stress and promoting community involvement by collectively maintaining of the garden (Barton et al, 2017). This makes them essential for a school environment.

Building and Garden Properties

The building properties and materials were assessed to ascertain the best system to implement for the North Munk building and possible complications to be addressed. The green-roof is located at the North Munk building of Graham library. The green-roof garden is 30 x 16 ft **[Fig. 1]** and aims to sustain all 100 biotop culture units. The biotops are cultural units used for growing organic fruits and vegetables; the system allows multiple horticultural plants to be grown on the roof terrace of the building. The base of the biotop units are fed by a common water supply that gradually releases water to the plants; this will be connected to the RWH system. After assessment of the green-roof dimensions and weight capacity, it was concluded that the roof would not be able to withstand a water tank big enough to sustain all the biotop units that aim to be installed. Furthermore, due to the small dimensions of the roof, placement of the tank on the roof would take up too much room, leaving little space for the biotops themselves. Based on this structural assessment, it was decided to place the system on the ground, adjacent to the building.

It was determined that the best placement for the harvesting cistern would be adjacent to the North Munk building in the Quidditch Pitch, a small field north of the building **[Fig. 1].** The tank can be buried right next to the green-roof to minimize the travel distance from the tank up to the roof. It is important to note during excavation the existence of a steam pipe that runs through the field.

The biotops sustain multiple vegetable types, such as tomatoes and beans. The optimal water pH for irrigation of crops is between 5-7 (Soil pH, n.d.). The average pH of Toronto's tap water is 7.7, and the average pH of rainwater in Ontario varies between 4.5-7.5 dependent on the level of acid rain (311 Toronto, 2018, Environment and Climate Change Canada, 2013). The pH of rainwater is therefore more conducive to plant growth when compared to Toronto's tap water.

Several potential contaminants from existing building materials were also addressed. The material of the roof itself, which will serve as the catchment area for rainfall, is made of asbestos cement sheet shingles. Asbestos is marked as a respiratory irritant and carcinogenic and is commonly theorized to increase risk of gastrointestinal cancers. However, both the risk of gastrointestinal cancers and contamination of irrigation waters has been eliminated following extensive research of the material. The material is non-friable, meaning the asbestos fibers are bound within the matrix of the product and not easily released (Asbestos Awareness at the University of Toronto, 2016). Due to the silicate fibers, their release can be harmful when inhaled, but due to the type used at the University of Toronto, this possibility is minimal. Multiple research studies have been conducted on the possibility of asbestos contaminated water and gastrointestinal penetration, all of which concluded there was no correlated risk (Morris, 1995; Lemen et. al, 1986; Edelman, 1988; Gamble, 2008). Mesothelioma, cancer of the lungs, is a persistent concern, however, risk due to ingestion was nominal across the board (Gamble, 2008). The rainwater that contacts the North Munk roof, therefore, will not contaminate the collected water.

We reviewed sources to assess the potential risks of leaching from the copper gutter. Copper levels present in water beyond a manageable amount can present adverse health effects (Community Public Water Supply, 2005) and according to Sheldon et al (2005), copper can have detrimental effects on plant growth including root damage and discolouration. Furthermore, water levels with lower pH values increase the rate of copper leaching into water (Hong & McCauley, 1998). Due to the risk of acid rain in Toronto, with pH values that range from 4.5-5.5 (Environment and Climate Change Canada, 2013), rainwater collected may expedite copper leaching from the gutter system. Mitigations and preventions of this harm will be evaluated in the delivery system.

Lastly, the roof is also exposed to natural debris, such as bird and squirrel droppings, dirt, and foliage. These contaminants do not present risks to the integrity of the harvested rainwater and will be properly filtered out by the system.

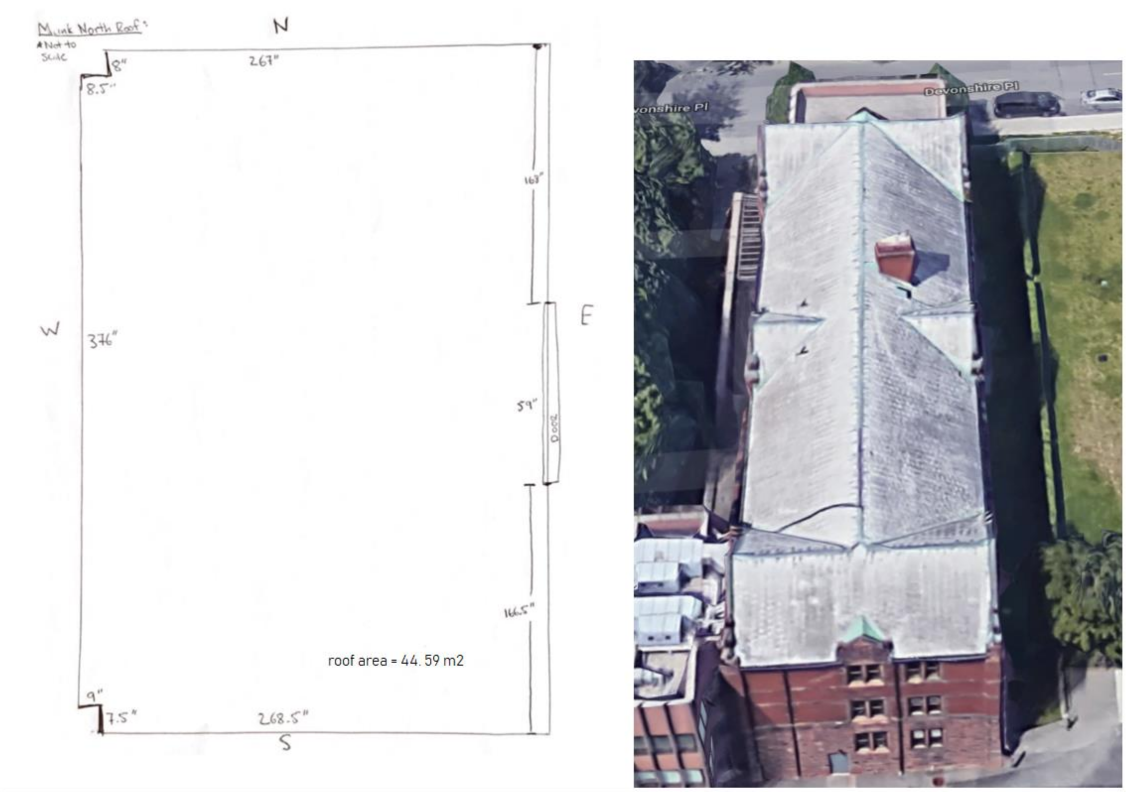

Figure 1. Dimensions of the North Munk Garden, and aerial view of the North Munk Building. The Quidditch pitch, site of burial, is to the right of the building.

Weather/Precipitation Patterns

Data on the total monthly precipitation from 2007-2018 was retrieved from Environment and Climate Change Canada at the Pearson International Airport weather station (“Total Precipitation”, 2018) [**Fig. 2**] [**Fig. 3**]. The overall monthly precipitation average was approximately 67.8 mm while the annual average was at 808 mm. We included the year 2007 in the dataset due to its abnormally dry period between January 1st to October 31st with only 413.2 mm of precipitation recorded (“Toronto’s Future Weather”, 2012). This information is important in helping us determine our tank size and water quantity.

*	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Month Avg.
Jan	38.6	58.2	44.4	24.4	42	54.2	66.4	26.6	31.8	38.4	69.8	61.8	46.4
Feb	24.6	107.6	73.6	24.8	47	26.6	92	54.4	34.1	46.9	57.8	65.4	54.6
Mar	33.4	61.6	68.8	62.6	91.4	18	21.6	27	14.5	80	76	32.6	49.0
Apr	60.8	54.6	133.6	36.2	96.6	43.6	110.4	91.6	78.8	59.8	110.8	150.6	85.6
May	73.6	68.8	60.8	51	142	44.4	76.2	56.2	62.8	34.2	142.6	65.4	73.2
Jun	43.2	110.4	70.2	191.6	59	76.4	100.6	97	160.2	26.4	97.2	50	90.2
Jul	47.4	193.2	84.8	89.6	32.4	100	181.8	86	24.4	39.8	37.6	64	81.8
Aug	20.8	92.6	144	58.6	72.2	52.4	69.2	38.8	76.8	66.8	74.8	118.2	73.8
Sep	28.6	83.4	40.2	88.2	85	121	69	102.8	62	66.4	29.8	50	68.9
Oct	41.2	39.6	71	57.2	119.2	126.4	82.8	55.6	67.6	40.6	57.8	69.8	69.1
Nov	87.4	79.8	32.2	66.2	98	10.2	34.6	43.2	33.4	55.2	59.8	104.4	58.7

Dec	92.7	99.8	80.4	36.8	52	58.4	65.8	34.2	45.6	77.4	40.4	N/A	62.1
Year Sum	592.3	1049.6	904	787.2	936.8	731.6	970.4	713.4	692	631.9	854.4	832.2	N/A

* = (in millimeters)

Figure 2. The table shows the monthly average precipitation from January to December between 2007 to 2018 and the total annual precipitation for each of the years.

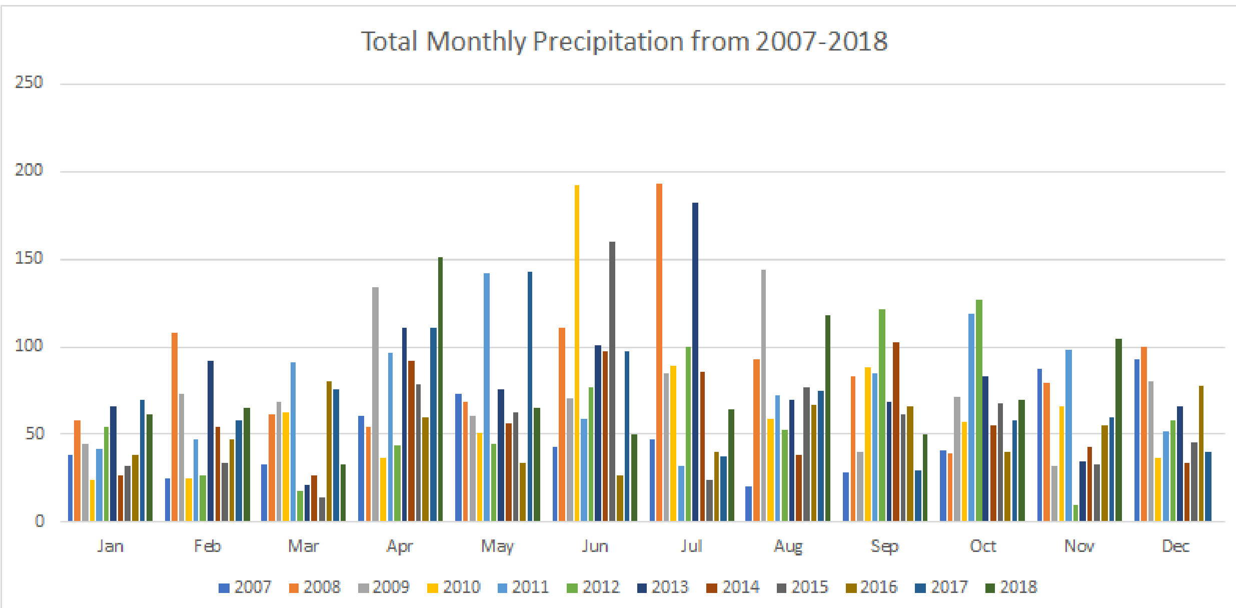

Figure 3. The bar graph shows a visual representation of the monthly average precipitation from January to December between 2007 to 2018.

Impact of Climate Change on Toronto Precipitation Patterns

According to the Climate Atlas Report created by Environment and Climate Change Canada, annual precipitation is expected to increase in the upcoming decades for representative concentration pathways RCP4.5 and RCP8.5 shown below (“Climate Atlas”, 2018). These are different greenhouse gas concentration trajectories adopted by the Intergovernmental Panel for Climate Change with RCP4.5 being the low carbon scenario and RCP8.5 the high carbon scenario (“RCPs”, 2018). Historically, mean annual precipitation was recorded at 786/786 mm (“Climate Atlas”, 2018).

Between 2021-2050, this is expected to rise to 824/817 mm and then to 854/854 mm between 2051-2080 ("Climate Atlas", 2018) [**Fig. 4**] [**Fig. 5**].

A study conducted by the Toronto Environment Office supports this prediction based on their modelled results for 2040-2049 ("Toronto's Future Weather", 2012). Researchers hypothesize Toronto should expect to see less snow and more rain, milder winters, longer growing seasons, and heavier rainfall ("Toronto's Future Weather", 2012). As the average annual temperature is expected to increase by 4.2-4.4°C, both average summer and winter temperatures increase (3.8°C and 5.7°C respectively) ("Toronto's Future Weather", 2012). This will result in a shorter winter with 26 fewer snow days per year, giving more time for the growing season ("Toronto's Future Weather", 2012). The number of days with temperatures exceeding 24°C will also increase six-fold ("Toronto's Future Weather", 2012).

Annual precipitation will likely increase anywhere between 0.5-14%, especially in the months of July (80%) and August (50%) ("Toronto's Future Weather", 2012). However, the number of days with rainfall exceeding 25 mm is will decrease ("Toronto's Future Weather", 2012). This means that there will be fewer but higher magnitude rainstorms of up to three-fold intensity ("Toronto's Future Weather", 2012). Lastly, the mean number of dry days are projected to increase while the mean number of dry spells (extended periods of dry days) are projected to decrease for southern Ontario (Sushama, 2010). This suggests more frequent rainfall although the intensity may only reach 0.5mm/day (Sushama, 2010).

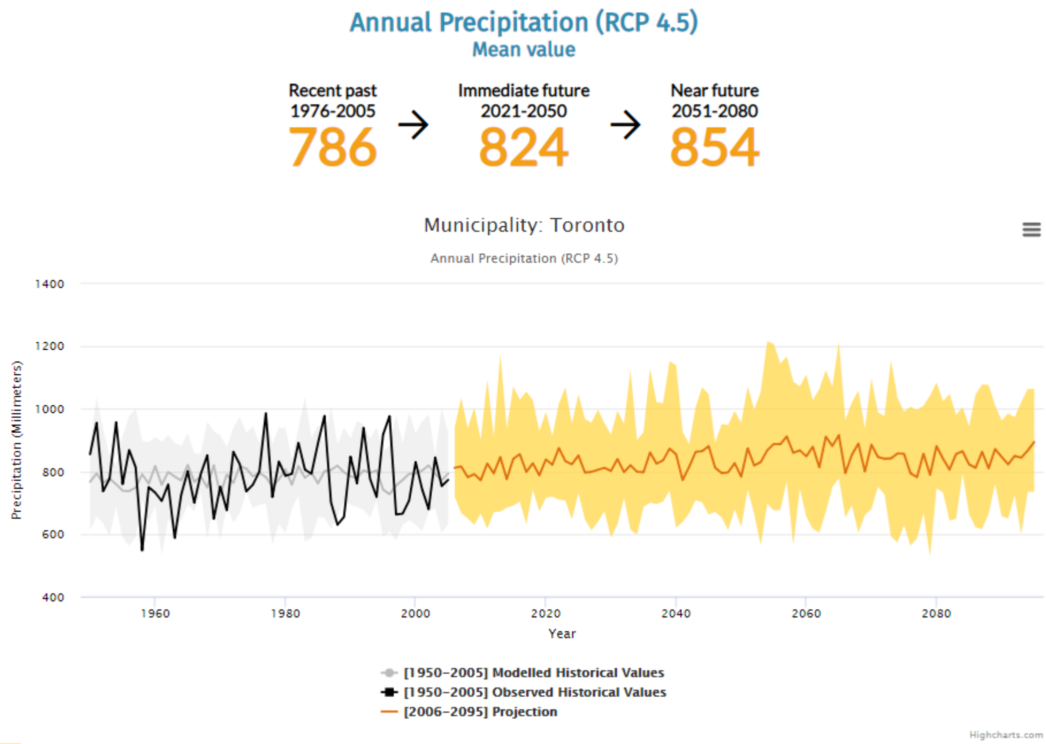

Figure 4. The graph shows the historical values and expected projections of annual precipitation for Toronto under RCP4.5.

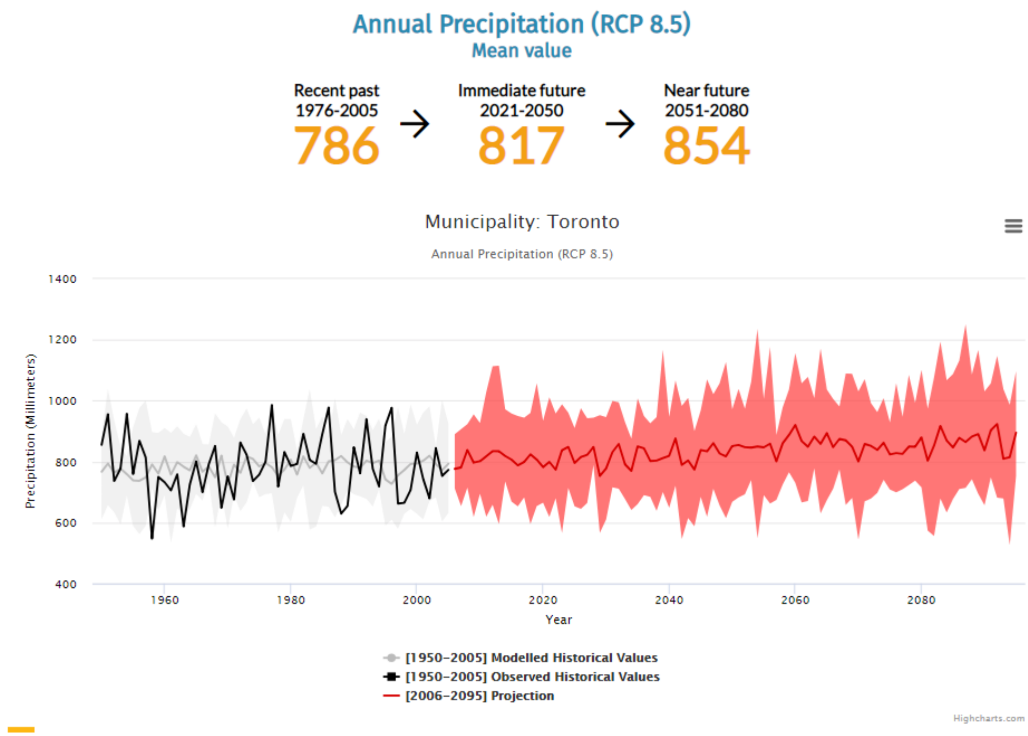

Figure 5. The graph shows the historical values and expected projections of annual precipitation for Toronto under RCP8.5.

Rainwater Harvesting Techniques

Literature review and interviews were conducted to inform our recommendations. Data collected from each method will be outlined individually in the following sections.

Interview Data

The first interview with Hila, a volunteer at the North Munk rooftop garden, provided us with information about the running of this rooftop garden. She gave us a list of the 20+ types of vegetables currently grown in the biotops. Hila could not quantify the amount of water used at the garden since they have been watering with buckets. Also, they were unsure how much water each plant received as they were all collectively fed in the biotops. Hila suggested that we have more rainwater available than needed, and to store the tank downstairs and pump water up to avoid excess weight on the roof.

Matt, the manager at Skygarden, provided specific data of their water usage. Pumps were required to feed the plants sufficient water. The main garden was fed from a building water line that used a timer to schedule irrigation periods. During the height of the season, water came on for about 8 minutes, 4 times a day. The system included a Dosatron unit that mixed with liquid fertilizer to produce diluted nutrients with every watering. This prevented peaks in fertilizer that came from weekly fertilizing. In the winter, all the electronics of the irrigation system were disconnected and stored in an office. The biotops were all interconnected via PVC lines at the bottom that stay on the roof year-round. Finally, following building regulations to protect the roof membrane, building managers wanted paving stones where people would be walking on the roof.

The GRIT lab on top of the Daniels Faculty of Architecture is an extensive green roof with a sophisticated RWH system. We spoke with Liat Margolis, the manager of the green roof, where rainwater as well as storm water runoff was captured. With a $300m^3$ cistern in the basement, the green roof acts as a storm water retention site. For research purposes, there were three irrigation pipes that ran from the cistern through the pump to the roof; one with cistern water only, one with domestic water only, and one with a mix of the two. They were currently monitoring the effects of water type on plant growth. Since they also collected storm water runoff, they dealt with contaminants like salt, pollutants from cars, debris and zinc from the roof. Liat stressed that water should be near potable quality, which can be achieved with a physical filter and a strong UV filter. Also, a storm water report should be done by a professional engineering company to calculate the size of the cistern and to determine how to contribute to water conservation and storm water retainment in the area. The winterization of the system should be done by a professional and pipes should be drained and blown before the weather drops to 0°C.

Additionally, the irrigation system used was Rainbird and another recommended option was Toro. In the GRIT lab, a rain sensor on the roof was used to stop irrigation during a rain event. The cistern was connected to domestic water to flush out any salts if needed, and to continue watering if the cistern was overdrawn. A sensor can be placed in the cistern to fill up with domestic water when quantities are low. A disadvantage of this would be that if the cistern is filled with domestic water it can no longer capture any rain or storm water. A mechanism detected when the pump was overdrawn, and a controller pumped the water from the cistern or from the domestic line to the roof for irrigation. Liat recommended drip irrigation as it is easy to control and almost no water is lost to evaporation.

At the Robertson building we spoke to the building manager Richard Barlow. They grew subterranean crops and did not harvest rainwater. Instead, they used an irrigation system that consisted of drip irrigation tubing that was connected to a tap on the roof. The system automatically came on at specific intervals throughout the week. Sensors were installed in the ground to indicate the amount of soil moisture which ensured that the irrigation system did not turn on when it rained.

The key findings from the interview are the following; (1) a below ground storage tank is needed to relieve weight from the roof, (2) fertilizer can be maintained with a special device (e.g. Dosatron), (3) timers can be used for an automated irrigation control, (4) the use of drip irrigation is optimal as it minimizes water loss from evaporation, (5) rain sensors are needed to prevent unnecessary watering during rainfall and, (6) it is advised to test the water quality for safety.

Literature Review Data

The literature review served to identify RWH techniques and considerations for developing a system.

A harvesting system consists of the following main components: a catchment area, a delivery system, a filter, a storage tank, treatment, and a distribution system (Despins, Farahbakhsh & Leidl, 2009; Li, Boyle & Reynolds, 2010). Each will now be considered in turn. Sections are organized to first offer a description of component *use* in the overall harvesting system. Then, main *considerations* for each component will be identified. These include key areas that suggest viable solutions for our final recommendations. Lastly, specific *solutions* are weighed against each other for suitability. Essential and supplementary options are then finally listed.

Catchment area

Use: The catchment area is where the rainwater is initially collected (Morrow, Dunstan & Coombes, 2010). Rooftops are often used to collect rainwater because of their large surface areas and convenience of the attached gutter system that can channel water to a desired endpoint (Campisano et al., 2017).

Considerations: The main concern when collecting rainwater from rooftops is that of potential contamination. This can come from external sources such as atmospheric deposition (i.e. dust), animal deposition (e.g. feces), insects, debris, and foliage, or the materials on the catchment surface (Peck & Kuhn, 2003). Roofing materials have been shown to impact water supply, specifically with contamination from materials found on the rooftop (Despins, Farahbakhsh & Leidl, 2009) or dissolved organic carbon (Mendez et al., 2011). These include metals and any organic materials that have been caught in the roofing materials, respectively (Mendez et al., 2011). Textured rooftops increase levels of dissolved organic carbon (Mendez et al., 2011). Morrow and colleagues (2010) compared metal contamination at various levels of rainwater collection which found that rooftop runoff adds relatively low levels of metal contaminants to the water supply.

Solutions: At this stage, physical contaminants can be filtered out by adding a guard on the side of the gutter to prevent materials from entering the water supply. Additionally, the rooftop can be washed on occasion (Sazakli, Alexopoulos & Leotsinidis, 2007), however, this is impractical and unlikely to make a significant difference given treatment options that can be used later in the collection process. Further filtration and treatment can be administered down the collection system.

Recommendations: The gutter net is supplementary because contaminants can be filtered out at a later stage.

Delivery System

Use: The delivery system transports water to the storage tank (Li, Boyle & Reynolds, 2010). Chosen delivery systems depend on the catchment area, but are typically gutters or piping (Li, Boyle & Reynolds, 2010). This is most convenient as gutters and piping are pre-existing and can direct water towards the storage tank.

Considerations: Gutters can contaminate water supply through metal leaching (Morrow, Dunstan & Coombes, 2010). Other contaminants such as those discussed in the catchment area section can also impact water supply through the gutters.

Solutions: Gutters would need to be coated with a different material or replaced entirely to ensure water quality. Gutters can be coated with galvanized metal or powder coating (Ward, Memon & Butler, 2010). Galvanizing a material provides a protective coating to a source object by dipping the material in molten metal (Barry, McGrath, Kanematsu, & Oki, 2003). Similarly, powder coating adds a thick layer of coating around the source object, before curing in an oven (Powder Coating Institute, 2016). For both methods, the gutters would need to be removed temporarily. Alternatively, existing gutters can be replaced by those made from galvanized metals. Galvanized steel, specifically with aluminum alloys and powder coating compositions have shown anti-corrosive properties (Barry, McGrath, Kanematsu, & Oki, 2003; Radhakrishnan, Sonawane & Siju, 2009). This means that either method is expected to create a sufficient barrier to prevent metal leaching. Costs for either coating method cannot be estimated. Contractors need to assess the site before providing an estimated cost.

Recommendations: Both coating methods or replacing the gutters should be equally effective and is essential for RWH. We recommend Trinity choose whichever method is most practical and cost-efficient.

Pre-Storage Treatment

Use: Filters are used to remove physical contaminants caught in the water supply (Campisano et al., 2017). As aforementioned, a small filter can be used to catch most physical contaminants.

Considerations: Some contaminants can still pass through the filter, such as deposition, metals and microorganisms such as bacteria. The first few mL of water has been shown to have the highest concentration of contaminants (Campisano et al., 2017). In a study looking at water quality at different stages of rainwater collection, Mendez et al. (2011) found the overall quality significantly increased when the first few mL was removed from the system.

Solutions: First-flush systems dispose of the initial 1-2 mm spell of rain that contains typically more pollutants from the air and roof (Mosley, 2005). A small container intercepts the water as it is sent to the storage tank that collects contaminants. Mendez et al. (2011) found a first flush system significantly improved water quality, decreasing metal concentrations and bacterial content. PVC piping and T-joins must be installed to flush out the initial bit of rainfall ("Downpipe Rainwater", 2018).

A filtration screen or downspout filter can be installed along the gutter line to catch any physical contaminants that have passed through (Mosley, 2005). These can be made of stainless steel or a synthetic mesh. It is mounted across the top inlet of the storage tank before or within the downspout (Mosley, 2005).

Slow sand or biosand filtration requires an additional chamber made of plastic or concrete to remove particulates, pathogens and turbidity by natural processes of separating elements through layers of sand, gravel and biofilm (Dangol, 2018). The system is cheap and easy to build and is typically used with UV light disinfection. The system may require a few days to develop the biological layers and must be used on a regular basis (Dangol, 2018).

Mechanical pre-filters are the most effective way to prevent debris from entering the tank ("Different Types of Filters", 2018). The system uses a stainless-steel mesh within a plastic body ("Different Types of Filters", 2018). The degree of filtration depends on the fineness of the mesh. Pre-tank filters require more cleaning than other filtration systems and may need more intensive treatments such as boiling to produce potable water (Li, Boyle & Reynolds, 2010). Boiling water kills viruses although that is not a concern for rainwater we collect.

Cartridge filters provide an inexpensive but finer degree of filtration by trapping particulate matter ("Different Types of Filters", 2018). This system uses a cartridge and sealed housing which needs to be periodically changed depending on how much rainwater is processed ("Different Types of Filters", 2018).

Recommendations: The first-flush and cartridge filters are essential for a RWH system to remove high concentrations of contaminants before reaching the storage tank.

Storage Tank

Use: The storage tank holds water until it is ready for use (Li, Boyle & Reynolds, 2010).

Considerations: Storage tanks should consider material, size, and location when installed (Li, Boyle & Reynolds, 2010). The storage tank must be practical in size to maximize usage of rainwater. Materials must be properly considered to minimize contamination and the impact on water quality.

Our client requested the tank be buried underground for aesthetic purposes. Burying the tank maintains water temperature and prevents algae from growing inside (Islam et al., 2013; Li, Boyle & Reynolds, 2010). A downside to underground tanks are that maintenance issues, such as cracks, are more difficult to detect (Li, Boyle & Reynolds, 2010). The *size* of the tank must take into consideration the amount of water required and the amount of space available. The garden requires 36,000L for the entire season but cannot realistically fit a storage tank of that size underground, nor would the system collect enough water at any point to justify a tank that large. An estimated tank size will be provided and explained further on.

Lastly, tank *materials* can impact water quality. Tanks are typically made from plastic, metal, or concrete (Li, Boyle & Reynolds, 2010). Generally, plastic tanks have the least effect on water quality (Despins, Farahbakhsh & Leidl, 2009). One study found plastic tanks have slightly decreased pH levels in the water supply in comparison to concrete, but the differences were not significant (Despins, Farahbakhsh & Leidl, 2009). Conversely, a different study found that concrete tanks had a significant impact on water pH. (Hart & White, 2006). Metal tanks have been found to increase metal content – specifically zinc, in the case of Hart and White (2006) – due to chemical leaching. Furthermore, there are no conclusive studies surrounding burying plastic cisterns and their potential to deteriorate, eliminating concerns of environmental degradation.

Solution: Plastic tanks should be used to minimize impact on water quality. The tank size should hold between 4,000-12,000L and our reasoning is as follows:

Given the estimation of 100 biotop units for the rooftop green space, the monthly water quantity requirement would be approximately 6,000L. This assumes average sized plants are watered every 5 days for 10L on hot summer days which are expected to increase due to climate change (“Technical Data”, 2018). Plants at Trinity are currently watered every 5 days. If that schedule is kept, 6,000L/month would suffice.

The monthly precipitation was calculated with data from Environment and Climate Change Canada ("Total Precipitation", 2018). During the growing season between May and October, it was found that May, September, and October had the lowest average monthly rainfall over 2007-2018 ("Total Precipitation", 2018). September and October both averaged 69mm of precipitation per month ("Total Precipitation", 2018). This estimates that 3,075L can be collected during one of these months. The optimal tank size would then be ~3,000L when 3,075L is subtracted from 6,000L. These calculations, however, do not fully take into consideration all the impacts of climate change found in the literature.

According to Environment Canada, the longest dry spell of recent years lasted ~3 weeks in 2009 between August and September ("Toronto's Future Weather", 2012). The longest period without significant rainfall (more than 12 mm) lasted for ~3 months in the summer of 2007 ("Toronto's Future Weather", 2012). Ultimately, our tank size did not require more than 3 months of water storage from adjusting for potential future dry periods. Later research determined that the dry period of 2007 was between July to October. Climate change trends should improve the amount of precipitation during July and August so only September and October were left as concerns. Therefore, after considering for the effects of climate change, the tank size should account for a minimum of three weeks' worth of rainwater and a maximum of 2 months. Therefore, a tank that can hold between 4,000-12,000L (average: 8,000L) should satisfy the water requirement. If tap water is used in addition to the rainwater storage, the tank size may be reduced to save space and costs.

Recommendations: An 8,000L (or approximately 2,000 gallon) plastic tank is essential for this system. This considers the longest historical dry period as well as the future impacts of climate change by providing extra space. A larger plastic tank can be chosen to account for the longest expected dry period in the next few decades bringing the water storage capacity to 12,000L (approximately 3400 gallons) which is the highest expected amount required. The added capacity is supplementary to our proposed system. It could also be implemented as 2 tanks; one being 8,000L and a second with 4,000L to total 12,000L.

Post-Storage Treatment

Use: Water will need further treatment after its storage to further improve quality for irrigation (Despins, Farahbakhsh & Leidl, 2009).

Considerations: At this stage, rainwater is expected to have concentrations of microorganisms, metal concentrations, organic compounds, and particulate contaminants (Despins, Farahbakhsh & Leidl, 2009).

Solutions: Chlorination is recommended if a) a known bacterial risk has been identified, b) the tank cannot be feasibly emptied for cleaning, or c) animal depositions have entered the tank (Mosley, 2005). A cheaper and effective alternative to this would be to add small quantities of household bleach (which contains chlorine) to the tank (Mosley, 2005).

Membrane filtration catches contaminants using a membrane layer that differs depending on the size of microns needed to be removed (Pushard, 2016). Examples include microfiltration, ultrafiltration, and nanofiltration (Pushard, 2016). Reverse-osmosis disinfection is another example of membrane filtration. Reverse osmosis systems however, tend to be expensive, wasteful of water, and typically follows chlorination to remove by-products of chlorine if it reacted with other naturally occurring organic materials (Pushard, 2016).

Ultraviolet (UV) light is often used in RWH systems and works by sterilizing water when passing over a glass tube exposed to UV light (Pushard, 2016). This system requires the UV bulb to be replaced annually and is only effective with the right light dose and particulate-free water (Pushard, 2016).

Ozone disinfection treats the rainwater through an ozone injection system or by continuously bubbling the ozone into the storage tank ("Ozone Rainwater", 2018). This system was found to be the most powerful disinfectant compared to chlorine and UV light treatments ("Ozone Rainwater", 2018). It prevents the formation of biofilms on tank surfaces and is also able to remove colours and odours. However, like chlorine, the chemical is dangerous to work with as it may produce by-products ("Ozone Rainwater", 2018).

Activated carbon filters or charcoal filters are required when rainwater is used for drinking ("Different Types of Filters", 2018). Taste, odour and discolouration are improved when water passes through carbon ("Different Types of Filters", 2018). This system also removes chlorine and other volatile organic compounds (VOCs) ("Different Types of Filters", 2018). The problem occurs when the system is not used often enough. Bacteria can enter the carbon filter where it can grow and pass through into disinfection (Pushard, 2016). This is in the case where the carbon filter comes before the UV light disinfection system. If the carbon filter were to come after disinfection, bacteria growth would not be an issue, but the system would require an extra installation of a backflow preventer between the two (Pushard, 2016).

Distillation purifies water through heating and then collection of the condensation (Pushard, 2016). This system is extremely energy intensive and loses about 5-10% of the water from evaporation. Distillation removes all contaminants except for VOCs (Pushard, 2016). Some may come with carbon filters to remove VOCs (Pushard, 2016).

Sedimentation may also be implemented to allow for particles within the water storage tank to separate (Islam et al., 2013). Water is given at least 4 hours to settle wherein the sedimentation process takes place. However, sedimentation removes nutrients from the water supply and requires constant water flow to be effective (Helmreich & Horn, 2009).

Recommendations: UV radiation is an essential component because of its effectiveness and practicality. Carbon filters are supplementary and can further improve water quality, if desired. A supplementary UV light and carbon filter are needed for the additional storage tank if it is purchased.

Distribution

Use: The distribution systems deliver water to the garden from the storage tank (Islam et al., 2013).

Considerations: The exact system depends where the tank is located and irrigation methods.

Solutions: Distribution systems can either be passive or active (Pushard, n.d.). Passive systems distribute water without use of mechanical methods. This can include declined piping leading to the garden from the water source or tank (Mackay Regional Council, 2018). In comparison, active systems use mechanical interventions to pass water to the garden, such as pumping (Pushard, n.d.). The system would require an active approach because the tank will not be located on the roof.

Two commonly used irrigation methods include drip irrigation and sprinklers (Camp, 1998; Pair, 1970). Drip irrigation delivers small quantities of water to the garden along piping laid out along the soil. Sprinkler systems rely on a device placed near the garden that sprays water onto plants. Drip irrigation ensures all water is used by the plants (Camp, 1998), while the latter releases larger quantities of water resulting in wastage (Pair, 1970).

Recommendations: An active system that uses drip irrigation is essential. Active pumping is required to feed plants and drip irrigation maximizes water use.

Maintenance

The system should be maintained to ensure proper functionality. This includes cleaning, making sure that the system is operating as intended, and looking out for any malfunctions that may occur (MacAskill et al., 2006). RWH system components should be cleaned when possible including catchment surfaces, gutters, storage tank, and filters (Campasino et al., 2017). Access to rooftop, gutters, and storage tank however, will likely be limited. Furthermore, the system can face problems such as leaks and pumping malfunctions (Mun & Hun, 2012; Peck & Kuhn, 2003). Options for post-implementation monitoring should be considered with installation companies.

Recommendations

The previous sections outlined different components that can be used in a RWH system. Only select components are needed to develop a system for the North Munk building.

The most essential pieces are as follows:

Catchment Area: N/A

Delivery System: Coating or replace gutters

Pre-Storage Treatment: Cartridge filters and first-flush diverter

Storage: 8,000L (~2,000 gallon) plastic tank

Post-Storage Treatment: UV radiation disinfection

Distribution/Irrigation System: Active pumping, drip irrigation

The following are supplementary pieces that can be added to further improve system functioning and water quality:

Catchment Area: Gutter net

Delivery System: N/A

Pre-Storage Treatment: N/A

Storage: Additional 4,000L of space in tank, totaling to 12,000L (3,400 gallon) plastic tank

Post-Storage Treatment: Carbon/charcoal filter

Distribution/Irrigation System: N/A

Budget

The final budget is comprised of all the different elements which make up the system as seen in **[Fig. 6]**. Using only essential pieces, the RWH system can break even in approximately 45 years. The entire system, including essential and supplementary pieces, will break even in approximately 65 years (see Appendix C). Estimates were made to determine the number of filters and PVC piping needed. The price of the gutter treatment is not included as we could not get an estimate on the price of replacing or coating the gutters without a professional company. However, the price of copper versus the price of steel is three to one, and a profit can be made when selling the current copper gutters to replace them with galvanized steel. ("Copper gutters", 2018) The price of adding a gutter guard per foot is available in the Appendix D but since the exact length of all the gutters is not known, this is not included in the preliminary budget. For more details and manufacturers per item, see Appendix D.

Essential pieces	
Downspout filters	$ 329.00
First flush Diverter	$ 105.00
2000 gallon (7571L) plastic below ground cistern	$ 3,351.00
GP 800 Garden pump	$ 432.00
UV filter	$ 1,113.00
Pipes connecting tank to roof	$ 750.00
Drip irrigation lines	$ 204.40
Irrigation control Rain Bird + rain sensor	$ 437.00
Dosatron in line fertilizer	$ 557.00
	$ 7,278.40
Supplementary pieces	
Gutter net	-
3400 (12.870L) gallon cistern, cost difference with 2000 gallon tank	$ 3,081.00
Carbon filter	$ 175.00
	$ 3,256.00
TOTAL	
	$ 10,534.40

Figure 6: Preliminary budget of the RWH system.

Limitations, Considerations, and Next Steps

Some retroactive considerations for this project are presented in Appendix E. While our project accounts for some major factors that will influence the RWH system, there are still some problems that need to be addressed. Our budget estimate focused on physical components. Any additional costs from installation and maintenance issues were not included and largely depend on the chosen system. Gutters, for instance, required inspection for cost estimation that we could not authorize, thus gutter options were omitted from the preliminary budget.

We are uncertain of the exact dimensions of the steam pipe that runs through the where we plan on burying the tank on the Quidditch Pitch. In addition, we have not considered the logistics of connecting tap water as a backup in the event of a significant shortage of rainfall. Our rainfall estimates were based on weather patterns near Pearson International Airport, thus our calculated water requirements in downtown Toronto might vary slightly. Once the system is built, water should be tested for pH and alkalinity to ensure quality meets our expectations and is suitable for use.

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Appendix

A.

Total amount of water required for the season:

30 (number of days within a month) / 5 (watering plants every 5 days) = 6

6 x 10 L (average amount of water required for each plant) x 100 (number of biotops) = 6,000L

Growing season: May - October (6 months)

6,000L x 6 = 36,000L (total)

B.

Water costs = $0.01729145/gal (2018 Water Rates & Fees, 2018)

1 gal = 3.78541 L

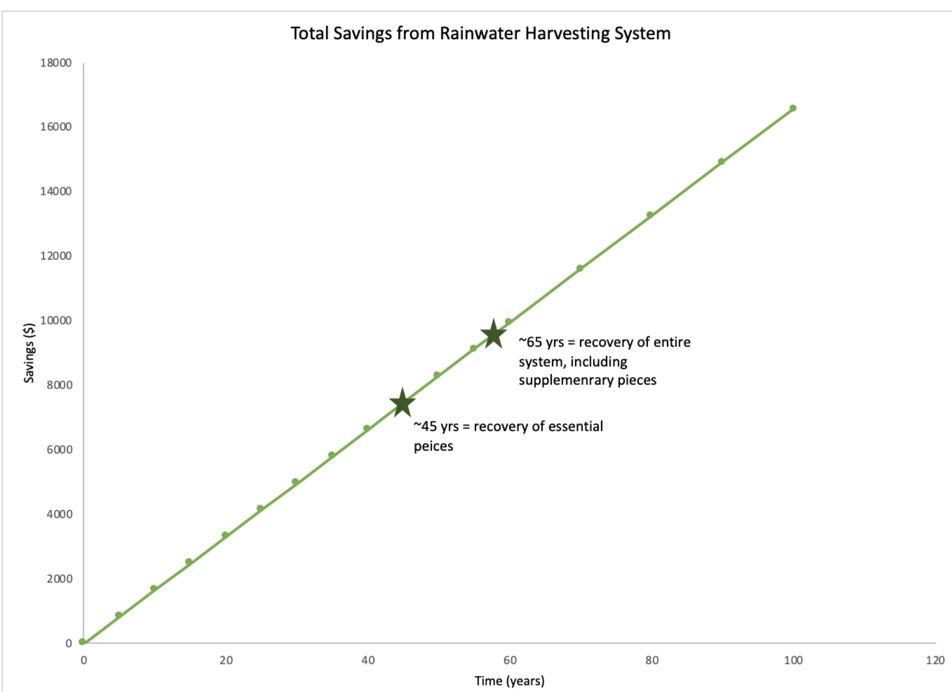
Water costs (in liters) = $0.01729145 / 3.78541L

= $0.0046/L

Total savings per season = $0.0046/L x 36000L

= $165.60

C.



**Time needed to recover system costs by water savings.*

D.

Item	Price	Description & Link	Image
Downspout Filters	329 CAD / 10 pieces	Rain Harvesting Pty Rain Catcher Downspout Filter Found on www.rainharvest.com	
Gutter Guard	About 10 CAD/ft	Aluminum gutter guard Found on www.homedepot.ca	
First flush Diverter	105 CAD	Rain Harvesting Pty First Flush Diverter for In Ground Systems Found on www.rainharvest.com	
2000-gallon plastic below ground cistern	3351 CAD	2000 Gallon Ace Rotomold Low Profile Water Aquifer Found on www.rainharvest.com	

3400-gallon plastic below ground cistern	6432 CAD	Graf Carat S 3400 Gallon Modular Cistern Underground Water Storage Tank Found on www.rainharvest.com	
Pump	432 CAD	GP 800 Garden pump with automatic pump controller RainFlo 115V Automatic Pump Controller Found on www.rainharvest.com	
Sand filter	629 CAD	Sand Media Filter Found on www.dripworks.com	
UV filter	1113 CAD	RainFlo Rainwater Purification Package, 9 GPM Found on www.rainharvest.com	

Carbon filter	175 CAD	20" X 4.5" 0.5-micron nominal, 1-micron absolute carbon block filter cartridge for chlorine, taste and odor reduction. + Full Flow 20" + 20" Filter Housing for Full Flow/Big Blue 20" x 4.5" Standard Filter Cartridges. Found on www.rainharvest.com	
Pipes connecting tank to roof	750 CAD	1 1/2-inch X 6 ft. PVC DWV Pipe About 15 CAD per 6ft. Given roof dimension approximately 300 ft PVC is needed. Found on www.homedepot.ca	
Drip irrigation lines	204 CAD	Garden Drip Tape Irrigation Kit 500' | BioPlus Minimum of 72 meters of drip irrigation lines for 100 biotops of 0.72 per biotope. Found on www.duboisag.com	

Irrigation control Rain Bird	437 CAD	ESP-TM2 Series Controllers +Rain sensor Found on www.store.rainbird.com	

E.

If we had to re-do this project from the start, we would have assigned each person an area to explore in the literature. We felt that areas of interest were divided up unevenly where there was more ground to cover than expected. For example, contamination required quite a bit of research. We would have also measured the gutter line in hopes of getting a proper estimate for replacement costs if that were possible.