Sustainable Technologies
EVALUATION PROGRAM

# Automated Real-time IoT Smart Blue Roof Systems for the ICI Sector for Flood and Drought Resilience and Adaptation

## Technical and Financial Feasibility Study

Credit Valley Conservation
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- Assessing technology implementation barriers and opportunities;
- Developing supporting tools, guidelines and policies;
- Delivering education and training programs;
- Advocating for effective sustainable technologies; and
- Collaborating with academic and industry partners through our Living Labs and other initiatives.

Technologies evaluated under STEP are not limited to physical devices or products; they may also include preventative measures, implementation protocols, alternative urban site designs, and other innovative practices that help create more sustainable and livable communities.

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# EXECUTIVE SUMMARY

Blue roof systems regulate rooftop runoff by storing and controlling the release of rainwater, thereby reducing the potential of overflow in the municipal sewer system and thus, the potential for localized flooding. Combining a blue roof system with rainwater harvesting (RWH) allows for rainwater reuse and provides additional benefits. Such a system can be further optimized by automation using weather forecasting algorithms via internet connectivity. To study the effectiveness of implementing such a smart blue roof system, Credit Valley Conservation Authority (CVC) received funding in December 2017 from the Federation of Canadian Municipalities under the Climate Change Adaptation, Municipalities for Climate Change Innovation Program to conduct a feasibility study entitled *"Automated Real-time IoT Smart Blue Roof Systems for the IC&I Sector for Flood and Drought Resilience and Adaptation."* Prior to this technical and financial feasibility study, a thorough literature review was completed to synthesize information about the current state of blue roofs and "Internet of Things" technology. This report, the technical and financial feasibly study investigates the following areas:

1. Structural and building science analysis of CVC's head office administrative building A for implementation of a smart blue roof system with RWH;
2. Technical and financial feasibility assessment of the applicability of "Internet of Things" (IoT) technology to automate and monitor a blue roof system in real time utilizing sensors, valves, controllers and data loggers
3. Technical and financial feasibility assessment of smart blue roof systems as applied to CVC's building A, as well as broader implementation on both the street and neighbourhood scale; and,
4. A review of public and private sector benefits of implementing smart blue roof technology.

In the structural and building science analysis included herein, it was determined that the existing flat roof on CVC's Building A as well as other similar roofs on industrial, institutional and commercial (ICI) buildings, have the capacity to support basic blue roof systems. For CVC's Building A, the load imposed by the blue roof system components as well as stored water should not exceed 1.9kPa (0.1kPa for hardware and 1.8kPa for water storage, which translates to a 180mm maximum depth). CVC's Building A has a divider berm with a height of 150mm, thus the maximum depth of water that can actually be stored due to this constraint is 150mm.

A structural and building assessment should be part of any blue roof implementation procedure. Blue roof systems should be designed using existing structural support as additional reinforcement and retrofit of roof structures is very It should also be noted that since CVC Building A's roof is sloped the available storage is approximately 2/3 of what it would be on a flat roof with a storage depth of 150mm. expensive and creates an unfavorable cost-benefit ratio.

An active, real-time, automated smart blue roof system provides optimal performance, while utilizing a local data logger and controller to read the sensor inputs, execute the logic, and adjust the valve outputs. This ensures safe operation of the system in the absence of network connectivity in the case of a power outage. Sensors and valves that are designed to work effectively under harsh weather conditions should be chosen. To avoid damage from freeze-thaw cycles, a blue roof system should be uncontrolled during the winter

months, (i.e. drains left open). During normal operation, it is recommended to have redundant measurement of critical inputs, such as water level, and a mechanical overflow provision for safety.

The automation analysis conducted and provided herein compares the advantages and disadvantages of different universal and customized control solutions. It has been determined that for an ICI building, a futureproof universal solution, such as a programmable logic controller (PLC) or programmable automation controller (PAC) (e.g. CompactRIO), could provide the required flexibility, reliability, and customer service. Such a solution, however, would cost more than a customized solution, such as Levelpro. For small property owners, where cost is frequently the predominant factor, customized solutions might be more suitable. However, for large ICI building owners and for adoption at a large scale, where economies of scale are achieved, universal solutions may be more appealing.

With regard to the IoT platform, the advantages and disadvantages of futureproof solutions offered by mega corporations, such as Amazon Web Services, versus a more affordable and customizable solution offered by smaller companies, such as Momentaj Inc, were examined. A blue roof system for a single building could use a dedicated weather forecast station connected to a local controller to achieve real time controls. As such, internet connectivity would not be critical as its only benefit would be to provide remote monitoring capability. For small projects, the more affordable solutions that come with better customization are preferred. In the case of multiple buildings cost savings can be achieved through internet connectivity (i.e. all buildings accessing climate data through existing weather stations rather than having local weather stations). In this case, the futureproof solutions offered by larger companies, such as Amazon Web Services, is recommended.

This study determined that blue roofs with rain harvesting capacity can create a positive return on investment (ROI) for ICI sector properties at the neighborhood scale, particularly for sites with high non-potable water usage, such as mixed-use sites and vehicle maintenance facilities, where minimal treatment of captured rainwater is required. If there is potential for flood damages, the ROI to that property owner increases.

Design optimization is required to balance the size of the blue roof and the RWH cistern with rainwater availability at the site of installation. To analyze the ROI, the following must be considered: a) estimate the daily water demand for all non-potable uses at the property; b) estimate the rainwater available at the site; and c) identify the surfaces and area of the rooftop, from which the rainwater is collected. When coupling blue roof and RWH systems together, it is important to balance stormwater detention and retention volumes to optimize usage and non-potable water availability. Incorporating smart IoT technology would enhance the system in this regard.

Due to scales of economy, scaling up implementation of smart blue roof systems to the neighbourhood scale will respectively increase the ROI.

The benefits of blue roof implementation for private landowners alluded to above include reduced stormwater charges (where applicable), water savings and associated cost savings, and reduced energy costs due to evaporation cooling from the stored water on the roof. For the private landowner, implementing a blue roof system may, however, not seem like an economically viable solution, since the savings, as determined in the current report, are relatively minimal compared to the costs of implementation. If other savings are included however, such as flood damage mitigation, an offset need to upgrade storm pipes and reduced land usage for a stormwater pond and the resulting avoided foregone property tax provide cost savings, blue roof implementation becomes more viable. Many of these benefits accrue to the municipality. Thus, to encourage implementation, it may be in the best interest of municipalities to offer an incentive for landowners to install smart blue roof systems with RWH.

There are, furthermore, several other avoided costs associated with a smart blue roof's ability to manage stormwater, which are much more difficult to quantify. For example, flooding can cause power outages, loss of the use of recreational spaces, and loss of animal habitat, among other issues that would be very site specific. Additional site-specific avoided costs might include replacing, upgrading, or expanding infrastructure, including retention ponds; watercourse and channel capacity upgrades; berm construction; and, source and conveyance control programs. This means that the true economic benefits for municipalities are likely far greater than could be quantified in this study and suggests that catchment-scale retrofit opportunities in flood-prone and similar priority areas should be explored prior to investment being made in expensive conventional stormwater infrastructure projects. It follows that a public and private sector integrated stormwater management approach can reduce the loading on aging municipal infrastructure and may be an effective method to address escalating flooding problems. However, municipal policy and financial mechanisms will likely be necessary to encourage wide-spread uptake of this emerging technology.

Given the ever-intensifying impacts of climate change on stormwater infrastructure, it appears that the benefits of smart blue roof technology should be further investigated in Canada as a potential wide-scale option for not only better controlling stormwater in urbanized communities, but also simultaneously saving costs in the process. Thus, further research in the form of a pilot-scale implementation project at CVC is warranted. Initial implementation on a small site (building) scale will allow for real-life site-specific costs and benefits to be assessed more accurately, which could improve the cost estimate for scaling up. In addition, there may be other lessons to be learned, as there always is when implementing an emerging technology, which could inform larger-scale implementation in the future.

# 1.0 INTRODUCTION

Storm events that were once considered rare are now becoming increasingly frequent, severe and difficult to predict in this era of a changing climate. Damage from storm events is becoming all too commonplace. Despite ongoing operation, maintenance and capital improvements, of conventional municipal stormwater systems, stormwater management remains of great concern to public agencies and private property owners. With stormwater related issues, such as flooding, water quality and stream erosion becoming even more challenging to deal with due to climate change, a public and private sector integrated stormwater management approach could help address these intensifying problems. There is a particular need for integrated stormwater management in urban areas, where infrastructure is undersized and is not meeting current required levels of service due to older design standards. Such areas are prone to surcharging sewer lines and flooding and contribute to downstream erosion and poor water quality. As stormwater infrastructure is underground and out of sight, such infrastructure typically attracts attention upon failure only— when roads are inundated, and properties are flooded. At other times stormwater infrastructure improvements are not top of mind. This needs to change.

Highly urbanized watersheds, with development pressures since the mid-1900s, have drainage infrastructure designed to quickly convey flows from table lands to receiving watercourses via storm sewers and culverts. Such highly impervious areas exhibit flash hydrologic responses during rain events, as there are neither stormwater quantity nor quality controls in place. New stormwater management and flood control measures (i.e. green infrastructure/low impact development (LID) source and conveyance controls) could help respond to the current stormwater management needs.

Urban watersheds have large industrial, commercial and institutional areas (ICI),typically comprised of industrial parks, malls, shopping centres, factories, warehouses, office buildings and schools with extensive paved parking areas as well as large flat-roofs resulting in very high levels of imperviousness. To decrease the loading on municipal infrastructure, smart blue roof systems are proposed here as a viable option to control stormwater at the source.

Preceded by green roof and flow control roof drain systems, blue roof systems are an innovative green technology for flood and drought resilience and adaptation. Blue roof systems temporarily capture rainwater using the roof as storage and allow it to evaporate and/or to be used for non-potable requirements (i.e. irrigation, toilet flushing, truck washing) and ultimately offset potable water demands. Any remaining water can be gradually released into the municipal stormwater system reducing peak flow rates.. Additionally, during the summer season, rainwater ponded on a flat roof can cool the interior of a building and reduce air conditioning pressures through evaporative cooling. As such, smart blue roof systems are advantageous to both the private and public sector.

Blue roof systems can be optimized by incorporating the “Internet of Things” (IoT) technology to make them “smart.” Utilizing a combination of sensors, valves, controllers, predictive weather algorithms as well as building management systems to monitor and manage rainwater that has or has yet to be accumulated on a rooftop, smart blue roofs function as active, automated roof runoff management systems. Predictive weather algorithms incorporated into smart blue roof systems allow for proactive planning ahead of impending storm events, allowing the system to take appropriate measures (i.e. to open or close roof drains) depending on the short-range weather forecast. Limits can be set so that when the system is reaching capacity an alert is triggered, building/facility operators are notified, and the system responds automatically.

The Smart Blue Roof Technical and Financial Feasibility Study, enclosed here within, investigates the possibility of retrofitting CVC's existing Building A flat roof with an active, smart blue roof. As per the figure below, the feasibility study project was completed in three phases. This report presents the results of Phase two and three. The fourth phase will be to secure funding and implement a pilot smart blue roof system.

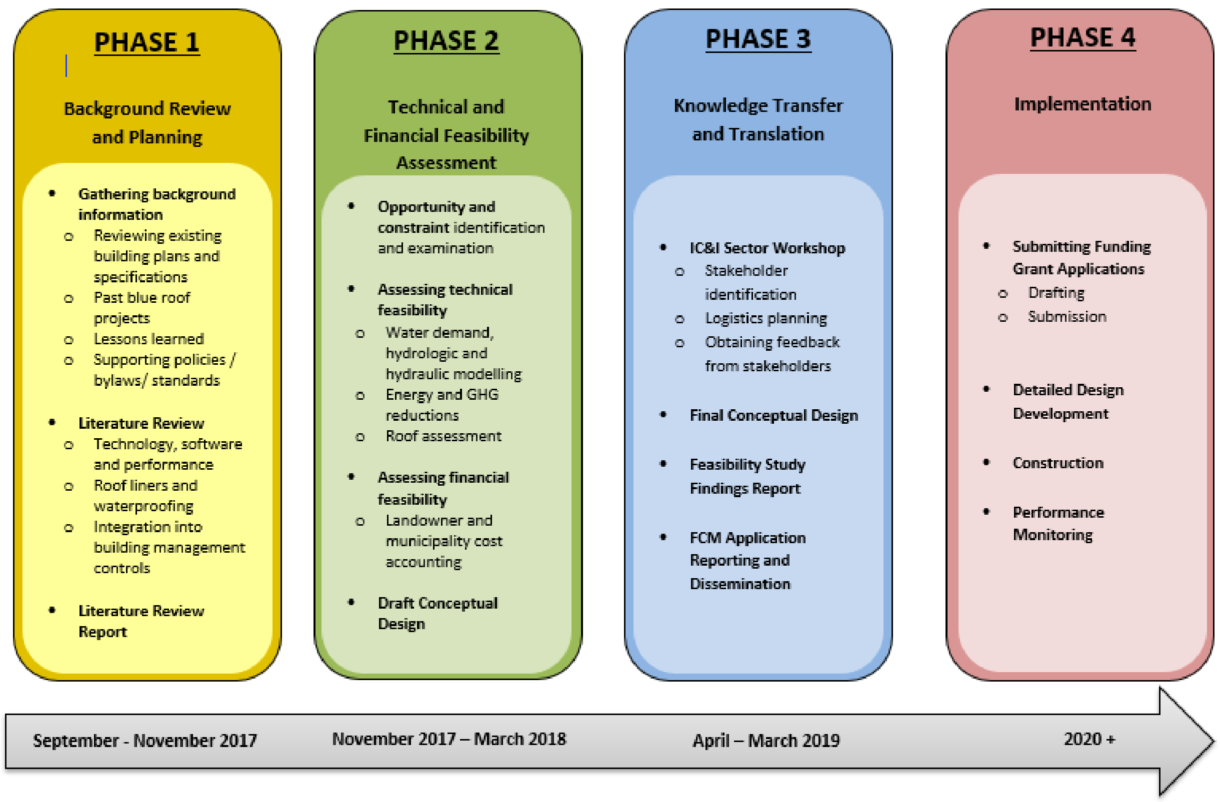


**Figure 1 Smart Blue Roof Project phases. Phases 1-3 were completed in March 2019. Phase 4 (Implementation) remains.**

Since smart blue roof systems have not yet been broadly used, as discovered in the literature review, the ultimate objective of this study is to evaluate the feasibility of implementing such systems on flat roof buildings across the ICI sector in the Greater Toronto Area (GTA) and across Canada.

## 1.1 Report Structure

The first section of this report entails a structural and building science assessment for the CVC administrative office building. The second section of this report presents an analysis and evaluation of different components of an active blue roof system, including sensors and valves at the field level, the controller at the automation level, and the cloud storage, monitoring and computing at the application level. The third section of this report assesses the technical and financial feasibility of smart blue roof systems with RWH capacity as applied to CVC's Building A and presents the benefits when this technology is scaled up to the street and neighbourhood. The study closes with a discussion of the financial and environmental benefits of smart blue roof systems with RWH capacity for private landowners and municipalities.

# 2.0 STRUCTURAL ANALYSIS OF CVC OFFICE BUILDING FOR USE OF A BLUE ROOF SYSTEM

Blue roof systems are explicitly designed to store rainwater on a roof, allowing it to evaporate, be used and/or be released at a controlled rate, thereby mitigating the impacts of intense rain events (see Figure 2 below) on existing stormwater infrastructure. Evaporation of stored rainwater from a roof can add cooling benefits during summer months. Systems can be designed with additional storage capacity to allow for increased reuse potential. The following presents a structural and building science assessment of a CVC office building used to analyze the technical feasibility of implementing a smart blue roof system with rain harvesting capacity.


**Figure 2 Graphical representation of concept of an actively controlled smart blue roof system with RWH capacity**

## 2.1 Rationale for Considering a Smart Blue Roof System at CVC

There is an opportunity to test a blue roof system with RWH as Building A (see Error! Reference source not found.**3**) at CVC's administration office was constructed with a RWH system. This RWH system is relatively small and, while it does offset some non-potable water consumption, it has limited stormwater management capacity, as will be discussed in Section 4 of the report. The addition of a blue roof system will increase the stormwater management capacity of the CVC building, enhance the existing RWH system, provide evaporative cooling benefits, and potentially allow CVC to obtain additional credit through the City of Mississauga's stormwater credit program.


**Figure 3 Credit Valley Conservation property at 1255 Old Derry Road, Mississauga**

Passive blue roof systems (i.e. where only the rate of flow to the storm sewer system is controlled) offer some benefit in terms of stormwater management but rely on physical flow control devices only

Integrating a smart blue roof system into the design has potential to provide significant stormwater management benefits, as compared to either a passive blue roof or a RWH system alone. For example, an actively controlled “smart” system would allow drainage of the roof before a storm event, thereby maximizing active detention capacity and reducing the burden on the storm sewer system. For this reason, CVC is interested in evaluating an active system for blue roof and RWH system optimization

## 2.2 CVC Office Building - Structural and Building Science

CVC’s office is located at 1255 Old Derry Road, Mississauga, Ontario and consists of two main buildings A and B (see Error! Reference source not found.**3**). CVC’s Building A, is a 4-storey structure with a partial basement level at the west side of the building. The total roof area of Building A is approximately 645 $m^2$. This 40 m long by 18.8 m wide building is located just south of older office Building B and is connected to it with a 1-storey corridor. A 1-storey garage is located on the southeast side of Building A. The administrative building does not have a penthouse. All mechanical equipment is placed on the west side of the roof, hidden behind a mechanical roof screen. This Structural and Building section of the report will investigate CVC’s Building A roof using the building’s existing design drawings, associated design calculations and the 2006 Ontario Building Code requirements. When proceeding to smart blue roof detailed design and implementation in the future, further structural assessments and investigative work is warranted.

### *2.2.1 Roof Design Loads*

The Ontario Building Code – OBC 2012 specifies Loads and Effects to be taken into consideration in the design of a building, as noted in **Table 1** (OBC 2012 Table 4.1.2.1.A). The Ontario Building Code loads relevant for a blue roof design are as shown below:

**Table 1 Extract from Table 4.1.2.1.A. (OBC 2012), relevant loads for roof structure**

| Symbol | Loads, Specified Loads and Effects | Relevant Load Factors |
|---|---|---|
| D | Dead load - a permanent load | 1.25 |
| L | Live load – a variable load | 1 |
| S | Variable load due to snow including ice and associated rain, or due to rain | 1.5 |
| W | Wind load - a variable load | 0.4 |

A roof structure should be designed for factored load combinations which consist of loads that act simultaneously, and which are described in **Table 1** (Table 4.1.3.2.A. of the OBC 2012). Based on article 4.1.6.1 in the OBC, the snow plus associated rain load (generally referred to only as the snow load) or rain load alone, whichever is greater, should be used as "S".

Consequently, the capacity of an existing roof to support a rainwater storage structure would be equal to "S" in Table 1 above. Below is an example of the design snow or rain load, based on OBC 2012, for Mississauga and Toronto, without considering snow drifting.

**Table 2 Example of snow and rain load**

| Location | Snow | | Rain | |
|---|---|---|---|---|
| | (kPa) | (mm of water) | (kPa) | (mm of water) |
| **Mississauga** | 1.28 | 130 | 1.11 | 113 |
| **Toronto** | 1.12 | 114 | 0.95 | 97 |

Water specific weight: $\gamma$ = 9.805kN/m3 at 0ºC,

The snow load capacity has governed most design cases in Mississauga and Toronto. It is reasonable to assume that the capacity of flat roofs (slope = 0º) to support a rainwater storage structure is equal to the snow load.

### *2.2.2 Review of Historical Snow Load Requirements*

Following the changes in climate patterns and advances in engineering, snow load requirements have evolved over time. The National Building Code (NBC) and Ontario Building Code (OBC) underwent two major changes in snow load requirements. One change came with NBC 1990 and second with NBC 2005. The following graph shows major changes to the snow load requirements for Mississauga.

Refer to **APPENDIX A** for full table presentation of historical evolution of snow load requirements from 1953 to 2012 for Mississauga and Toronto.

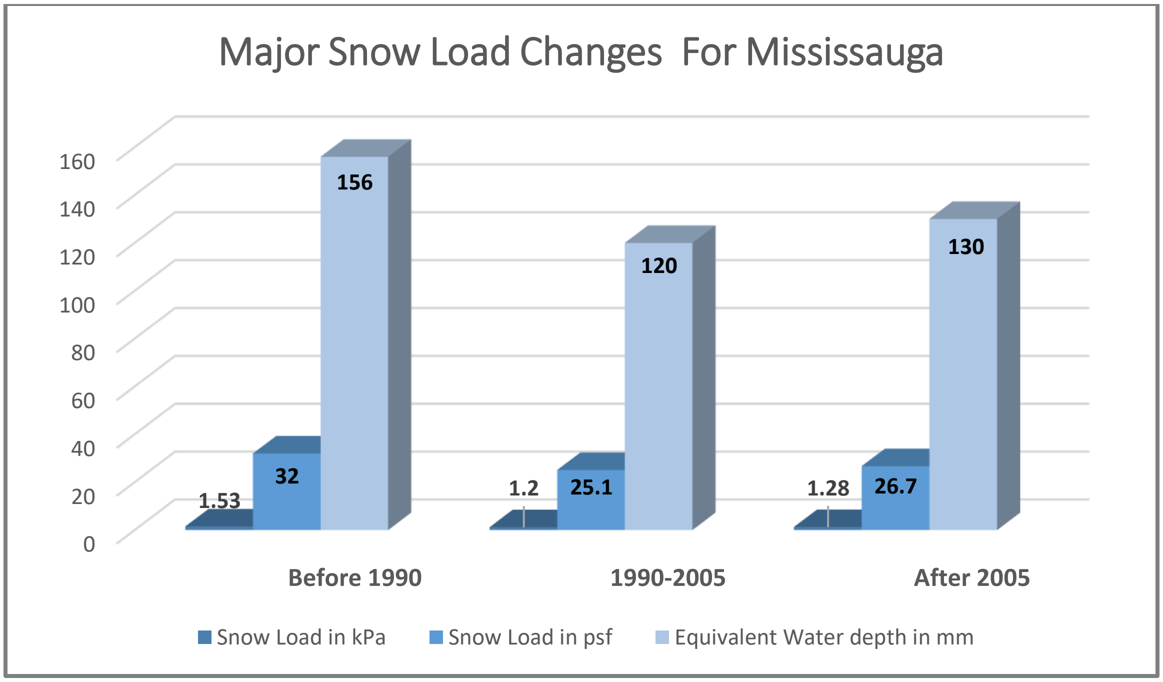


**Figure 4 Historical major changes of snow load requirements for Mississauga**

The above snow loadings are for standalone flat roofs only. They do not account for snow accumulation due to shaped roofs or near higher roofs.

### *2.2.3 Typical Roof Assembly and Parapet*

The typical structural roof assembly in a steel framed building is comprised of a corrugated steel roof deck over steel joists or beams. Other systems, such as a concrete slab on composite steel deck over steel joists or a precast slab over steel beams, are rarely used except when future extension is intended. High-rise concrete buildings with a flat roof commonly have a concrete slab. Wood roof decking is used predominantly in conjunction with wood structure framing, which usually features a sloped roof. The typical roof assembly is shown in **Figure 5**. Refer to **APPENDIX A**, **Figure A 1** to **Figure A 6** for examples of the roof structures.

A parapet wall at the roof edge is an architectural feature that is only sometimes used, as it is not required by the Building Code. Shorter parapets, commonly lower than 400mm, are often part of cladding or a roofing system and are not considered a structural element.

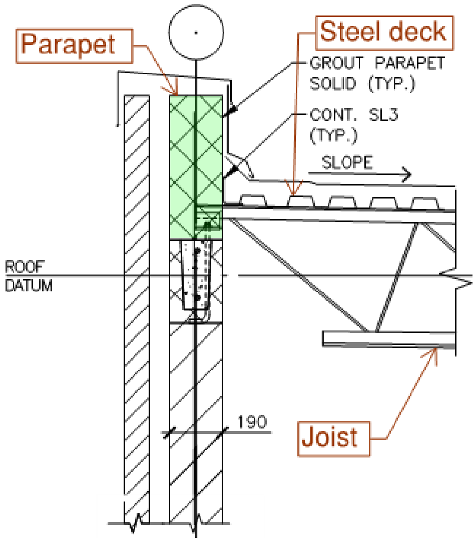


**Figure 5 Typical roof assembly**

While the parapet wall is considered the roof edge, there are nonetheless different ways to address and design the edge of a roof. Factors involved may include: the type of roofing being installed (Protected Membrane Roofing (PMR) versus Conventional Roofing); the type of roofing membrane chosen; and whether the roof drains to the interior or exterior of the building. Many flat roofs are designed to include a parapet.

According to the Ontario Building Code 2017 (Section 9.20.6.5), the height of parapet walls above the adjacent roof surface shall not be more than three times the parapet wall thickness, and parapet walls shall be solid from the top of the parapet to not less than 300mm (12 inches) below the adjacent roof level.

Beyond the above restrictions, parapet height may be determined to address fall protection or wind uplift protection. The roofing industry suggests a minimum parapet height of 200mm (8”), but this is not a requirement.

A higher parapet wall is a structural element that needs to be designed. Those parapets are mainly block walls (refer to **Figure 5**). Though not common, parapets may be concrete. The governing design load for parapets is lateral load due to wind.

### 2.2.4 Scuppers

There are two specific uses for a scupper (an outlet in the side of a building): primary drainage and emergency overflow. In the case of primary drainage, the scupper must be installed level with the finished roof surface. Optionally, a sump can be utilized to slightly lower the scupper relative to the roof surface to promote more efficient drainage. See **Figure 6**.

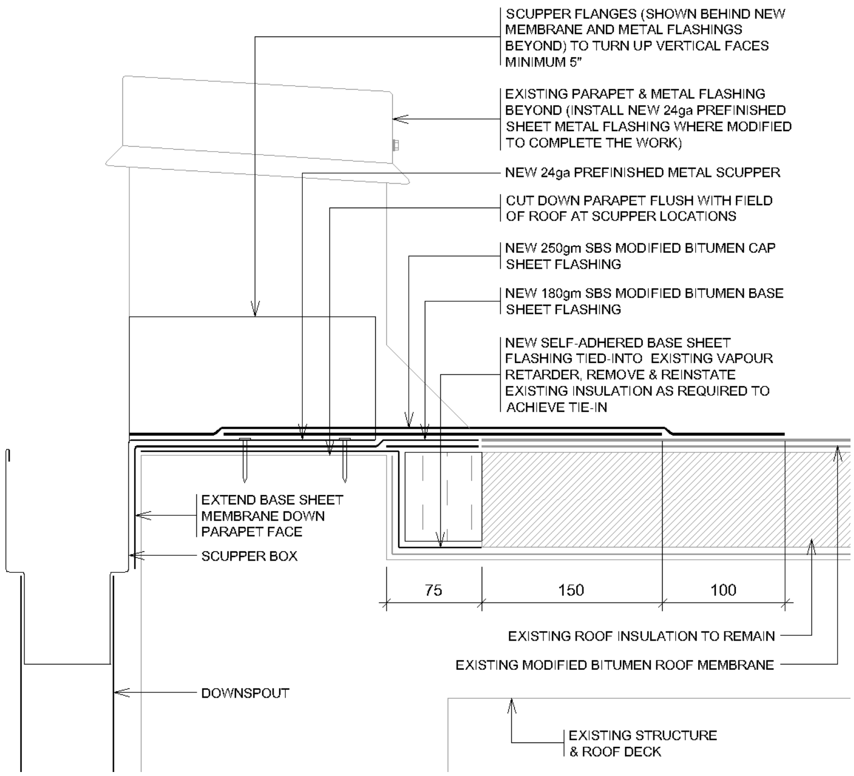


**Figure 6 Primary drainage scupper**

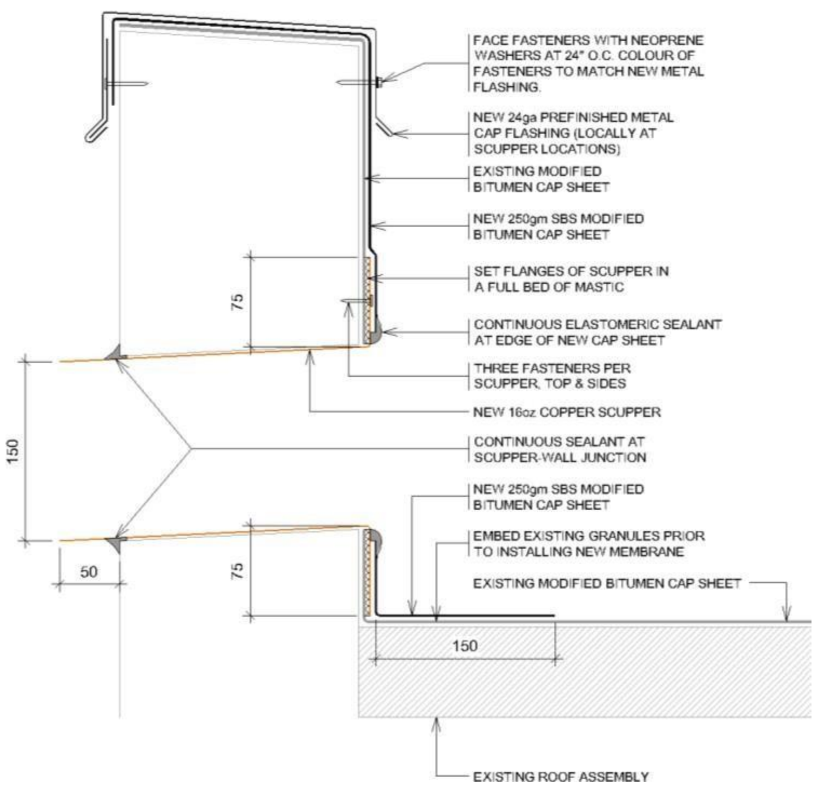


**Figure 7 Overflow scupper**

In the case of emergency overflow, the scupper's elevation relative to the roof surface is determined by the roof's maximum load capacity. Once this is calculated, the elevation of the scupper can be determined. Where a roof is flat, an elevation of 19mm (0.75 inches) above the finished roof surface is typical. To allow for main roof drainage, the overflow scupper cannot be lower than the roof surface. See **Figure 7**.

According to the Ontario Building Code 2017 (Section 7.4.10.4), where the height of the parapet is more than 150mm (6 inches) or exceeds the height of the adjacent wall flashing, emergency roof overflows or scuppers shall be provided, and there shall be a minimum of two roof drains. Emergency overflow scuppers are also required when installing flow control roof drains.

### *2.2.5 Increasing Roof Structural Capacity*

As mentioned in section *2.2.1 Design Loads in Conjunction with Blue Roof,* snow load capacity has governed most design cases in Mississauga and Toronto as it is greater than rain load. For the most common roof structure, variable snow or rain load is bigger or equal to dead load. Since the load factor for dead load is 1.25 and 1.5 for variable load (refer to **Table 1** Extract from Table 4.1.2.1.A. (OBC 2012)), the variable load factor has the greater impact on structure.

An increase of up to five per cent in variable load is considered acceptable and common practice and does not require existing structural reinforcement. When applied to calculations regarding ponding on roofs in Mississauga, this would mean an insignificant increase in ponding from 130mm to 137mm.

However, increasing roof load over five per cent would require further consideration of the following:

- load assessment;
- existing structural assessment; and,
- roof structure reinforcement, if required.

Roof reinforcement may be done either by reinforcing individual roof elements or adding additional roof members. While reinforcement and/or retrofit of a roof structure is possible, it is expensive and should be measured against the benefits provided by the implementation of a blue roof system.

The impact of increasing variable rain load on the parapet wall is minor compared to the roof primary structure. This is due to the geometry and size of the elements; more specifically, while parapets are short walls that would not bear much load from snow or rain, primary structure elements are longer and would bear a much larger load.

### *2.2.6 Common Practice for Parapet Modifications/Retrofits*

Roofs, which are being considered for blue roof technology, but which do not have a parapet wall, will require a parapet addition. To add a parapet to a building with bearing walls, bar dowels must be incorporated into the bearing masonry walls and then a masonry parapet erected (Figure 8).

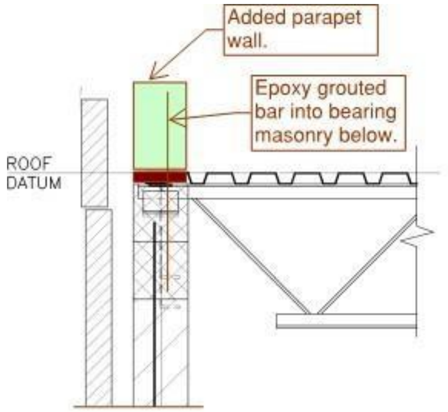


**Figure 8 Adding a parapet wall to bearing masonry**

The cost of adding a parapet is much less then structurally reinforcing a roof so although it may not be cost effective to reinforce a roof for the purpose of installing a blue roof system, adding a parapet may be worthwhile.

When replacing an existing roof system, a parapet typically only requires modification when the thickness of the new roof system requires it to be raised and/or when the top of the parapet does not slope toward the interior of the building.

If a parapet height was designed for a specific purpose (i.e. fall protection, wind uplift protection, etc.), the height of the parapet must remain at or above the minimum requirement for that purpose. If a parapet was designed with no specific technical purpose other than for aesthetics, and if the new finished roof system surface is less that 100mm (4 inches) below the top of the parapet, it is good practice to raise it.

#### *2.2.7 Retrofitting Drains from Conventional to "Smart" Flow Control Drains*

Good roofing design practice requires a balance between the roofing membrane's physical resistance to standing water and responsible storm water management. It is considered acceptable, in most cases, that water can remain on the surface of a roof, provided the water will evaporate or drain within 24 hours following a rain event. To detain stormwater, flow control devices may be added to existing standard drains, or new drains specifically designed for flow control may be installed. When determining the restrictive properties of the flow control device(s) to be installed, a drainage system study of the building and municipal storm water management system should be conducted by a mechanical engineer. It is also important to calculate the structural capacity of the building to support additional loads as a result of installing flow control drainage. Additionally, according to the Ontario Building Code 2017 (Section 7.4.10.4), the maximum drain down time is 24 hours.

## 2.3 CVC Office Building – Structural Systems

### *2.3.1 Applicable Codes and Standards*

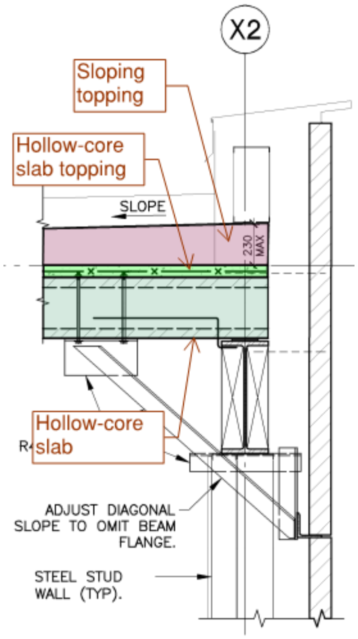


**Figure 9 Typical roof structure**

CVC's administrative office Building A was designed in 2008 and completed in 2010. The applicable code at the time was the 2006 Ontario Building Code (OBC 2006). Design loading was in accordance with Part 4 of Division B. Environmental loading data for Mississauga was per Supplementary Standard SB-1. Additional requirements included the User's Guide – NBC 2005 Structural Commentaries (Part 4 of Division B).

### *2.3.2 General Structural System*

The building structure is a steel framing system. Floor steel beams and supporting floor slabs are connected to the steel columns that are supported on cast-in-place footings. Floor plates are 254 mm deep hollow-core slabs with 50 mm concrete topping. At the ground and basement levels, the floor consists of 115 mm thick slab-on-grade. The cast-in-place footings are connected along the perimeter with the foundation wall. At the west side, the foundation wall and footings step down to form basement walls. Finally, the lateral load resisting system is a conventional moment frame in one direction and a conventional braced frame in the other direction.

### *2.3.3 Roof Plate*

The roof plate is comprised of 254 mm deep hollow-core slabs with 50 mm concrete topping, supported on the roof steel beams. Above the roof plate, a topping was added that slopes from 230 mm at the perimeter to 50 mm at the center.

### *2.3.4 Roof Scuppers*

The roof of Building A does not have scuppers. The 2012 Ontario Building Code edition, section 7.4.10.4, was amended to include, among others, requirements for the installation of overflow scuppers. However, according to code, because the CVC Building A roof was constructed before the 2012 requirements were implemented, no scuppers need to be added. For the purpose of a blue roof, design, however it would be beneficial to install emergency overflow scuppers.

## 2.4 CVC Office Building – Roof Structure Loads

### *2.4.1 Roof Design Loads*

The applicable code at the time of constructing Building A was the 2006 Ontario Building Code (OBC 2006). The applicable ground snow load and associated snow load used in the design was S=1.28kPa. The additional snow piling load was used as well.

As such, the design loads for the roof plate were:

- Basic snow load S = 1.3 kPa
- Wind uplift W= 1.3 kPa
- Basic superimposed dead load (SDL) = 1.6 kPa
- Average sloping topping SDL = 4.7 kPa

The sloping topping load varies from 2.8 kPa to 6.6 kPa.

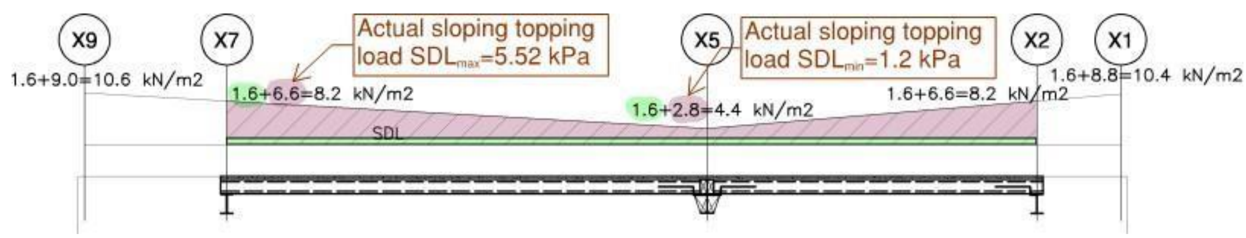


**Figure 10 SDL diagram for precast design**

### *2.4.2 Additional Design Criteria*

The western side of the roof was designed for the additional load from equipment and housing pads. The roof was designed with the assumption that there is no water retained on the roof as a result of flow control measures.

### *2.4.3 Actual Superimposed Dead Load*

The actual sloping layer was cast in two directions (refer to the diagram in **Figure 11**). Although the roof was designed for a superimposed deadline load of 4.7kPa for the sloping topping, the actual average load over one roof segment is 4.1 kPa, leaving an average allowance of 0.6 kPa.

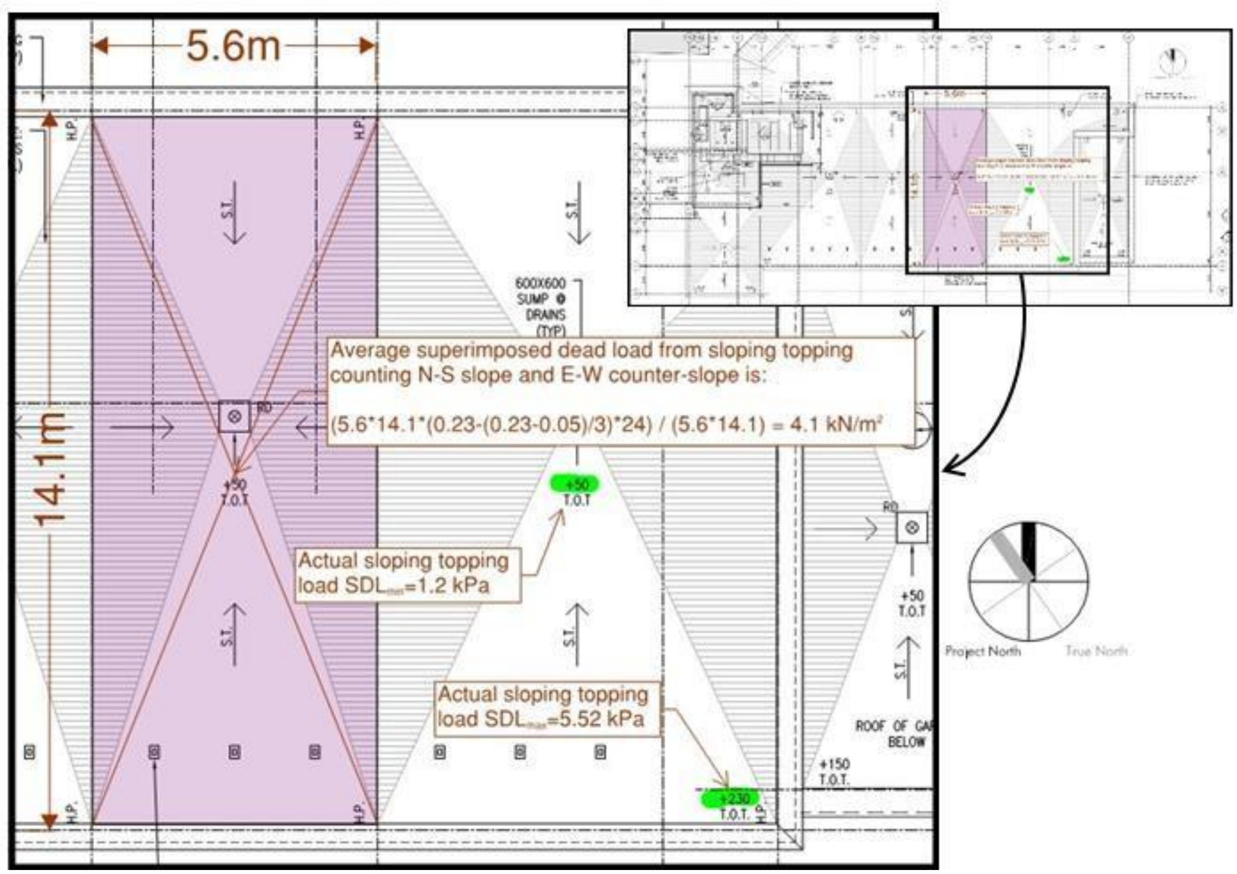


**Figure 11 Actual SDL for sloping topping**

## 2.5 Conclusion and Summary Table

The existing flat roof of CVC's Building A has the capacity to support a blue roof system. The load imposed by the blue roof should not exceed 1.3kPa+0.6kPa (snow load + allowance). If the load imposed by the hardware were 0.1kPa, then there would be a capacity of 1.8kPa for water storage, which translates into a 180mm maximum depth of water. If the entire roof is used as one storage area, the maximum depth at the lowest roof point is 180mm. However, due to divider berms on CVC Building A's roof being 150mm in height, 150mm of water depth can be stored on the roof at the deepest point (i.e. at the roof drains). It should also be noted that since CVC's Building A's roof is sloped the available storage is approximately 2/3 of what it would be on a flat roof with a storage depth of 150mm. A structural assessment of concrete making up the roof slabs on the CVC building should be part of the design stage of a blue roof system to confirm load bearing capacity.

In principal, any flat roof has the capacity to support a rainwater storage structure without having to reinforce the roof, as long as the load is no greater than the variable design load (snow+rain or rain only).

### 2.5.1 Summary

The following is a summary of the preceding structural analysis for use of a blue roof system.

1. An existing roof, such as the one on CVC's Building A, has the capacity to support a rainwater storage structure, as long as the imposed load is no bigger than the design variable load.
2. Roof parapets are not a Code requirement. Their purpose and size vary.
3. Flow control drains are not a Code requirement; however, if flow control drains are installed, emergency overflow scuppers are necessary. Emergency roof overflows or scuppers are also necessary if the height of a parapet is greater than 150 mm or exceeds the height of the adjacent wall flashing.
4. Detailed building-specific structural assessments should be part of any blue roof detailed design procedure.
5. Reinforcement and/or retrofit of a roof structure is possible, but it is expensive and should be measured against the benefits provided by the implementation of a blue roof system.
6. Reinforcement and/or retrofit of the parapet wall is less costly than reinforcement and/or retrofit of the roof structure. Adding parapets in order to install a blue roof system may be cost effective.

# 3.0 FEASIBILITY ASSESSMENT OF THE REAL-TIME AUTOMATED IOT COMPONENTS OF A SMART BLUE ROOF

## 3.1 Purpose and Introduction

This chapter provides an analysis of the feasibility of a real-time automated smart blue roof system with rain harvesting capacity that uses IoT connectivity. Blue roof systems can be optimized by incorporating the "Internet of Things" (IoT) technology to make them "smart." IoT technology is proving to be effective in developing "smart" approaches to urban problems.

Utilizing a combination of sensors, valves, controllers, predictive weather algorithms to monitor and manage rainwater that has or has yet to be accumulated on a rooftop, smart blue roofs that use IoT technology function as active, automated roof runoff management systems. Predictive weather algorithms incorporated into smart blue roof systems allow for proactive planning ahead of impending storm events, allowing the system to take appropriate measures (i.e. to open or close roof drains) depending on the short-range weather forecast. Limits can be set so that when the system is reaching capacity an alert is triggered, building/facility operators are notified, and the system responds automatically.

In this section, first, the design considerations of an automated system are addressed. This includes examining the controller at the automation level, and cloud storage, monitoring and computing at the application level. This is followed by an examination of the sensors and valves at the field level. The automation level assessment presents a comparison of different universal and customized control solutions. Finally, IoT platforms are assessed, whereby the advantages and disadvantages of solutions offered by mega-companies versus smaller companies offering more affordable and customizable solutions are compared.

## 3.2 System Design Considerations

It should be noted that the sensors and valves are connected directly to a local controller and data logger, which executes the logic, handles the valves, visualization and/or analysis of the data. This controller then communicates with the internet, within an IoT platform, to send data for (remote) monitoring and also receives data such as weather forecast information, which may be used in the automation process. The logic and data are initially stored locally in the controller, so that the roof system can continue to operate in case internet connectivity is lost for a period of time.

A very critical component of the decision-making is to have a reliable and accurate reading of the water level in the storage area. The level of the water is typically measured by a sensor which could be converted into a volume using the known area. It is recommended to have at least two sensors in place to ensure accuracy and reliability.

For safety reasons, there should be an overflow sensor that triggers release of water, as well as a physical overflow, in case of a power outage and/or heavy rain. It is also important to know the maximum amount of water the blue roof can support without creating stress on the overall structure.

To assure safe operation of the electrical valves during a power outage, a “Normally-Open” configuration for the valves/actuator is mandatory. This ensures that the valves stay open during emergencies. There are two valve options for this application: the butterfly valve and the ball valve. These two types of valves will be compared below on different aspects, such as seal, weight, price, etc.

When selecting the data logger and controller, one should consider the interface options, communication protocols, programming language, and technical/material support. It is recommended to consider an industry-level solution that is more resilient and stable with a proven record of technical support and customer service.

There are several customized and packaged solutions tailored to a blue roof or rain water harvesting application. The use of an industry-level universal data logger and automation controller, such as Programmable Logic/Automation Controllers (e.g. Allen Bradley, Siemens, or National Instruments (NI)) is recommended. More specifically, NI offers a wide range of solutions that could accommodate the functionalities needed for this application and has built-in provisional extension integration into existing Building Management System (BMS) (BACnet or Modbus), as IoT platforms. Moreover, there should be numerous companies offering system set-up and maintenance of such industrial and universal solutions. This provides peace of mind to property owners with regard to maintenance and future upgrades as they will not be tied to and reliant upon a sole service provider.

As this is a feasibility study, only a rough estimate of prices for IoT services is provided, since the actual cost would require detail specifications of the needs. Therefore, information presented in this section is generic and based on offerings from two different service providers: Amazon and Momentaj. Both service providers can set-up and maintain the system to provide monitoring, storage, analytics, and triggering services.

## 3.3 Field Level: Sensors and Valves

This section explains different types and options for the sensors and valves and a rough estimate of the cost.

### *3.3.1 Sensors*

Blue roof systems will require at least two (2)sets of water level sensors, two (2) temperature sensors, a flow meter, and two (2) actuated valves. The water level sensors on the roof will detect the amount of rainwater on the roof for release planning, as well as provision to avoid overflow. The water level sensor in the tank measures the tank's water level. The temperature sensors are set on both the top and bottom sides of the roof to calculate the differential temperature, which relates to the heat energy transfer of the building through the roof and the flow meter are used for monitoring the flow going to the tank. All the field instruments should be regularly inspected and calibrated, where required, due to their operating in harsh conditions.

**Level Sensor:**

One example of a water level sensor for the blue roof system is FPI's three-level float switch. This sensor has the additional capability of temperature sensing as it has a built-in thermocouple. The minimum actuation range of this sensor is 1 inch, operated in either normally open or normally closed position. This three-level switch can have three (3) statuses of water level on the roof; for example, we can set status one as "keep water on the roof," status two should "drain the water," and status three as "must drain the water."

**Temperature Sensor:**

National Instruments offers thermocouples and Resistance Temperature Detectors (RTDs) for the temperature measurement. While thermocouples are the most popular sensors because of their low cost and wide temperature range, RTDs are widely used because of their accuracy. Because more accurate temperature sensors are required for the heat energy transfer calculation, RTDs are recommended to provide accurate information about the temperature difference between the two sides of the roof. National Instruments offers 3-wire, 100Ω platinum RTDs that conform to the DIN 43760-1980 (European) standard curve (a = 0.00385). These RTDs are available as field-cuttable metal sheathed probes and ready-made element configurations. A temperature input module (NI-9217) is required for transferring the data to the NI's controller (e.g. CompactRIO).

**Flowmeter:**

There are two types of flowmeters that can be used for the blue roof application: the turbine flowmeter and the electromagnetic flowmeter. The turbine flowmeter measures when the fluid moves through the pipe and acts on the vanes of a turbine. The electromagnetic flowmeter works by a voltage being induced, when a conductor moves through a magnetic field. Since there is already a flowmeter on the RWH system in CVC's building A, there is no need to install another one.

### *3.3.2 Valves*

There are two types of valves considered for this application: ball valve and butterfly valve. Note that regardless of type, valves require frequent maintenance, as these are a core component of the system operating in harsh conditions.

**Ball Valve:**

A ball valve utilizes a ball with a hole running through it. Turning the valve blocks, partially blocks, or opens the flow path through the valve.

Advantages of ball valves include a good seal or little to no leak-by, when the valve is fully closed. A ball valve will turn regardless of the pressure on the supply side. If the hole through the valve is as large as or larger than the supply pipe inner diameter, the ball valve will offer essentially no additional pressure drop or restriction when fully opened. Ball valves are often used in high pressure liquid or gas lines, usually 6 inches or less in diameter, where a complete cut off is important.

**Butterfly Valve:**

A butterfly valve is a disk mounted on a rotating shaft. When fully closed, the disk completely blocks the line. When fully opened, the disk is at a right angle to the flow of gas or liquid. The butterfly valve disk is still in the flow path when fully open, so there will always be a greater pressure drop across a butterfly valve. Also, if the pressure difference across the butterfly valve is great, it may be difficult to open the valve. Some applications require a bypass valve to bring the pressure difference down before large butterfly valves can operate.

One of the advantages of butterfly valves is that they are relatively inexpensive to build and maintain. They are the most common valve for large volume water systems, such as municipal water works. They can be used for dirty liquid applications, such as sewage or controlling river water.

**Table 3 Comparison between ball valve and butterfly valve**

| Parameter | Ball valve | Butterfly valve |
|---|---|---|
| **Price** | Expensive | Less expensive |
| **Weight** | Heavier | Lighter |
| **Seal** | Reliable seal | Not completely as ball valve |
| **Application** | High pressure application | Most common valve for water systems |

Based on the function features and price, the butterfly valve is preferred for the blue roof application.

**Table 4 A rough estimate of the price of sensors and valves**

| Sensors | Price (CAD$) |
| --- | --- |
| **2 x Field-Cuttable RTDS** | 320 |
| **Spring Loaded Fitting** | 65 |
| **Cables (e.g., Ethernet)** | 150 |
| **Flow Meter *** | 2090 |
| **2 x FPI's Three-level Float Switch** | 2300 |
| **2 x Butterfly Valve + Actuator** | 4200 |
| **Maintenance** | Price cannot be estimated at this time |

* Note, CVC's Building A's RWH system already has a flow meter. Price is included here for reference purpose only. Price is based on 4-inch pipe, as per Section 4.0 of this report.

## 3.4 Automation Level: Data Logger and Controller

To automate a blue roof system, a local programmable controller and data logger should be used. This system is an electronic digital processing device that controls a process by reading inputs from sensors, executing logic, and adjusting the outputs/valves accordingly. The controller will respond by operating the valves in the roof system to regulate the flow rate from the roof to the storm drain. Indoor installation of the controller in a properly air-conditioned enclosure is recommended to guard against harsh outdoor weather and extreme indoor temperatures respectively.

In this section, we will provide solutions, as well as a rough cost estimate, for the controller at the automation level, which will allow for scalability and integration of third party devices.

There are two types of solutions: customized controllers and universal controllers. Each is assessed below.

### *3.4.1 Customized Solutions*

There are different customized solutions in the market. These include:

- Levelpro
- SmartBlu Roof system (offered by RainGrid)
- AquaControl+ system
- RWA-Automation Controller, and
- Open-storm system.

The Levelpro controller (e.g. ITC 4000) is a device that combines data logging, process control, and display all together. This system can be connected to other controllers, such as PLCs and BMSs. Although currently a residential product, RainGrid believes its system can be scaled to blue roof systems on commercial buildings.

### 3.4.2 Universal Solutions

There are also different platforms for universal solutions: PLCs and PACs. Both PLCs and PACs are well-established industry-level solutions widely used for both industrial automation and building automation. Over the last couple of decades, PLCs have been significantly improved from a simple sequential controller to a more complex process controller, making a fully automated system without any human intervention more feasible. Such universal controllers provide more flexibility and reliability for future development with extensive support for system integration, maintenance, sourcing parts and repairs. **Table 5** lists the main criteria of a controller for a smart blue roof system.

**Table 5 Smart Blue Roof System Controller Criteria**

| Criteria | Specifications |
|---|---|
| **Number of I/O** | 6 inputs from sensors, 2 outputs for valves and 1 for switch with option for additional I/O for scalability |
| **Memory Size** | 3 GB |
| **Communication** | Protocols which BMS can communicate with, such as Modbus, BACnet, RS-485 |
| **Software** | Easy operated interface and Programming Language |
| **Physical environment** | Needs to withstand the environment in a basement setting |
| **Maintenance and Future Proof** | Easy to maintain and will not become obsolete in the next 10 years |

PAC systems, such as NI'sCompactRIO controller, have more computational power and flexibility. The CompactRIO is a real-time controller with reconfigurable I/O modules, a FPGA module and an Ethernet expansion chassis. The CompactRIO is a data logger and a controller at the same time, which supports a variety of protocols for communicating with other devices, including Modbus, Profibus, Serial, TCP/IP, BACNet, and so on (See **Table 6** for detailed specification). The CompactRIO can be integrated with other systems for easier management. For example, BACNet and Modbus supports integration with Building Management Systems, and there is an Ethernet port to connect to the internet and cloud services, such as Amazon. It is worth noting, when comparing NI's solution with other solutions, one should consider other factors, such as reliability, durability, flexibility and the possibility of future development and system expansion. **Table 7** provides an estimate of a control solution using a CompactRIO controller and includes hardware, software, commissioning and installation cost.

**Table 6 Specifications of CompactRio**

| Specifications | |
|---|---|
| **Operating Temperature** | -20 C ~55 C |
| **CPU** | Intel Atom E3825, Dual Core, 1.33 GHz |
| **Operating System** | NI Linux real-time |
| **Software** | LABVIEW 2014 or later |

**Table 7 A rough estimate of the cost based on NI solution**

| Pricing for National Instruments (CAD $) | |
|---|---|
| **CRIO-9030 (Main Controller)** | $4,490 |
| **LABVIEW Full version (Software)** | $4,370 |
| **NI-9217 (Temperature Input Module)** | $850 |
| **NI-9381 (Input Module)** | $605 |
| **NI-9482 (C-Series Relay Output Module)** | $265 |
| **Development and System Commissioning** | $22,000 |
| **Installation (Cabling and Installation of the hardware)** | $ 14,000 |
| **Maintenance/IT Operation Costs** | $2,400 ($200/month) |
| **Total Cost (excluding maintenance)** | **$ 46,580** |

In the following section, we will compare a sample of a customized solution and a sample of a universal solution.

One should note that a universal solution such as PAC or PLC can be used by different applications, while a customized solution has been modified to work with a specific application. Universal solutions for the automation level may provide a greater advantage in the long term than a specialized solution.

**Table 8 Comparison of a universal solution (CompactRio) and the customized solution (Levelpro)**

| Factors | Universal Solution<br><br>NI-ComactRIO + IoT | Customized Solution<br><br>Levelpro-ITC 4000 |
|---|---|---|
| **Total Cost** | Moderate | Low |
| **Scalability** | High Scalability | Not determined |
| **Reliability** | Very Reliable | Reliable |
| **Futureproof** | High | Low to medium |
| **Ease of Maintenance** | High | Low |
| **Size of Data Storage** | High | Low to Medium |
| **Automation** | High | Not determined |
| **Online Dashboard** | Fully Customizable (IoT) | Limited |
| **Data Visualization** | Advanced (Graphing, Patterns, Charts, Data Analysis) | Basic (Graphing, Charts) |
| **3rd Party Integration** | Very Flexible (Many Devices and Protocol add-ons) | Limited (only Modbus) |
| **Application** | Universal | Customized for small scale control such as blue roofs |

## 3.5 Application Level: Internet Connectivity

In this section, two alternative solutions for the internet connectivity component of the blue roof system and a rough estimate of the cost per month with ten (10) devices are provided.

### *3.5.1 Amazon Web Services*

The Amazon Web Services (AWS) offers a variety of services for different applications. Google Cloud and Microsoft Azure also have similar offerings. For the smart blue roof set up one would require Amazon IoT Core, Greengrass and S3 from AWS. Amazon IoT core is a cloud service that lets devices interact with Amazon Cloud and other connected devices. Amazon Greengrass is a service that allows devices to operate together in the Local Area Network (LAN) even without the presence of internet connectivity (specifically for when the internet goes down). Amazon S3 is a cloud-based data storage system for all the sensor data, which allows you to download and retrieve data from the storage system. With this set up, CVC would be able to store data on the cloud retrieve it and analyze it. Proprietary solutions, such as AWS, are more reliable than open source services and are easy to scale up. However, they may be more expensive for small scale projects, such as the blue roof project at CVC.

**Table 9** provides an estimate of the cost for using the Amazon services for the smart blue roof. The table assumes that the following values can be stored on Amazon S3: (water level in the tank, flow rate, temperature differential, and the volume of the stored water). The devices would all be connected with Greengrass and Core. All charges are calculated for ten (10) devices per month and costs provided in USD.

**Table 9 Rough estimate of Amazon Web Services (AWS) for IoT.** (Amazon Web Services, 2019).

| Items | Cost | Total Cost |
|---|---|---|
| **AWS IoT Core** | | |
| Connectivity (Connection between devices and core) | $0.03456 | $12.66/month |
| Publishing Messages (Messages sent between devices and Core) | $5.184 | |
| Shadow and Registry (Current state of device storage) | $4.32 | |
| Rules Engine (IF/THEN/ELSE) | $3.11 | |
| **AWS Greengrass** | | |
| Total Cost for AWS Greengrass (10 devices) | $1.60 | $1.60/month |
| **Amazon S3** | | |
| Storage Costs (500 TB) | $0.069 | $0.39/month |
| Data Transfer Cloud to Canada (500 TB) | $0.02 | |
| Data Transfer Cloud to Internet (Greater than 150 TB) | $0.30 | |
| Implementation | Unknown | Unknown |
| | **Subtotal** | **14.65 USD/month (or 19.75 CAD/month)*** **+ Implementation** |

* At time of writing, conversion rate was USD:CAD (1.35), generating the price of 19.75 CAD.

### 3.5.2 Momentaj

Compared to giant IoT service providers, such as Amazon, Microsoft, and Google, there are other Small-to-medium Enterprises (SME) that would offer the same service but at a lower price. Momentaj Inc. is a Toronto-based company that offers real-time IoT solutions for data monitoring, storage, analytics, and controls. Compared to Amazon, Momentaj's solution has: no costs for initial set up or configuration; online dashboards for up to five (5) users for small plans; real-time IoT data monitoring for your dashboard with low latency (one second delay between data gathered and data displayed on dashboard)); and, both data retention for six (6) months and storage capacity at no cost. The cost for Momentaj is CAD $5.00 per connected device in the network with a minimum of ten (10) devices. The devices can be any piece of hardware that communicates with their cloud. Because there is no set-up cost, the total price is lower than what Amazon would cost, though the actual difference in cost remains unknown because the set-up costs of AWS could not be verified.

### 3.5.3 Comparison Between Momentaj and AWS

Momentaj and AWS both offer an IoT solution, but they do differ in some ways. Looking at cost alone, AWS has a higher initial cost but low monthly maintenance costs, while Momentaj offers low initial cost and a high upkeep cost. Depending on the duration of the Smart Blue Roof Project, the differences will vary. Unlike the controllers at the automation level, both of these solutions are fully customizable, which is ideal at the application level, in order to be able to suit the project's requirements. Momentaj offers a general platform for all solutions, which include: dashboard, connection, and real-time IoT data monitoring with low latency. AWS offers many different services, which can be used to make the solution more efficient and durable, such as the Greengrass service, which keeps the system running when internet connectivity is lost, and different data analysis tools and databases. According to Momentaj, the IoT service can be provided using both their platform and the AWS platform, depending on customer's preference.

The following is a general overview of an IoT solution provided by Momentaj Inc. (Momentaj, 2019):

1. Device (sensor): Hardware that generates specific values of data in a specified time. Should sense levels of temperature, humidity, water level, etc. Can also be hardware that generates values to operate a device's status, such as relays, gates, etc.
2. Gateway (edge): Piece of hardware that uses the internet to send local device data to the cloud within specific formats.
3. Endpoint: Where the gateway meets the cloud service, which is provided by the provider, such as Amazon or Momentaj, to support protocols that will provide raw data to the cloud.
4. Processor: Processes data and generates records for the devices.
5. Data storage: Processed data is stored in a large data support storage databases, such as SQL and NoSQL.
6. Web user interface: Provides end users online access to stored data and real time data, as well as dashboards, reports and graphs.

**Table 10** provides a comparison between AWS' and Momentaj Inc.'s offerings.

**Table 10 Comparison of the IoT service offered by AWS and Momentaj Inc.**

| IoT Cost Breakdown for Connectivity | Service Providers | |
|---|---|---|
| | Amazon AWS | Momentaj Inc. |
| **Device/Sensor** | IoT Solutions Developer | IoT Solutions Developer |
| **Gateway/Edge** | IoT Solutions Developer | IoT Solutions Developer |
| **Initial Setup** | IoT Solutions Developer | Free |
| **Endpoint** | Free | Free |
| **Processor** | Free | Free |
| **Data Storage** | Free | Free |
| **Web User Interface** | Free | Free |
| **Authentication** | IoT Solutions Developer | Free |
| **Other Services** | Provided by AWS | IoT Solutions Developer |
| **Connectivity Costs Per Month** | \$19.75 CAD<br>(\$14.65 USD) | \$50 CAD |

Weather API can be integrated into both IoT services. The weather API has an associated cost, depending on how many times the weather information is requested from the server. Free versions may have 60 calls per minute.

In addition to the connectivity cost, there are maintenance and implementation costs. Implementation includes setting up dashboards, connecting the sensors to the cloud, and setting up graphics, etc. The implementation cost will vary depending on the customization and, therefore, will need to be determined during the design phase. Maintenance is required every time an update to the firmware and software occurs. The costs for maintenance cannot be provided at this time.

When applied to many neighboring buildings, then a service such as AWS would be a better option for blue roof operation. However, implemented on only one (1) single building, then a smaller/medium option, like Momentaj, may be more suitable. Since CVC is looking at the feasibility of using a blue roof on its own building, which is a small setting, Momentaj, would suit this requirement best.

#### *3.5.4 Other Solution Providers*

RainGrid currently has an IoT-based RWH system for the residential sector, and according to RainGrid, is working towards commercial buildings for Stormwater Smart Grids. Their system takes the weather forecast data into consideration for the control (referred to by RainGrid as "Quantitative Precipitation Forecast"). Currently, their platform offers a dashboard for a homeowner or municipality to monitor and control the

RWH systems. The dashboard offers valve control, cistern capacity level, a weather forecast-controlled emptying plan for the cistern, and data on how much water is saved. Data saved can be viewed for up to 90 days. Finally, the municipal dashboard gives priority commands to the municipality over the homeowners.

## 3.6 Conclusions

CVC is investigating the feasibility of using a smart blue roof system on its roof to captures stormwater, allowing it to evaporate and/or be reused and for the remaining water to be released to municipal sewer system in a controlled manner. If real-time control and connectivity to the internet is implemented, a local data logging and controller should nonetheless still be used to read the inputs (sensors), execute the logic, and adjust the outputs (valves). This assures safe operation of the system in the absence of the network connectivity, for example, due to a power outage. It is important to make sure the field devices (sensors and valves) are designed to work effectively under harsh weather conditions. It is also recommended to have redundant measurement of critical inputs, such as water level. A safe design also requires a pure mechanical overflow provision.

For the automation level, this report provided the advantages and disadvantages of different universal and customized control solutions. For an ICI building, a universal solution, such as PLC or PAC (e.g., CompactRIO), could provide much more flexibility, reliability, and better customer service. Furthermore, a universal solution is futureproof, although it may cost more than a customized solution, such as Levelpro. At a small scale, when cost is the main factor in decision making, customized solutions have a market. However, when it comes to large scale (across multiple buildings) adoption of the technology or adoption by large ICI building owners, the universal solution may be more appealing.

Finally, with regard the IoT platform, this report examined the advantages and disadvantages of the solutions provided by large suppliers, such as Amazon, and smaller companies, such as Momentaj Inc. A smart blue roof system for a single building with a local controller would use the IoT platform for remote connectivity, monitoring the status of the sensors and devices and to access weather data from the internet. Internet connectivity would not be critical, if a separate, dedicated on-site weather forecast station could be directly connected to the local controller. As a result, for such projects, more affordable solutions that come with better customization would be recommended. In the case of a larger system spanning multiple buildings that is monitored/controlled through the internet, the more futureproof solution, such as AWS, would be recommended.

# 4.0 TECHNICAL AND FINANCIAL FEASIBILITY ASSESSMENT OF SMART BLUE ROOF SYSTEMS AT A SITE, STREET, AND NEIGHOUBRHOOD SCALE

## 4.1 Introduction

To assess the feasibly of implementing a smart blue roof on CVC's Building A, this report began with a structural assessment using CVC Building A's design drawings, associated design calculations and a Building Code evaluation. This was followed by a general feasibility assessment of the automated aspects of an active, smart blue roof systems with rain harvesting capacity. The present chapter focuses on a technical and financial feasibility assessment of implementing a smart blue roof system on three different scales: at the building scale, at the street scale, and at a neighbourhood scale. This assessment includes a hydrologic and hydraulic analysis, water demand modelling, energy conservation and GHG reductions, as well as cost and benefit estimates for implementing a smart blue roof system at these three different scales.

## 4.2 Evaluation of Localized Flood Control Potential of Blue Roof Retrofits on a Site Scale

Using the existing conditions of CVC's Office Building A as the foundation, the following presents an analysis of the feasibility of blue roof implementation at the building scale in Mississauga, Ontario.

### *4.2.1 Hydrologic and Hydraulic Modelling at the Site Scale*

Using data collected from CVC's existing RWH system, peak flow control, runoff volume reduction and water quality treatment were assessed for three (3) different roof system options:

1. Solely a RWH system with a 5 $m^3$ storage tank (RWH) and existing roof drains (i.e. no flow control);
2. A RWH system coupled with passive Zurn flow control drains (BR), and;
3. A RWH system coupled with a blue roof with real- time controls (SBR+RWH).

The first two (2) scenarios do not allow for any active control in terms of stormwater detention, while the third scenario is connected to weather data and allows for active storage control.

#### *4.2.1.1 Existing Conditions – RWH*

**Table 11** summarizes the total precipitation that fell on Building A from 2014 through 2017, sorted by event size. The largest event occurred in 2015, with 73.8 mm of precipitation. Over this four-year period, it appears that the existing RWH system was able to capture, on average, 14% of the rain events by volume (using actual consumption and RWH tank water level data). Potential capture volume was calculated using the total roof area (645 $m^2$) and the precipitation depth for each event.

As expected, cumulatively, the smallest events contributed most to the captured volume (31%) while the larger events contributed significantly less (5%). It is worth noting that these values are most likely lower than they appear in the table, as the RWH system is also supplemented with water collected by a sump pump. Thus, the ability of the RWH system to capture rain events is limited due to less available active storage. Total event capture rates for each year are shown in **Table 12**. The volume of water collected by the sump pump has been estimated, as shown in Table 13. It is estimated based on increases in the water level in the RWH tank during times when there is no precipitation overnight. Based on analysis of the water level in the tank during these times, it is considered unlikely that the sump pump pumps water into the RWH tank at a constant rate. Thus, it is not considered reliable enough to apply to rain events to determine actual event capture rates.

**Table 11 Total precipitation event capture rates, 2014-2017**

| Event Size | 2-5 mm | 5-10 mm | 10-15 mm | 15-20 mm | 20-25 mm | 25-30 mm | ≥ 30 mm | Total |
|---|---|---|---|---|---|---|---|---|
| **Event Count** | 77 | 33 | 19 | 16 | 9 | 6 | 9 | 169 |
| **Event Frequency (%)** | 46% | 20% | 11% | 9% | 5% | 4% | 5% | 100% |
| **Potential Capture Volume ($m^3$)** | 169.28 | 153.25 | 151.51 | 175.96 | 128.87 | 107.81 | 242.39 | 1,129.07 |
| **Captured Volume ($m^3$)** | 51.80 | 28.00 | 26.47 | 26.94 | 8.22 | 6.82 | 12.53 | 160.79 |
| **Percent Captured** | 31% | 18% | 17% | 15% | 6% | 6% | 5% | 14% |

**Table 12 Precipitation event capture rates by year, 2014-2017**

| Year | Volume Captured ($m^3$) | Potential Volume ($m^3$) | Percent of Events Captured |
|---|---|---|---|
| **2014** | 29.19 | 205.11 | 14% |
| **2015** | 36.95 | 362.68 | 10% |
| **2016** | 35.62 | 199.82 | 18% |
| **2017** | 59.02 | 361.46 | 16% |

**Table 13 CVC RWH system historical collection and usage, 2014-2017**

| Year | Precip-itation (mm) | Maximum Potential Volume[1] ($m^3/y$) | Metered Usage[2] ($m^3/y$) | Tank Level Usage[3] ($m^3/y$) | Potential Sump Added Volume[4] ($m^3/y$) | Potential Actual RW Use[5] ($m^3/y$) | Municipal top-up[6] ($m^3/y$) | Municipal Water Use[7] ($m^3/y$) | Average Daily Water Use[8] ($m^3/d$) |
|---|---|---|---|---|---|---|---|---|---|
| **2014** | 688.20 | 443.89 | 160.15 | 195.10 | 109.11 | 51.04 | 0.85 | 1,023.77 | 4.75 |
| **2015** | 658.35 | 424.64 | 173.70 | 237.37 | 116.29 | 57.41 | 3.62 | 1,142.17 | 5.28 |
| **2016** | 621.60 | 400.93 | 222.96 | 228.84 | 118.86 | 104.10 | 0.13 | 1,402.78 | 6.56 |
| **2017** | 815.80 | 526.19 | 263.43 | 248.36 | 121.50 | 141.93 | 0.00 | 1,027.33 | 5.20 |

#### *4.2.1.2 Conceptual Design Analysis (BR and SBR+RWH)*

Peak flow and runoff reduction were evaluated for each of the following three various system design scenarios:

1. Rainwater harvesting only (RWH only). Existing conditions at the CVC office.
2. Passive blue roof with no active controls (passive BR)
3. Smart blue roof with active controls and existing rainwater harvesting (Smart BR + RWH)

The current rainwater harvesting tank volume equates to a roof ponding depth of 7 mm. Increasing the size of the rainwater harvesting tank was considered however, because approximately 70% of precipitation events in southern Ontario are < 10 mm, increasing the rainwater harvesting tank was deemed inefficient, costly and would decrease available storage area in the basement.

Two design storms were then applied to illustrate the capacity of the blue roof systems:

- the City of Mississauga intensity-duration frequency curves was used to estimate the rainfall intensity for the 100-year 10-minute storm and the rational method was used to calculate peak flow
- The peak intensity from the Chicago 100-year four-hour design storm with the rational method in order to calculate peak flow

[1] Maximum potential volume refers to the total rainwater that lands on the roof over the year

[2] This is the actual amount of rainwater usage metered at the outlet of the rainwater storage tank

[3] This is the amount of water used from the rainwater storage tank calculated from the tank using a level-logger

[4] The rainwater storage tank is also fed by sump water, a significant amount of the storage volume is used up by sump water

[5] This is the amount of water used from the storage tank that is rainwater. It is the difference between metered usage and sump water.

[6] When the storage tank level reaches the lower limit the level is top-ed up with municipal water to ensure supply

[7] Total municipal water use on site, change in basement municipal water meter throughout the year

[8] Total average daily water use on site

These storms were chosen for the analysis, since they were both used in CVC's stormwater credit application.

The conceptual design for the smart blue roof with RWH on Building A is illustrated in Drawings 1-4 in **APPENDIX C**. Passive flow control roof drains are proposed for Zones 1 and 3 of the roof, where the HVAC units are located as well as the 1-storey garage roof. A simple schematic is provided in
**Figure 12** below.

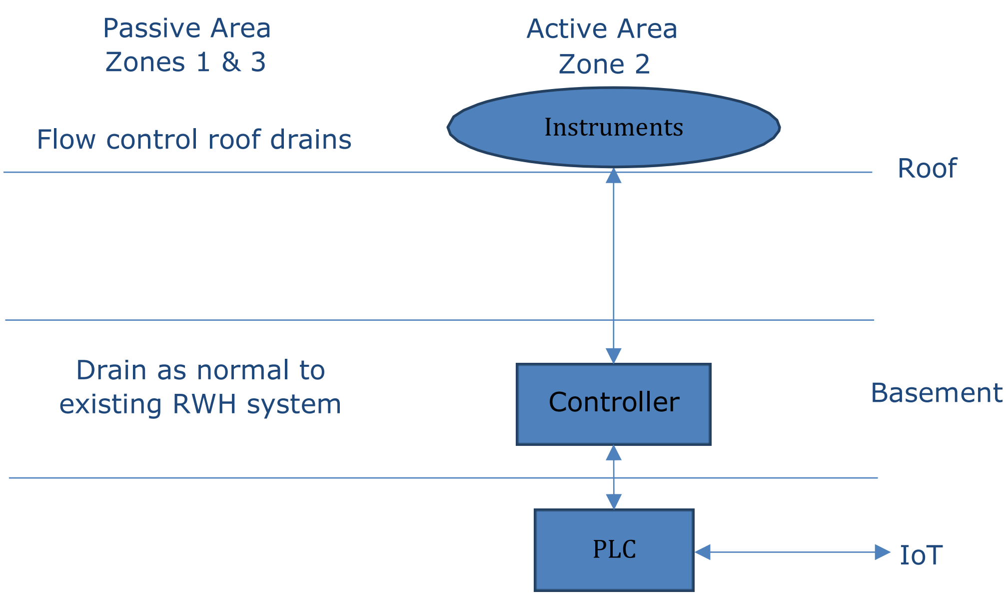


**Figure 12 Schematic diagram of Proposed Conceptual Smart Blue Roof with Active Controls and Rainwater Harvesting System**

The RWH system does not significantly reduce peak flow, since the tank provides little active storage capacity. The blue roof with passive Zurn flow- controlled drains will not reduce the volume of runoff, but it will reduce peak flow by 85% (0.027 $m^3/s$) in the Mississauga case, and by 89% (0.062 $m^3/s$) in the Chicago case (based on seven (7) flow-controlled Zurn roof drains with a rated flow rate of 37.85 LPM on average over the duration of a 25 mm  rain event), Table 14.

The smart blue roof with RWH will reduce peak flow almost entirely in both the Mississauga and the Chicago storm case, since the part of the roof used with active controls will eliminate the flow that would have otherwise entered the storm sewer, and zones 1 and 3 will have three flow-controlled roof drains, slowing down runoff. For the Mississauga storm, the combined SBR + RWH system will reduce runoff volume by 54%, and for the Chicago storm, 36% of runoff volume will be reduced, as shown in **Table 14**. The runoff volume reduction percentages are less for larger storms because the active area is about half of the total roof area (13.85 m x 22.895 m = 317.1 $m^2$; See design drawings in **APPENDIX C**), and the contribution to reduction of the RWH system remains the same for both storms, since the RWH storage volume does not change. Using the maximum potential depth of water on the roof (150 mm (6”) at the lowest point due to the height of the barrier separating the different zones of the roof, as seen in the drawings in **APPENDIX C**) and factoring in the sloped roof (which reduces the total water volume by a third as compared to a completely flat surface), the potential available storage volume of the blue roof is 16 $m^3$. When combined with the existing RWH system, total available storage becomes about 21 $m^3$.

**Table 14 Peak flow and runoff reduction comparison for RWH system, flow-controlled blue roof and smart blue roof with RWH**

**Mississauga Intensity-Duration-Frequency (IDF) Curve**

| | |
|---|---|
| 100-year storm maximum rainfall intensity (mm/h) | 176.3 |
| Depth (mm) (10 minutes using Mississauga IDF curve) | 29.38 |

| | Existing Conditions | RWH (5 $m^3$) | Passive BR | SBR + RWH (21 $m^3$) | | |
|---|---|---|---|---|---|---|
| | | | | Passive Area | Active Area | Total |
| **Peak flow ($m^3$/s)** | 0.032 | | 0.0048 | 0.002 | | |
| **Peak flow reduction ($m^3$/s)** | | | 0.027 (85%) | 0.014 | 0.016 | 0.030 (94%) |
| **Water volume ($m^3$)** | 18.95 | | | | | |
| **Runoff reduction (mm)** | | 1.5 | | 2.95 | 29.38 | 15.95 |
| **Runoff reduction ($m^3$)** | | 0.9675 | | 0.9675 | 9.32 | 10.28 (54%) |

**Chicago Design Storm**

| | |
|---|---|
| Chicago design storm max rainfall intensity (mm/h) | 370.68 |
| Chicago design storm depth (mm) | 72 |

| | | RWH (5 m3) | BR (no storage) | BR + RWH (21 $m^3$) | | |
|---|---|---|---|---|---|---|
| | | | | Passive Area | Active Area | Total |
| **Peak flow ($m^3$/s)** | 0.066 | | 0.0071 | 0.002 | | |
| **Peak flow reduction ($m^3$/s)** | | | 0.059 (89%) | 0.032 | 0.033 | 0.065 (97%) |
| **Water Volume ($m^3$)** | 46.44 | | | | | |
| **Runoff reduction (mm)** | | 1.5 | | 2.95 | 49.98 | 26.07 |
| **Runoff reduction ($m^3$)** | | 0.9675 | | 0.49 | 15.85 | 16.82 (36%) |

**Notes:**

- Peak flow was calculated using the maximum rainfall intensity multiplied by the roof area. For example: 176.3 mm/h x 1 m/1000 mm x 1 h/60 min x 1 min/60 s x 645 $m^2$ = 0.032 $m^3$/s.
- Volume of water falling on roof was determined using the rainfall depth multiplied by the roof area. For example: 29.38 mm x 1 m/1000 mm x 645 $m^2$ = 18.95 $m^3$Although the RWH tanks has a capacity to capture 5,000L, only 1/5$^{th}$ of the capacity is available for active storage. Runoff reduction for the RWH system used the active storage volume calculated by CVC based on data collected from their monitoring system (967.5 L) divided by the roof area to get depth in mm.
- The runoff volume reduction was then calculated using the total water volume divided by the roof area used for storage and added the reduction associated with the RWH system for the non-storage area of the roof. For example: 18.95 m3 x 317 m2 / 645 m2 + 0.9675 m3 x 328 m2 / 645 m2 = 9.81 m3
- It is important to note that due to the sloped nature of the roof and the maximum storage depth of 150 mm, the Chicago design storm exceeded the capacity of the active blue roof area. Thus, the runoff reduction is equivalent to the maximum storage capacity of the blue roof.
- Effects on water quality are negligible in all three scenarios, as there is no filtration system prior to discharge to the storm sewer. If a filtration system is installed, water quality would need to be measured to determine effectiveness. The draft smart blue roof with RWH design includes such a filter, and, if implemented, water quality improvements could then be measured.
- Based on this analysis, the smart blue roof with RWH out-performs both the RWH system alone and the Blue roof with flow-controlled drains in terms of peak flow and runoff mitigation. This will have stormwater management benefits and will also allow for more water to be reused, as discussed in the following section.

## 4.3 Water Demand Modelling at the Site Scale

The following provides a water demand modelling analysis for two blue roof system options at CVC.

### *4.3.1 Water Use from Existing Rainwater Harvesting System*

Water demand was determined using the most recent and most complete consumption data collected from CVC's existing RWH system during 2016 and 2017. Demand is estimated to be 1.58 m3/day for toilet and urinal flushing only. The system is tied in for irrigation use, but the rainwater collected is not currently being used for irrigation. Total consumption (i.e. potable and non-potable water use in both building A and B) at the CVC office (see

Table 13) was 5.68 m3/day, on average, from 2016-2017. This means there is potential for increased reclaimed water use. Although a full analysis of water use has not been done, if a greater volume of potable water can be offset with rainwater, water savings will increase.

### *4.3.2 Smart Blue Roof with Rainwater Harvesting*

Rainwater use for the RWH system only scenario and for the smart blue roof with RWH were analyzed using Connect the Drops RWH software for illustrative purposes (note: it does not take into account sump water). **Table 15** shows potential water use along with overflow volume, percentage and number of events. It can be seen that the potential annual rainwater use increases 185% with the increase storage volume provided by the active blue roof. It should be noted that this analysis does not take into account the potential need to drain the blue roof for inspection and maintenance purposes.

**Table 15 Potential water savings for RWH system & smart blue roof with RWH**

| | RWH ($5\ m^3$) | BR + RWH ($21\ m^3$) | | |
|---|---|---|---|---|
| | | Passive Area | Active Area | Total |
| **Daily RW consumption ($m^3$)** | 1.58 | 1.58 | 7.33 | 10.42 |
| **Annual Rainwater Use ($m^3$)** | 190.5 | 312 | 350.8 | 351.9 |
| **Annual Water Purchase Savings ($)** | $276 | $452 | $509 | $510 |
| **Annual Overflow ($m^3$)** | 140 | 75.1 | 36.3 | 35.1 |
| **Percent of Rainwater Collected that is Used** | 57.6% | 80.6% | 90.6% | 90.9% |
| **Annual Number of Overflow Events** | 28 | 11 | 8 | 8 |

Using the precipitation data collected at the CVC office, potential water volume collection was calculated. Using two (2) different consumption scenarios, the number of times two days' (48 hours) worth of water consumption was exceeded was calculated. In addition, the number of times three days' (72 hours) worth of water consumption was exceeded was calculated (since there may be potential to apply for an exception to the Ontario Building Code legislation ie. municipal flow control drain declarations). With the current consumption, there were 42 events, which would have resulted in the loss of 100 $m^3$ over three years (or 19 events losing 52 $m^3$, if water can be stored for three days). If all consumption can be offset, there were five events losing 13 $m^3$ over three years (or just a single event losing 3.9 $m^3$, if water can be stored for three days). This suggests that if more reclaimed water can be used, issues associated with storing water for more than two or three days may not be much of a concern. In fact, if the CVC grounds were irrigated using the stored rainwater, two days' supply was exceeded just once, and three days' supply not at all. It should be noted that evaporation was also taken into account for this exercise (see example calculations/tables in **APPENDIX D**).

**Table 16 Potential drainage events for blue roof under various usage scenarios (2014-2017)**

| | | No. of Times 2 days' Supply Exceeded | Volume "lost" ($m^3$) | No. of Times 3 days' Supply Exceeded | Volume "lost" ($m^3$) |
|---|---|---|---|---|---|
| **Daily Consumption ($m^3$)** | 1.58 | 42 | 100.27 | 19 | 52.44 |
| **Potential Daily Consumption ($m^3$)** | 5.68 | 5 | 12.91 | 1 | 3.89 |
| **Potential Irrigation Demand ($m^3$)** | 5.75 | 1 | 6.79 | 0 | 0.00 |
| **Potential Irrigation Demand ($m^3$)** | 8.84 | 1 | 1.14 | 0 | 0.00 |

#### 4.3.3 Scaling Up and Transferability Across ICI Sector

As illustrated in the previous section, increased usage of stored rainwater improves the efficacy of a blue roof in terms of both stormwater management and reduced potable water consumption.

The CVC building that is serving as the basis for this particular analysis and design is a small office. As such, it has relatively few non-potable water uses. It should be noted that the benefits of smart blue roof systems increase when taking economies of scale into consideration.

In addition, different ICI buildings can have a varying degree of demand for non-potable water uses, such as vehicle washing or cooling tower makeup. This means that there is even greater potential to increase blue roof benefits when implementing at a street or neighbourhood scale.

### 4.4 Evaluation of Localized Flood Control Potential of Blue Roof Retrofits on a Street Scale

An analysis was carried out to assess the localized flood control, runoff volume reduction, and greenhouse gas and energy emission offset benefits associated with a street-scale blue roof retrofit within an industrial/commercial (I/C) landscape. The goal was to assess the net, cumulative benefit associated with smart blue roofs and RWH cisterns at the street-scale. The potential increase in infrastructure resiliency to extreme weather events was of interest.

#### 4.4.1 Hydrologic and Hydraulic Modelling at the Street Scale

##### 4.4.1.1 Study Area

I/C neighbourhoods across the GTA are typically highly impervious. The typical imperviousness ranges between 50% to 80% and 60% to 90% for light and heavy I/C areas respectively. Depending on the age of development, different standards were required by municipalities for sizing storm sewer systems. For example, the study area selected for this analysis (**Figure 13**) was designed and built in the 1980's and used a post-development runoff coefficient of 0.60. Conversely, current standards dictate that a runoff coefficient of 0.75 or 0.80 be used for this area instead. This particular area was selected, as many of the building rooftop sizes are similar in size to CVC's building A. The study neighbourhood is also representative of typical I/C neighbourhoods that exist across Southern Ontario and have no meaningful onsite or end-of-pipe SWM controls.

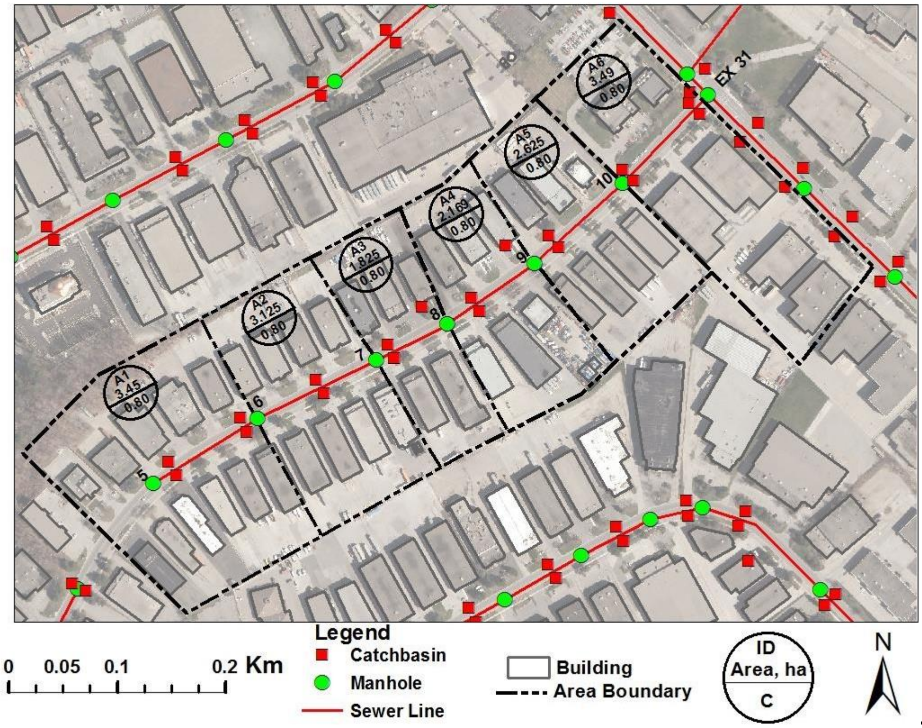


**Figure 13 Selected study area**

### 4.4.1.2 Methodology and Results

The Rational Method is commonly used to size storm sewers, with individual municipalities specifying the input parameters to be used within the computational formulae. The Rational Method provides the highest peak flow for a given return period for a specified storm intensity and duration. Parameters which may be specified include: inlet time, travel time, and runoff coefficients for different land use types (e.g. grass, asphalt, etc.). The size of the storm sewer system for this neighbourhood was dictated by the input parameters used and appears to have been designed to convey the 1-in-10-year storm event (using an historically applied runoff coefficient of 0.60). The total site area is approximately 16.7 ha with relatively uniform slope graded from southwest to northeast (**Figure 14**). The existing and proposed conditions of the subject property based on 2, 5, 10, 25, 50 & 100-year storms events have been analyzed.

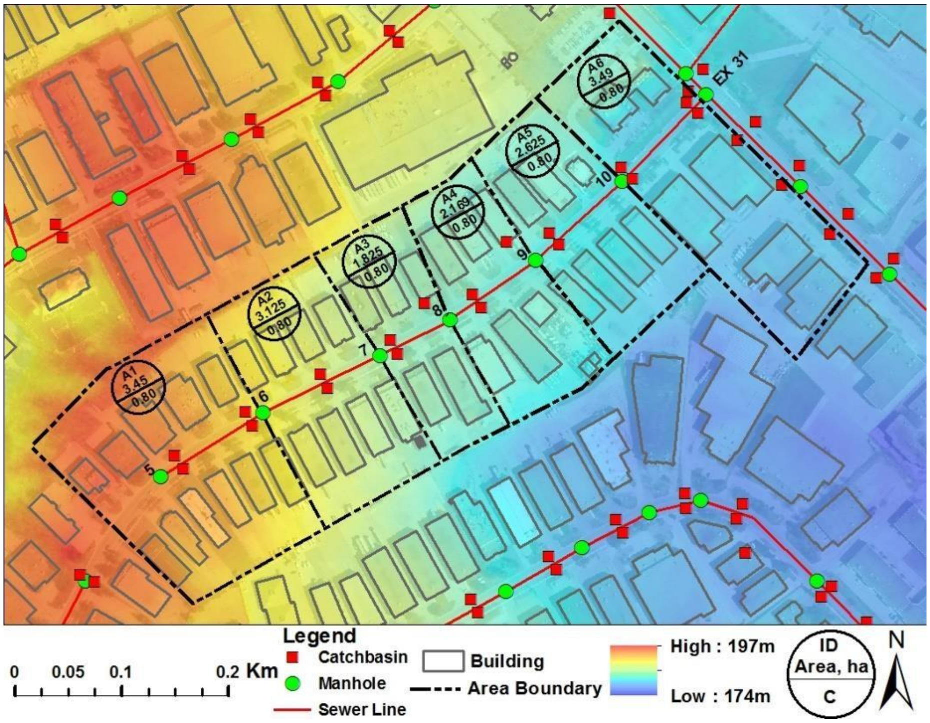


**Figure 14 Topographic relief within the study area**

##### 4.4.1.2.1 Storm Sewer System Capacity Based on 1980's Design Standards

Using the existing storm sewer network, the peak discharge from the study drainage area was estimated using the Rational Method for the various storm return periods. The Rational Method is primarily used as a design tool for the design of minor drainage systems such as storm sewers. It uses runoff coefficients, hourly rainfall intensity, and drainage area to calculate the peak flow rate. The runoff coefficient represents the fraction of rainfall converted to runoff. The peak flow for the design storm (10 years) was calculated using the following equation:

$$Q = \frac{\mathrm{CIA}}{360}$$

Where:

C = Runoff coefficient (0.60 according to original 'as built' design)
I = Rainfall Intensity (mm/hr)
A = Total area (ha) for each drainage sub-catchment that contribute flow to an outlet.

The rainfall intensity – I – is in turn computed according to the following:

$$I = \frac{\mathrm{A}}{(\mathrm{Tc} + \mathrm{B})^{C}}$$

Where:

$T_c$ = Time of Concentration (mins)
A = Total area (ha) for each drainage sub-catchment
a, b and c are coefficients (summarized below in **Table 17**)

**Table 17 City of Mississauga Intensity-Duration-Frequency curve parameters**

| Storm Events (Years) | a | b | c |
|---|---|---|---|
| **2** | 610 | 4.6 | 0.78 |
| **5** | 820 | 4.6 | 0.78 |
| **10** | 1010 | 4.6 | 0.78 |
| **25** | 1160 | 4.6 | 0.78 |
| **50** | 1300 | 4.7 | 0.78 |
| **100** | 1450 | 4.9 | 0.78 |

The rainfall intensity was calculated by using the City of Mississauga IDF rainfall curves. The $T_c$ term describes the time response of a watershed to the runoff and is the time required for a parcel of runoff to travel from the most hydraulically distant part of a watershed to the point under investigation. It is a theoretical concept but is useful for design purposes. The most upstream pipe in the minor system was designed for $T_c$ = 15 minutes. For each subsequent pipe section, the time of concentration is based on the sum of $T_c$ and time of flow in the section. The time of flow in the sections (t) was calculated according to the following:

$$t\,(\text{min}) = \frac{L}{V\text{x}60}$$

Where:

L = Length of section (m) and V = the velocity of pipe (m/s)

Subsequent to the above, the calculated peak flow rate can be used to size the storm sewer system. The capacity of a pipe flowing full is calculated using Manning's equation (below) for a pipe of a set material, specified Manning’s roughness coefficient, internal pipe diameter, and slope.

$$V = \left[\frac{1}{n}\right] R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where:

V = flow velocity
n = Coefficient of roughness (0.013 for a smooth walled concrete pipe)
R = Hydraulic Radius (m), calculated by diving the cross-sectional area of flow within the pipe by the wetted perimeter (AF/PW)
S = slope (m/m)

For a concrete storm sewer pipe (flowing full), the City of Mississauga reported maximum and minimum permissible flow velocities are 4.0 m/s and 0.75 m/s, respectively.

$$Q = VA$$

Where:

Q = the pipe capacity ($m^3/s$)
V = flow velocity
A = Cross-sectional area of pipe ($m^2$)

The 10-year peak flow rate computed using the rational method was determined to be 2.48 $m^3/s$. Similarly, the estimated storm sewer pipe capacity calculated using Manning's equation was determined to be 2.78 $m^3/s$. The peak flow rate and designed storm sewer pipe capacity for different pipe sections in the case study neighbourhood network for the 10-year storm event are tabulated in Table 18.

**Table 18 Storm sewer system design flows for 10-year storm event (runoff coefficient = 0.6)**

| Street Scale Sub-catchment ID | From up-stream | To down-stream | Pipe size/ Diameter | Adjacent contributory area | Peak flow by Rational Method (Q) | Slope | Concrete pipe diameter | Length of section | Capacity of pipe (Q) |
|---|---|---|---|---|---|---|---|---|---|
| | MH# | MH# | mm | ha | $m^3/s$ | % | mm | m | $m^3/s$ |
| **A1** | 5 | 6 | 525 | 3.45 | 0.57 | 2.8 | 525 | 120 | 0.73 |
| **A2** | 6 | 7 | 600 | 3.13 | 1.06 | 4.2 | 600 | 120 | 1.27 |
| **A3** | 7 | 8 | 750 | 1.83 | 1.33 | 2.4 | 750 | 97 | 1.74 |
| **A4** | 8 | 9 | 975 | 2.17 | 1.65 | 0.6 | 975 | 94 | 1.75 |
| **A5** | 9 | 10 | 1050 | 2.63 | 2.01 | 0.6 | 1050 | 112.5 | 2.13 |
| **A6** | 10 | EX31 | 1200 | 3.49 | 2.48 | 0.5 | 1200 | 120 | 2.78 |

In the present analysis the peak flow rates were also calculated and compared for the 2, 5, 25, 50 and 100-year return period storms.

#### 4.4.1.2.2 Storm Sewer System Capacity Based on Existing Conditions

The street scale study area's storm sewer was designed and constructed in the 1980's using a runoff coefficient of 0.60 for the 10-year storm event. The runoff coefficient values that are recommended for common urban land use types in future developments are shown in Table 19.

**Table 19 Runoff coefficient values for different land use types**

| Land use | City of Brampton[2] | City of Mississauga[3] |
|---|---|---|
| **Parks** | 0.25 | 0.30 |
| **Single ad Semi-Detached** | 0.50 | 0.55 |
| **Multiple, Institutional** | 0.75 | |
| **High-rise residential** | | 0.90 |
| **Industrial and Commercial** | 0.90 | 0.90 |
| **Roadways** | 0.90 | 0.90 |

The City of Mississauga recommends that a runoff coefficient of 0.90 is used where future industrial or commercial development is expected. Moreover, in order to account for the increase in runoff due to saturation of the catchment surface, an adjustment factor of 1.0, 1.1, 1.2 or 1.25 is used for the 10, 25, 50 and 100-year return period storms, respectively. Where storm sewers are being planned and include a direct outlet to a receiving stream or watercourse, an adjustment to the design flows (e.g. a 20% increase to the IDF curve intercept) is proposed to account for future climate change scenarios. This is in conformance with guidance provided by Canadian climate research groups. Stormwater management is required to mitigate the impacts of changing runoff patterns and a modified hydrologic cycle which results from urbanization and climate change.

For analysis of the site being analyzed in this section, actual pervious and impervious areas on the study site were measured and their respective runoff coefficients weighted. An actual runoff coefficient of 0,80 was calculated for the site. No adjustment for climate change was made in this analysis as current existing conditions were being assessed.

The peak flows from the case study area were recalculated for the 2, 5, 10, 25, 50 and 100-year return period storms, this time using the calculated runoff coefficient of 0.80. Recalculating the design flows using an increased runoff coefficient value led to the determination that the capacity of the existing storm sewer system would not be able to convey the 10-year storm. Subsequently, flows in excess of the 5 year event (ie. capacity of the as-built minor system) would result in overland flow (**Table 20**).

**Table 20 Existing Peak Flows for street scale sub-catchment ID A6, Section 10 to EX31 (See Table 20) (runoff coefficient = 0.8)**

| Storm event return period (years) | Adjacent contributory area (ha) | Rainfall intensity (mm/h) | Peak Flows (Q: $m^3/s$) |
|---|---|---|---|
| **2** | 16.68 | 53.8 | 1.99 |
| **5** | 16.68 | 72.3 | 2.68 |
| **10** | 16.68 | 89.1 | 3.3 |
| **25** | 16.68 | 102.3 | 3.79 |
| **50** | 16.68 | 114.2 | 4.23 |
| **100** | 16.68 | 126.5 | 4.69 |

#### 4.4.1.2.3 Storm Sewer Capacity Under Smart Blue Roof Retrofit Scenario

Analysis was performed to determine the stormwater management benefit derived by applying the smart blue roof concept. The total roof area was calculated for each drainage sub-area. The percentage of rooftop area is listed in **Table 21**. In the neighbourhood area selected for this case study, the total drainage area is approximately 30% rooftops.

**Table 21 Percentage of Drainage Area that is Rooftop in the study I/C area**

| Street Scale Sub-catchment ID | Adjacent contributory area (ha) | Rooftop Area (ha) | Percentage as Rooftop Area (%) |
|---|---|---|---|
| **A1** | 3.45 | 1.14 | 33 |
| **A2** | 3.13 | 0.85 | 27 |
| **A3** | 1.83 | 0.57 | 31 |
| **A4** | 2.17 | 0.67 | 31 |
| **A5** | 2.63 | 0.71 | 27 |
| **A6** | 3.49 | 1.08 | 31 |

The application of smart blue roofs can reasonably be expected to reduce peak flow rates for the 2, 5, 10, 25, 50 and 100-year return period storms. In the analysis it was assumed that all rooftops are flat and will capture 100% of the rainfall that lands on it. A complete list of assumptions is provided below:

- Each roof has the structural and storage capacity to pond a minimum of 100 mm of water
- The entire roof area of each building can be used for storage
- There is a parapet on each rooftop
- Each building is complemented by a RWH tank in addition to a blue roof
- All rooftops in the neighbourhood would be operated as a single, optimized system using real time controls via an IoT-based approach

In accordance with the assumptions listed, the roof area was subtracted from the drainage area for each sub-catchment and the peak flow was estimated by considering the remaining drainage area and applying an adjusted runoff coefficient (C = 0.70). The adjusted runoff coefficient accounts for the decrease in total effective imperviousness associated with rooftop-based stormwater retention. Table 22 provides a summary of peak flows for the various return periods, if all the buildings were retrofitted with smart blue roofs.

**Table 22 Peak flow comparison pre and post Smart Blue Roof Retrofit for the** street scale sub-catchment ID A6, **Section 10 to EX31**

| Storm event return period (years) | Adjacent contributory area (ha) | Rainfall intensity (mm/h) | Post Retrofit (with Blue Roof) peak flows (Q: $m^3/s$) | Pre- to post- retrofit peak flow reduction (%) |
|---|---|---|---|---|
| **2** | 16.68 | 53.8 | 1.22 | 38 |
| **5** | 16.68 | 72.3 | 1.64 | 38 |
| **10** | 16.68 | 89.1 | 2.01 | 39 |
| **25** | 16.68 | 102.2 | 2.31 | 39 |
| **50** | 16.68 | 114.2 | 2.58 | 39 |
| **100** | 16.68 | 126.5 | 2.86 | 39 |

#### 4.4.1.2.4 Deferred or Avoided Capital Expenditures

The analysis above demonstrates that the smart blue roof application on a street scale has the potential to reduce peak flows and to relieve pressure on the existing minor drainage system, where the existing pipes are undersized. Since storm sewers are typically designed for a service life ranging between 80 and 100 years, and the study area was originally built in the 1980's, it stands that peak flow reductions resulting from blue roof application have the capacity to extend the useful remaining service life of the existing storm sewers by 40 to 60 years. In the analysis that follows, it is assumed that there is no defined overland flow route and thus when the minor system surcharges there is risk of flooding. In such a case, it may be warranted to consider the avoided cost of upgrading the minor system from use of smart blue roof systems. This may not be the case in every situation where the minor system is undersized.

#### 4.4.1.2.5 Estimated Annual Runoff Volume Reduction

The average annual precipitation from a nearby City of Mississauga rain gauge (located on the roof of the CVC head office) was analyzed for the period of 2014 – 2017 inclusive. The average precipitation received each year was of 695 mm. Summary metrics related to this dataset are provided in the following table (**Table 23**).

**Table 23 Average annual precipitation characteristics**

| Year | Annual Precipitation (total: mm) | Total Number of days with precipitation | Largest single day event (mm) | Number of days with >0 but ≤1 mm of precipitation | Total precipitation accounted for by events <1 mm in size (mm) |
|---|---|---|---|---|---|
| **2014** | 688.2 | 103 | 35.8 | 59 | 20 |
| **2015** | 658.4 | 80 | 39.4 | 35 | 14 |
| **2016** | 621.4 | 99 | 28 | 54 | 23 |
| **2017** | 815.8 | 109 | 38.8 | 59 | 23.6 |

The average monthly distribution of precipitation received by the CVC head office gauge is plotted in **Figure 15**.

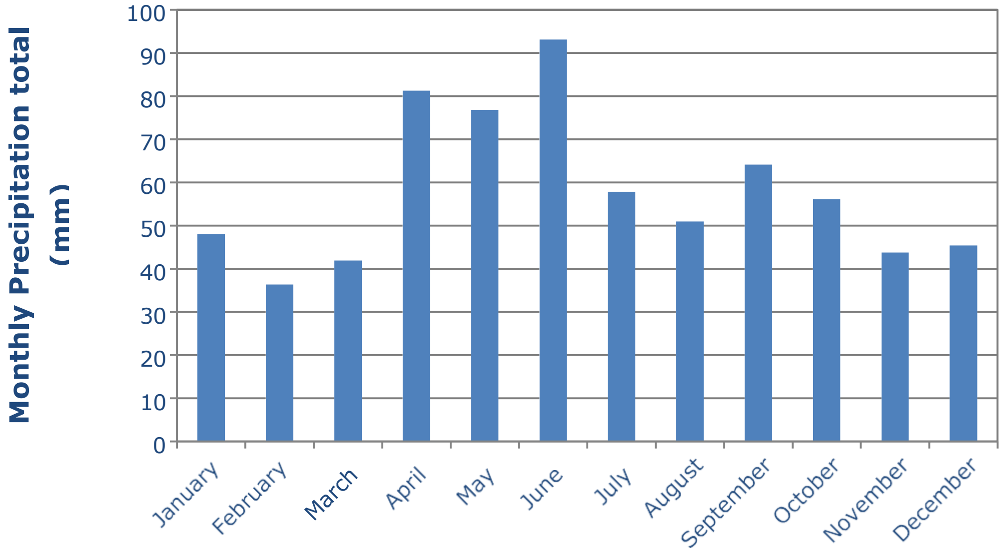


**Figure 15 Mean monthly precipitation totals (CVC office) (2014-2017)**

Since the largest single-day event was 39.4mm over the 4 years analyzed and estimating that most buildings in the study area have a rooftop capacity approximately equal to 180 mm of water, (similar to CVC's Building A) it is reasonable to assume that the rooftops in the study area are capable of retaining all events over the time period specified (695 mm annually). Multiplying the sub- catchment rooftop areas reported in **Table** 15**22** by 695mm yields the following (**Table 24**):

**Table 24 Average annual runoff volume abstraction (street scale sub-catchment basis)**

| Street Scale Sub-catchment ID | Rooftop Area (ha) | Average Annual Runoff Volume Reduction ($m^3$) |
|---|---|---|
| **A1** | 1.14 | 7,923 |
| **A2** | 0.85 | 5,908 |
| **A3** | 0.57 | 3,962 |
| **A4** | 0.67 | 4,657 |
| **A5** | 0.71 | 4,935 |
| **A6** | 1.08 | 7,506 |

**Total: 34,891 ($m^3$)**

Therefore, if rainwater can be fully utilized and/or evaporated for cooling purposes, the average annual runoff reduction equates to approximately 34,891 $m^3$ (approximately 210mm/year) across the study area.

## 4.5 Evaluation of Localized Flood Control Potential of Blue Roof Retrofits on a Neighbourhood Scale

In addition to the above discussed site and street scale analyses, a third analysis was conducted at the neighbourhood scale. Based on flood control needs identified in the Cooksville Creek Flood Evaluation Master Plan (Aquafor Beech Ltd., 2012), a catchment area in the Matheson neighbourhood located in the headwaters of the Cooksville Creek watershed in Mississauga near Matheson Road was selected. This analysis will assess the localized flood control, runoff volume reduction, water efficiency improvements, as well as greenhouse gas and energy emission offset co-benefits associated with a neighbourhood-scale blue roof retrofit within a commercial/residential landscape. While the street scale analysis considered an area of 17 ha with a rooftop area of 5 ha, this neighbourhood scale analysis considers a drainage area of 565.2 ha with 133.6 ha of rooftop drainage area suitable for blue roof application.

### *4.5.1 Assessment Approach of Matheson Pond Neighbourhood Scale Analysis*

The study area currently contains a wet pond facility called the Matheson Pond, which consists of both a wet pond and wetland, which provides water quality control and flood attenuation during major storm events. For this analysis we sized a new end of pipe facility to achieve a similar level of service based on the current conditions and level of impervious cover. **Figure 16** illustrates the footprint of the existing Matheson pond drainage areas within the Cooksville Creek watershed.

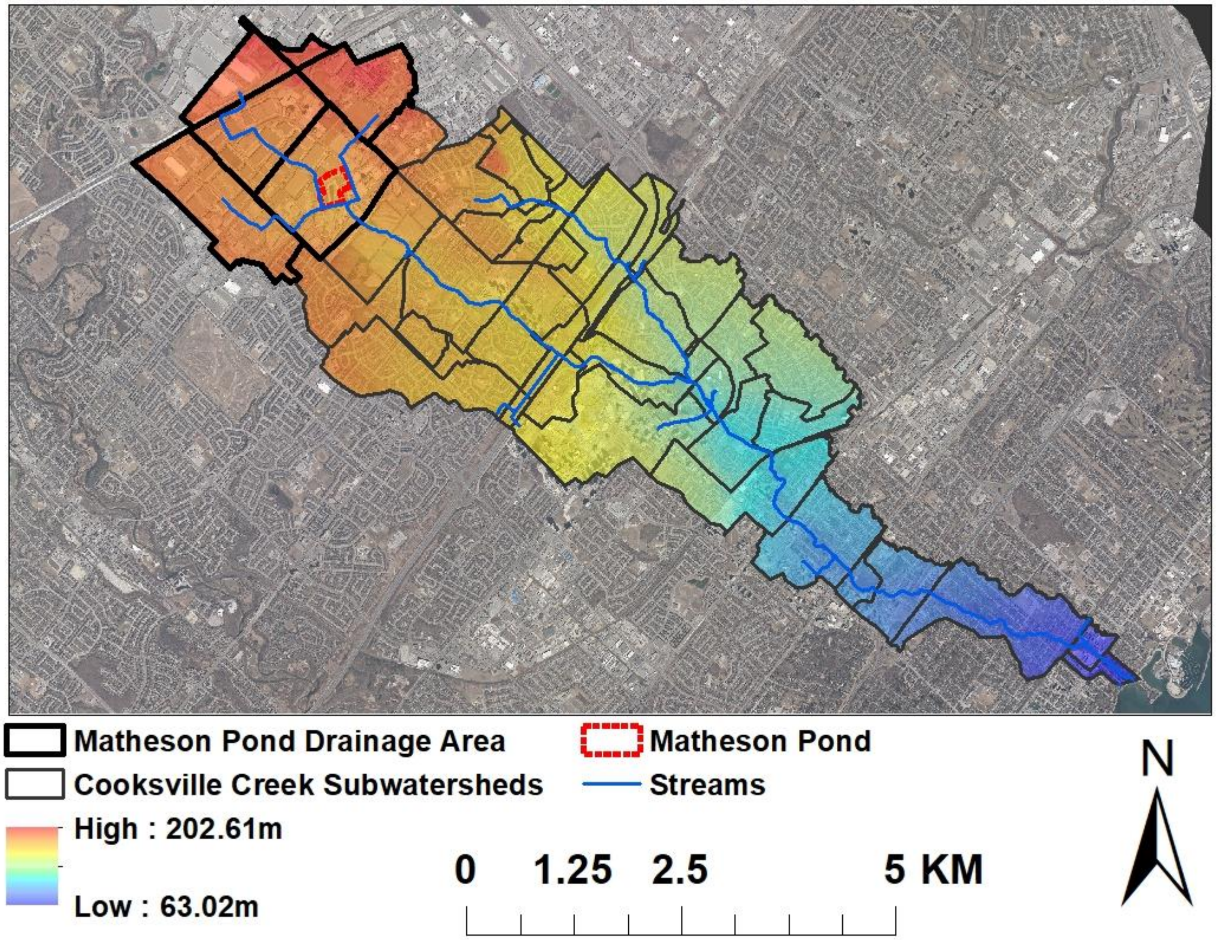


**Figure 16 Cooksville Creek watershed**

A 2015 companion report entitled the Cooksville Stormwater Management Pond – Facility #3702 and a 2017 report entitled the Cooksville Creek and Cawthra Creek Hydrologic Model Update Study were assessed to support the analysis (Aquafor Beech 2015, 2017). According to the 2017 report, the drainage areas of Matheson Pond comprise approximately 565.20 ha (based on characterization of the existing pipe network) and are distributed as follows in **Figure 17**:

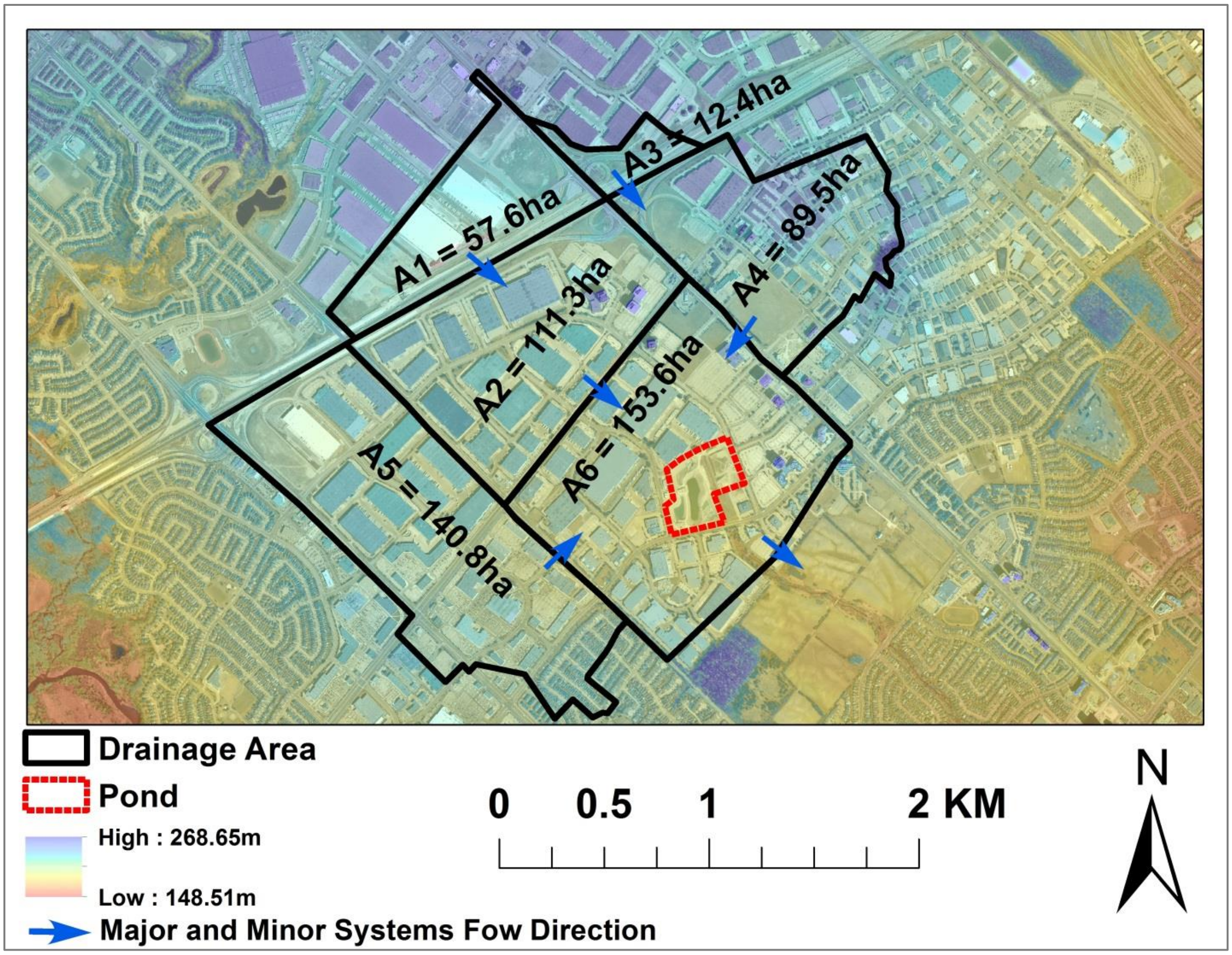


**Figure 17 Drainage area served by Matheson Pond (Pond 317)**

The area that drains to the proposed pond is primarily commercial retail land with some residential land use, accounting for approximately 85% of the total drainage area, while the remaining 15% is undeveloped/open space. Overall, the catchment area is highly impervious with an imperviousness level of approximately 90% in the developed areas and approximately 80% for the overall catchment.

All viable, flat-rooftops within the pond's drainage area were delineated and measured using ArcGIS, totalling 133.6 ha of rooftop drainage area suitable for blue roof application. Note that for the purposes of the analysis, residential rooftops and pitched rooftops within the study area were deemed to be unsuitable for blue roof application and were, therefore, excluded from the analysis. The resultant rooftop areas deemed to be suitable within the analysis appear as follows (**Figure 18**):

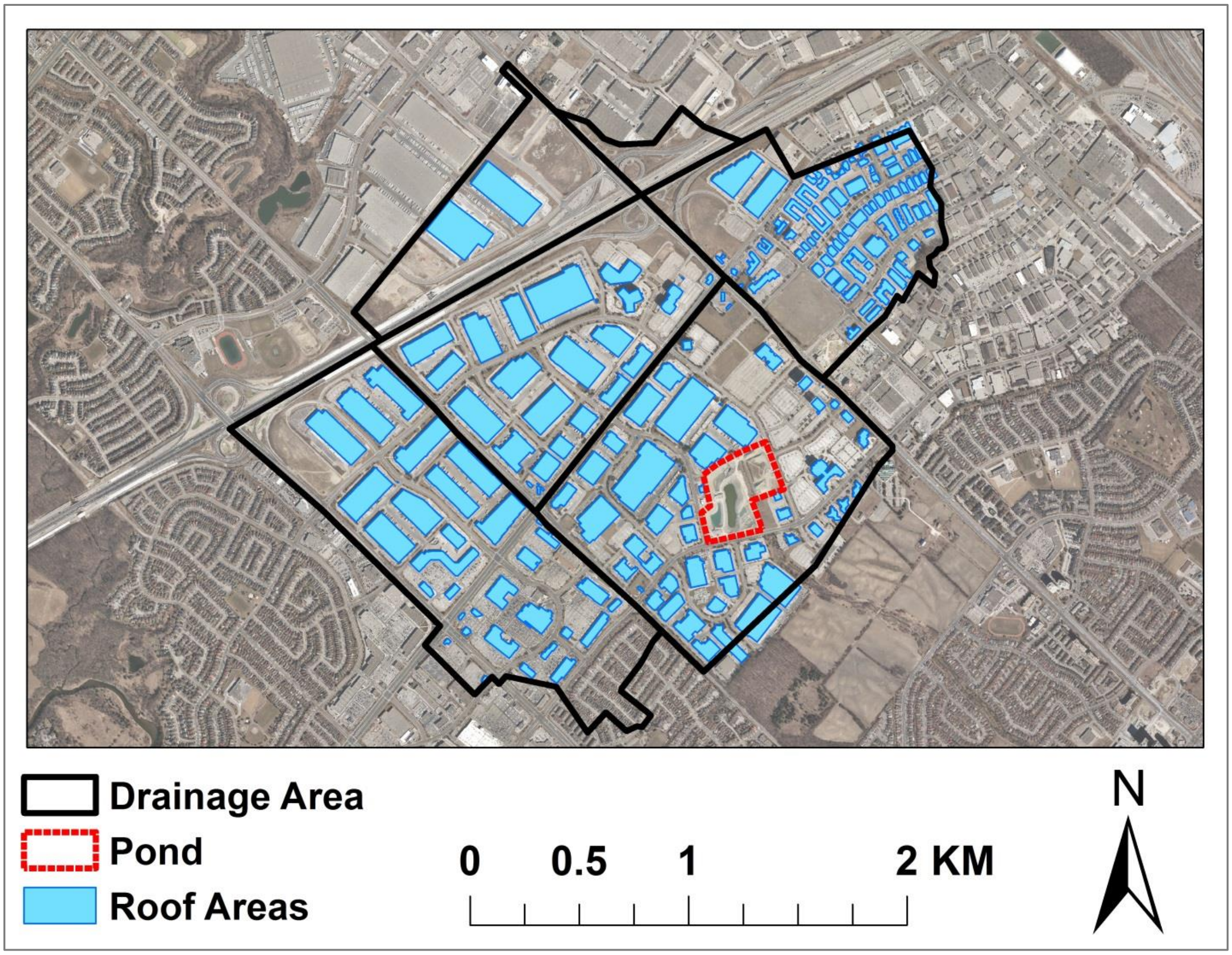


**Figure 18 Suitable blue roof retrofit areas within the pond catchment area**

Based on the age of development (circa 1990s), it was assumed that these roofs can hold a total ponding depth of 130mm (OBC 1990).

#### *4.5.1.1 Methodology*

##### 4.5.1.1.1 Scenario Assumptions

To assess what impact the application of blue roofs could have on peak flows and runoff volumes discharging from the Matheson neighbourhood and the corresponding pond size requirements, a three-scenario analysis was completed, which assessed:

- Peak flow and runoff volumes under pre-development conditions ($Q_{pre}$);
- Peak flow and runoff volumes under the existing (post-developed) conditions ($Q_{post}$); and,
- Peak flow and runoff volumes under smart blue roof (post-retrofit) conditions ($Q_{retrofit}$).

##### 4.5.1.1.2 Model Development

An existing hydrological model for Cooksville Creek, the Cooksville Visual OTTHYMO model, which modelled the entire Cooksville Creek watershed, a total drainage area of approximately 33km$^2$ was modified for use within the pond drainage area only (565.20ha) (updated model, CVC 2017). The model was executed to simulate watershed rainfall-runoff responses for the 2, 5, 10, 25, 50, and 100 year return period storm events for the three (3) scenarios above.). The drainage area was subdivided into six (6) subcatchments, as depicted in the model schematic diagram in **Figure 19**. Based on the analysis of aerial mapping and other available data, the pervious areas that are more than 1 ha within subcatchments have been segregated and modelled as separate NASHYDs (Nash Instantaneous Unit Hydrographs). The following methods and commands were employed:

- The modified Soil Conservation Service *(*SCS) method was used to generate the runoff hydrograph.
- The NASHYD and Standard unit hydrograph methods were used to simulate runoff flows from natural (open meadow space) and developed/urban areas respectively.
- The Route Channel command was used to route hydrographs through channel elements within the model.
- The Route Reservoir command was used to route hydrographs through the proposed stormwater management facility.

As noted above, the proposed pond was incorporated into the model using the reservoir routing command. The storage curve for the stormwater pond is based on the storage-volume data reported in Cooksville Creek and Cawthra Creek Hydrologic Model Update Study Final Report (Aquafor Beech, 2017).

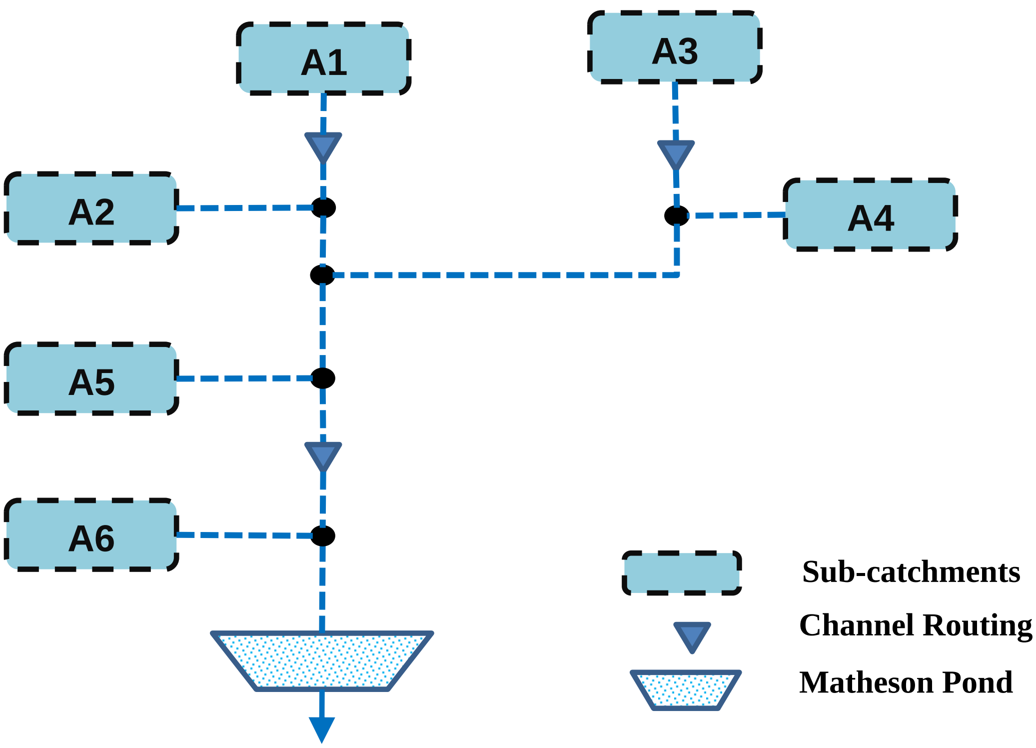


**Figure 19 Model schematic diagram**

#### 4.5.1.1.3 Model Parameters

A revised SCS curve number (CN) method was used to convert the base curve number to a revised curve number and the corresponding initial abstraction. A summary of the base CN and depression storage values is tabulated in **Table 25**.

**Table 25 Summary of base CN and depression storage values**

| Land Cover | Depression Storage (Initial Abstraction) | CN | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A Soils | AB Soils | B Soils | BC Soils | C Soils | CD Soils | D Soils |
| **Woods / Greenspace** | 10 mm | 32 | 46 | 60 | 67 | 73 | 76 | 79 |
| **Parks – lawns** | 5 mm | 49 | 59 | 69 | 74 | 79 | 82 | 84 |
| **All other urban lands – lawns** | 5 mm | 49 | 59 | 69 | 74 | 79 | 82 | 84 |
| **Impervious surfaces** | 2 mm | n/a | n/a | n/a | n/a | n/a | n/a | n/a |

The ratio of total impervious area (TIMP) and the ratio of those areas that are directly connected (XIMP) to the urban drainage system are key modeling parameters. All the model parameters were defined in accordance with the values recommended in CVC's updated model and CVC's Draft Technical Guidelines (EWRG, 2015). Selected model parameters are shown in **Table 26**.

**Table 26 Summary of selected model parameters**

| Neighbourhood Sub-catchment ID | Total Area | Developed Area | Undeveloped/ Pervious Area | TIMP | XIMP | Manning's roughness coefficient | | CN (Pervious area) |
|---|---|---|---|---|---|---|---|---|
| | ha | ha | ha | | | Impervious Area | Pervious Area | |
| **A1** | 57.6 | 20.1 | 37.5 | 0.86 | 0.71 | 0.045 | 0.25 | 47.4 |
| **A2** | 111.3 | 109.6 | 1.7 | 0.91 | 0.83 | 0.045 | 0.25 | 54.4 |
| **A3** | 12.4 | 12.4 | - | 0.87 | 0.76 | 0.045 | 0.25 | |
| **A4** | 89.5 | 73.9 | 15.6 | 0.92 | 0.84 | 0.045 | 0.25 | 50.4 |
| **A5** | 140.8 | 128.1 | 12.7 | 0.9 | 0.82 | 0.045 | 0.25 | 47.4 |
| **A6** | 153.6 | 134.2 | 19.4 | 0.93 | 0.85 | 0.045 | 0.25 | 55.9 |

Physical watershed characteristics, such as neighbourhood subcatchment area, slope, length, area of flat rooftops etc., were measured using the ArcGIS tool. The area of all flat rooftops was calculated to be approximately 133.6 ha. For the smart blue roof post-retrofit scenario, this area was subtracted from the total impervious area within the existing (post-developed) conditions model, as it was assumed that the rooftop areas would not generate any runoff, even under 1-in-100-year storm event conditions, since the depth of storage on each rooftop is 130mm, and the total storm depth for the 100-year storm is only 119mm.

#### 4.5.1.1.4 Calculation Methods

Subcatchment time-to-peak for use with the NASHYD was estimated using the Airport Formula, as recommended in the CVC Draft Technical Guidelines:

$$t_p = 0.67 * t_c$$

where, the time of concentration ($t_c$) was computed using the Airport Method:

$$t_c = 3.26 * (1.1 - C) * L^{0.5} * S_w{}^{-0.33}$$

$t_p$ = Time to peak (min)
$t_c$ = Time of concentration (min)
C= Runoff coefficient
L = Length (m)
S = Slope (%)

For the pre-developed condition, it was assumed that 100% of the drainage area was natural (open meadow space) and fully pervious (C = 0.15 to 0.30 for park/lawn surfaces). For the post-development (existing) condition, the composite runoff coefficient generated in the model was used. For the post-retrofit scenario, where the roof top area is subtracted from the impervious area, another composite runoff coefficient was generated in the model. As noted earlier, length (L) and slope ($S_w$) were measured using ArcGIS.

The 24-hour Chicago distribution design storm was generated based on the IDF parameters prescribed by the City of Mississauga. The IDF parameters ($I = \frac{A}{(tc+B)^C}$) and computed rainfall values are summarized in **Table 27**.

**Table 27 IDF Parameters, as per City design standards and computed total event rainfall**

| Return Period (Years) | A | B | C | Total rainfall (mm) |
|---|---|---|---|---|
| **2** | 610.0 | 4.60 | 0.78 | 50.2 |
| **5** | 820.0 | 4.60 | 0.78 | 67.4 |
| **10** | 1010.0 | 4.60 | 0.78 | 83.1 |
| **25** | 1160.0 | 4.60 | 0.78 | 95.4 |
| **50** | 1300.0 | 4.70 | 0.78 | 107 |
| **100** | 1450.0 | 4.90 | 0.78 | 119.24 |

#### *4.5.1.2 Results*

##### 4.5.1.2.1 Peak Inflows

The peak inflow to the pond for each return period event under each scenario was calculated to be as follows (**Table 28**):

**Table 28 Neighbourhood catchment peak inflows for varying return period events and scenarios**

| Peak inflows ($m^3/s$) | | | |
|---|---|---|---|
| **Return Period (Years)** | $Q_{pre}$ | $Q_{post}$ | $Q_{retrofit}$ |
| **2** | 3.3 | 24.4 | 18.5 |
| **5** | 6.2 | 35.8 | 27.4 |
| **10** | 9.4 | 47.8 | 36.4 |
| **25** | 12.3 | 58.1 | 44.0 |
| **50** | 15.2 | 67.8 | 51.3 |
| **100** | 18.6 | 78.4 | 59.1 |

Based on the computations outlined above, the peak inflow summary provided in **Table 28** provides clear evidence that the application of blue roofs on flat rooftops within the study area can be expected to reduce the 100-year peak runoff volumes to a level roughly equivalent to the post-development 25-year event (59.1 $m^3/s$ vs. 58.1 $m^3/s$, respectively).

##### 4.5.1.2.2 Required Flood Storage Volumes

Based on the anticipated changes in peak flows across the drainage area to the pond, the critical flood control volume associated with each return period event for both the post-development and blue-roof retrofit implementation scenarios was modeled as follows in **Table 29**:

**Table 29 Critical storage volumes for varying return period events (post-development and post-retrofit scenarios)**

| Critical Control Volume Requirements | | |
|---|---|---|
| **Storm Event Return Period (yr)** | **Required Storage Volume – Post-Development ($m^3$)** | **Required Storage Volume – Post-Retrofit (with Blue Roof) ($m^3$)** |
| **2** | 83,707 | 60,738 |
| **5** | 121,868 | 87,198 |
| **10** | 163,096 | 112,959 |
| **25** | 197,907 | 135,939 |
| **50** | 230,553 | 158,713 |
| **100** | 243,050 | 184,039 |

For the post-retrofit scenario, the inflow volume to the pond was computed by multiplying the rainfall depth for each storm return period by the cumulative capture area of all suitable blue roof locations within the catchment area. The inflow volume reduction to the pond was calculated by subtracting post-retrofit (with blue roof) inflow volume from the existing (post-developed conditions) inflow volume, as the rooftop areas would not generate any runoff. The assumption underpinning such calculations is predicated on the fact that flat commercial rooftops are engineered to accommodate snow loads, which meet or exceed the mass of rainfall that would be received during a 1-in-100-year storm. The total runoff volumes retained on the proposed blue roofs are as follows (**Table 30**):

**Table 30 Total Blue roof runoff capture volumes (varying return period events)**

| Return Period (years) | Total Blue Roof Captured Volume ($m^3$) |
|---|---|
| **2** | 67,067 |
| **5** | 90,046 |
| **10** | 111,022 |
| **25** | 127,454 |
| **50** | 142,952 |
| **100** | 159,305 |

#### 4.5.1.2.3 Required Water Quality and Extended Detention Storage Volumes

According to section 3.3.2 of the 2003 Ontario Ministry of the Environment, Conservation and Parks Stormwater Management Planning and Design Manual, the permanent pool volume of a SWM detention facility is directly proportional to the size and relative imperviousness of the contributing drainage area (CDA).. The volume requirements for the pond was computed for post-development and post-retrofit scenarios using 80% imperviousness. The water quality and flood control requirements for wet pond facilities are tabulated in **Table 31**.

**Table 31 Volume requirements for wet pond facilities**

Imperviousness = 80%, Drainage area excluding blue roof = 431.6 ha

| Parameter | Volume requirement – Post-Development ($m^3$) | Volume requirement – Post-Retrofit (with Blue Roof) ($m^3$) | Net volumetric reduction (%) |
|---|---|---|---|
| ***Water Quality Volume Requirements for Wet Pond Facilities*** | | | |
| Required Permanent Pool ($m^3$) @ 150 $m^3$/ha | 84780 | 64732 | 24% |
| Required Extended Detention ($m^3$) @ 40 $m^3$/ha | 22608 | 17262 | 24% |
| ***Flood Control Requirement*** | | | |
| Required flood storage volume | 243,050 | 184,039 | 24% |

The pond was designed to provide enhanced water quality treatment (80% TSS removal), which requires a storage volume of 150$m^3$/ha for an impervious level of 80%.. The purpose of this analysis is to show the percent volumetric reduction that results from incorporating smart blue roofs into the study area.

#### 4.5.1.2.4 Reduction in Total Storage Volume Requirements

The reduction in the 100-year flood storage volume requirement after retrofitting the drainage area with blue roofs is 59,011 $m^3$. The computed reduction in permanent pool and extended detention volumes is 20,048 $m^3$ and 5,346 $m^3$ respectively. This brings the total estimated volume reduction to 84,405 $m^3$ – about a 24% reduction, compared to the pond facility storage volume without smart blue roofs, which is a significant reduction. The cost implications of this reduction will be discussed in Section 4.8.2.3 below.

## 4.6 Energy Conservation and GHG Reduction Co-benefits of Smart Blue Roof Implementation

In addition to the peak flow and runoff volume reduction benefits resulting from smart blue roof implementation, as demonstrated in the analyses above, the evaporative cooling and potable water offsets associated with the capture, storage, evaporation and reuse of rainwater is also expected to lead to significant energy, greenhouse gas (GHG) emissions and related cost reductions.

### *4.6.1 Historical GHG Emissions at Site Scale*

Historical electricity and natural gas consumption records for the CVC buildings were analyzed and GHG emissions estimated for 2013 through 2017 (see **Table 32**). Consumption for Building A was estimated based on square footage, as it is not measured for each individual building.

**Table 32 GHG emissions associated with electricity and natural gas consumption, 2013- 2017**

| YEAR | ELECTRICITY CONSUMPTION kWh | NATURAL GAS CONSUMPTION $m^3$ | GHG EMISSIONS tonnes |
|---|---|---|---|
| **2013** | 245,051 | 20,731 | 51 |
| **2014** | 238,763 | 20,851 | 51 |
| **2015** | 218,282 | 18,993 | 47 |
| **2016** | 201,394 | 16,150 | 41 |
| **2017** | 186,483 | 7,481 | 23 |

**Notes:**

**GHG emission factors:**

| | |
|---|---|
| Ontario electricity aggregate factor (kg $CO_2e$/kWh) | 0.05 |
| Natural gas emission factor (kg $CO_2e/m^3$) | 1.89 |

| | |
|---|---|
| Building B area ($m^2$) | 2,082 |
| Building A area ($m^2$) | 1,935 |
| Consumption factor | 0.48 |

It is worth noting that the GHGs associated with natural gas consumption are much more significant than those associated with electricity consumption. This is due to the nature of electricity generation in Ontario, which is in large part hydroelectric and nuclear.

Electricity consumption was compared to cooling degree days to determine the correlation between consumption and weather, as shown in Figure 20. Similarly, natural gas consumption was compared to heating degree days, illustrated in Figure 21. The graphs show that electricity consumption is affected by weather, but not to the same degree as natural gas consumption, since most electricity use in an office building is for equipment such as computers and lighting for example.

Electricity consumption does increase slightly in the winter, which may be due to increased lighting needs and perhaps individual unit heaters. It can be seen that in the summer months when there are more cooling requirements, electricity consumption does increase slightly as compared to those summer months with lower cooling requirements.

Natural gas consumption can be seen to be highly dependent on weather, although in 2017 natural gas consumption was significantly less than in previous years, despite having similar heating degree days as 2016.

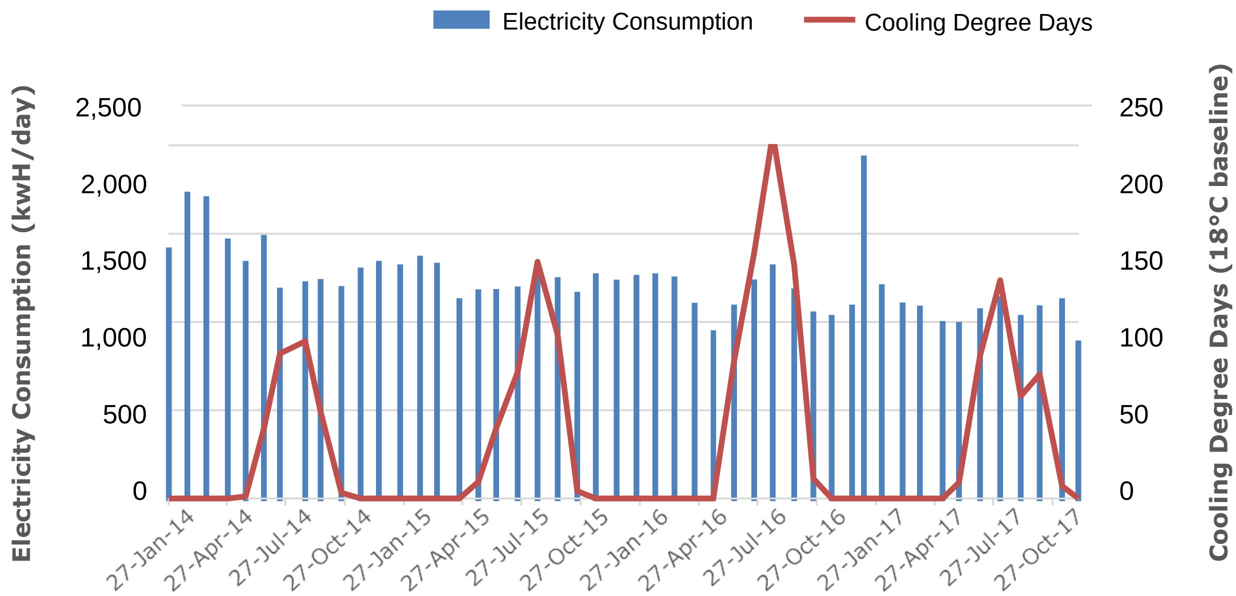


**Figure 20 Effects of weather on electricity consumption**

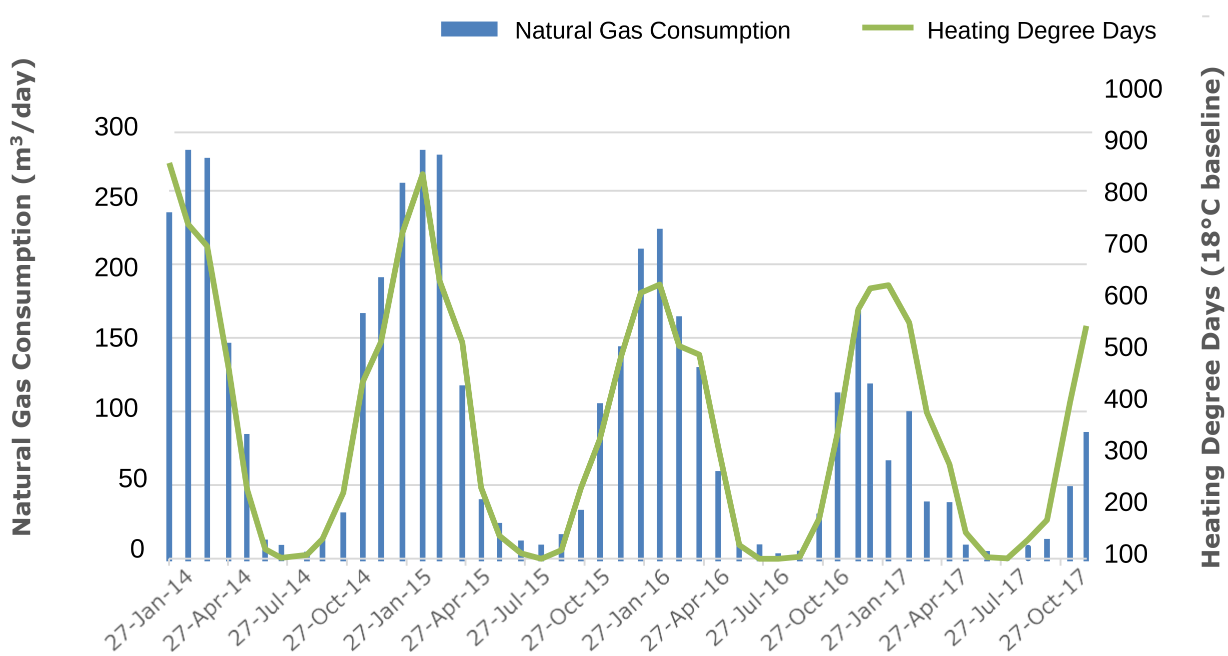


**Figure 21 Effects of weather on natural gas consumption**

### 4.6.2 Analysis of Potential Energy and GHG Savings

Using measured temperature differences between the liner on the existing roof, the temperature inside the building directly under the roof, and average summer temperatures, energy transfer between the roof and inside the building was calculated. When there is no pooled water, energy is transferred into the building, and when there is pooled water, energy is transferred out of the building since, on average, the pooled water will be cooler than the setpoint inside the building. **Table 33** shows the parameters used in the calculations.

**Table 33 Energy transfer parameters**

| | |
|---|---|
| **Zone 2 Surface Area:** | **317.16 m$^2$** |
| **Project allotted period:** | **June 1 to Sept 30** |
| **Daily heat transfer period:** | **10 hrs/d (8 am to 6 m)** |
| **Estimated heat transfer resistance coefficient:** | **2.042 ft$^2$·°F·hr/BTU** |
| **“U” heat transfer factor:** | **0.4897 BTU/(ft$^2$·°F·hr)** |
| **June – September average maximum liner temperature:** | **27.25°C (81.05°F)** |
| **Bottom of concrete slab average temperature:** | **21.65°C** |
| **Roof liner to concrete pad bottom average temperature difference:** | **5.6°C (10.08°F)** |
| **Zone 2 heat flux June through September “NON-POOLED” roof conditions:** | **21.34 GJ** |
| **June through September average daily pooled rainwater temperature:** | **18.15 °C** |
| **Zone 2 heat flux June through September “POOLED” roof conditions:** | **13.34 GJ** |
| **Zone 2 Net Heat Flux June thru September:** | **34.67 GJ** |

** Heat exchange parameters are based on data obtained from the Guide to thermal properties of concrete and masonry systems reported by ACI Committee122 (ACI 122 R-02).

As seen in the table above, the difference in energy transfer between the two scenarios was 34.7 GJ/year. Assuming a coefficient of performance of 3 (typical for air conditioners), this means that the air conditioner will use 11.6 GJ/year less with water pooled on the area of the blue roof. This translates into annual electricity savings of 3,210 kWh, about $302 or a 1.5% reduction compared to existing condition. GHG reduction due to pooled water is therefore about 0.2 tonnes $CO_2e$ annually. This amount is small since electricity consumption at CVC is not highly dependent on weather conditions. The roof area covered by water is also relatively small. Additionally, evaporation of the pooled water on the roof will be mainly due to outside conditions, such as temperature. Details of these calculations can be found in **APPENDIX D**.

Greenhouse gas emissions will not only be reduced at the site due to reduced energy consumption at the site, but they will also be reduced at the municipal level due to reduced water consumption and, therefore, less pumping and treatment of water.

Unit intensity figures pertaining to GHGs and energy consumption are provided below (**Table 34**).

**Table 34 Greenhouse gas intensity figures for wastewater, water treatment and distribution Plants for the Region of Peel**

| Treatment Plant or Pumping System, as Appropriate | Electricity GHGs (tCO2e) * | Natural Gas GHGs (tCO2e) | Total GHG Emissions (tCO2e) | Water Volume (ML) | Total GHG Emissions per ML (tCO2e/ML) |
|---|---|---|---|---|---|
| **Lakeview WTP** | 2,559 | 915 | 3,474 | 139,922 | 0.02483 |
| **Water Distribution** | 4,070 | 334 | 4,404 | 208,683 | 0.02110 |

*tCO2e = tonnes of CO2 equivalent

Multiplying the aggregated potable water volume offsets summarized in **Table 24** by the unit intensity GHG emissions provided in **Table 34** results in an average GHG decrease of 1.6 tonnes of CO2 equivalent per year.

Since evaporative cooling would provide a cost savings to building owners and operators, the cost savings are accounted for from their perspective only. Electricity savings per square meter of blue roof on CVC's building A were prorated to calculate savings for each catchment of the street scale study area. Although roof composition for the buildings in the catchment area are not likely to be exactly the same as Building A, this method was considered to be a good estimate. When compared to using annual pan evaporation data, where evaporation will not be due to the heat coming out of the roof of a building but rather by environmental conditions, this method was considered to be more accurate for a building roof scenario. **Table 35** illustrates the estimated savings due to ponding water on a roof for each building in the catchment area. Electricity savings were calculated to be 11.26 kWh/y/m$^2$, cost savings \$1.06/y/m$^2$, and associated GHG emissions reductions were 0.56 kg/y/m$^2$.

**Table 35 Estimated annual electricity, cost and GHG savings for rooftops in the street scale catchment area prorated from CVC Building A's savings per square meter**

| Street Scale sub-catchment ID | Rooftop Area (ha) | Annual Electricity Savings (kWh/y) | Annual Cost Savings ($/y) | Annual GHG savings (tCO2e/y) |
|---|---|---|---|---|
| **A1** | 1.14 | 128,395 | $12,069 | 6.42 |
| **A2** | 0.85 | 95,733 | $8,999 | 4.79 |
| **A3** | 0.57 | 64,198 | $6,035 | 3.21 |
| **A4** | 0.67 | 75,460 | $7,093 | 3.77 |
| **A5** | 0.71 | 79,965 | $7,517 | 4.00 |
| **A6** | 1.08 | 121,638 | $11,434 | 6.08 |
| | **Column Totals** | **565,389** | **$53,147** | **28** |

It can be seen in the table above that there are some significant savings when several buildings in the catchment area have ponded water on the rooftops. The GHG and association cost savings for the neighborhood scale have been extrapolated from the site scale values in Table44 below. For the full summary of cost/benefits at the site, street and neighbourhood scale, refer to Table 44.

## 4.7 Conceptual Design of Smart Blue Roof with RWH System at the Site Scale

Since the smart blue roof with RWH system provides significantly more benefits than either a RWH system on its own or a passive blue roof, as discussed in previous sections, a conceptual Smart Blue Roof design was developed and is described in this section.

### *4.7.1 Selected Active and Passive Roof Areas*

Three separate areas of the existing roof have been identified based on existing infrastructure and overall suitability.

**Table 36** outlines estimated surface areas and operating conditions of all identified roof areas. Note that approximately 11 $m^2$ of roof area is not accounted for in the table as part of Zone 2 is not usable as storage due to the presence of equipment.

**Table 36 Conceptual design zone descriptions**

| Zone | Description | Surface Area | Operating Status |
|---|---|---|---|
| **Zone 1** | North Side Roof Area. This area includes roof access stairs hatch and cooling & mechanical /electrical equipment | 263 $m^2$ | Passive Roof Area. Rainwater accumulated in Zone 1 will be discharged via existing 2 x 4” diameter roof drains equipped with new Zurn Flow Control Caps. No flow control valves are associated with Zone 1. |
| **Zone 2** | Central Roof Area where the weather station and fans are located. | 317 $m^2$ | Active Blue Roof Selected Area. Rainwater accumulated in Zone 2 will be discharged via existing 2 x 4” diameter roof drains equipped with new Zurn Flow Control Caps. 2 x 4” diameter Flow control valves are responsible for providing controlled rainwater flow discharges from Zone 2, based on a predetermined operating logic. |
| **Zone 3** | South side roof area on top of the garage and equipment storage area | 54 $m^2$ | Passive Roof area. Same as Zone 1 |

Zone 3 (garage & equipment storage area) is considered not fully suitable for heat recovery or a “blue roof”. It is recommended however that this Zone be provided with a new single Zurn flow control roof drain cap. This would allow a more controlled discharge of rainwater to the sewer line during heavy storm events, thus reducing overall sewer flow surges. Including Zone 3 into the Active Blue Roof area would represent a substantial capital cost increase of 24.7% and provide a small increment in active roof area (approx. 17%). In summary, the limited roof area associated with Zone 3, compounded by the limited active volume of the existing RWH cistern (5,000L, renders any water reuse potential from Zone 3 of limited benefit.

### 4.7.2 Smart Blue Roof Implementation on CVC's Building A

#### 4.7.2.1 Main Implementation Activities

The implementation of a smart blue roof system at Credit Valley Conservation Authority's building A in Mississauga entails the following main activities:

- Roof project area selection and roof area segregation based on existing infrastructure and overall suitability;
- Relocation of existing non-project associated infrastructure currently located on selected project areas;
- Modification and water proofing of fixed infrastructure currently located inside the selected project area;
- Retrofitting of existing roof liner in selected project areas;
- Retrofitting of the existing roof drainage system in selected project areas to accommodate the installation of rainwater flow control valves;
- Installation of an emergency rainwater management overflow system;
- Installation of a roof rainwater monitoring system including water level and temperature sensors, associated PLC, data logging system, and control panel.
  Note: This latter item might be further complemented, if so desired, by the addition of a central master PLC system, incorporating additional I/O parameters and communication peripherals "as deemed necessary."

#### 4.7.2.2 Basic Control Philosophy

The basic control philosophy described below is associated with the operation of the following components.

**Component 1**

- 2 x 4" diameter, electrically operated solenoid valves (Ball Valve Model 4" 415IIT/FSE-1770-FO 120/60) and TRIAC FSE Series Fail-Safe Actuators. This component is to be located on the third-floor attic.

**Component 2**

- 1 x FPI (4-20 mA) water level and temperature sensor with transmitter located in Zone 2, inside a NEMA 3R BUDD casing.

**Component 3**

- I/O signal wiring system from Zone 2 monitoring equipment to the PLC control panel located in the basement.

**Component 4**

- 1 x ITC 8000 Controller and Data Recorder and associated electrical control panel having the following suggested process set points and parameters:

  - Maximum allowable rainwater level accumulated at lowest point on Zone 2 "Blue Roof" designated area: 0.150 meters

- Maximum estimated rainwater temperature level on “Blue Roof” designated area: 27°C
- Emergency overflow elevation set point in Zone 2: 0.150 meters (6”)
- Estimated Zone 2 cross sectional area: 317.16 $m^2$
- Zone 2 maximum rainwater accumulated volume: 16 $m^3$ (Note: This amount is based on a maximum 0.150 m of water head over the entire Zone 2 surface area. An estimated 2 to 3 $m^3$ of water is accumulated, due to roof slope in selected areas (1.5%), under the minimum water level set point of the water level instrument.
- Maximum retention time for rainwater accumulation in Zone 2: 24 to 48 hours (trial-error determination based on bacterial growth and accumulated rainwater quality and Ontario Building Code exceptions).
- The estimated “Zone 2 empty time” to evacuate all rain water from the roof via the two 4” diameter cast iron pipes would be approximately 6 hours at full open valves position.

#### *4.7.2.3 Basic Control Logic Outline*

Note: The following control logic starts with zero water accumulation at time = 0 of the rainwater accumulation-discharge cycle in Zone 2 as the system will have drained down in anticipation of a rain event.

##### 4.7.2.3.1 Control Valves in Fully Closed Position

Upon notification of a rain event the “blue roof” cycle begins. Control flow valves 1 and 2 are automatically positioned in a fully closed position. During the rain event, accumulated rainwater level and temperature values are continuously monitored, transmitted and recorded by the controller/data logger located in the basement control room. All roof rainwater above the maximum allowable level (0.150 m above roof line)will by-pass the flow control valves via two 4” diameter cast iron sewer downpipes (see Drawing 2 in Appendix C) emergency overflows located in Zone 2. .

##### 4.7.2.3.2 Control Valves in Semi-Open Position

Control valves 1 and 2 will be partially opened following a pre-programmed opening ramp profile, based on low and high rainwater level set point signals from the existing RWH cistern level sensors(cistern retrofitted and equipped with an ITM Instruments or equivalent pressure transducer/sheath system) located in the basement. Upon reaching the low- level set point in the cistern, valves will be gradually opened to fill up the cistern.

Valves will be closed upon reaching the high-water level set point in the cistern. Note: Final water level set points for valve control operation would be selected based on site observations.

##### 4.7.2.3.3 Control Vales in Fully Open Position

Upon reaching the maximum allowable rainwater retention time set point, control valves 1 and 2 will be automatically opened following a ramp profile opening pattern, until the entire volume of water accumulated in Zone 2 is drained. This would complete the “blue roof” cycle. At this point, no rainwater is stored in the blue roof system.

If another rain event is forecasted before the maximum allowable retention time is up, both control valves will be gradually opened and all water accumulated in Zone 2 will be discharged gradually into the sewer line, in anticipation of the expected rain event.

Additional Points:

- Blue roof rainwater discharge rates would be calculated and logged based on water level elevation changes in Zone 2.
- Blue roof system to be operable only during non-winter conditions. Valves to remain fully opened during winter and/or freezing conditions.

A more comprehensive control philosophy will be required in the event that a central master PLC, addressing additional I/O process variables, is incorporated as a complement to the primary PLC.

#### 4.7.2.4 Additional Disinfection Requirements

The capture of rainwater from blue roof system is likely to contribute to an increase in the organic contamination of the water stored in the RWH cistern. Therefore, it is recommended that the existing 50 micron filter be complemented by a 5-micrometer down-stream filter (Flow Max FMI Model or equal) followed by a 25 USGPM UV disinfection system (VIQUA K Model or equal). This would ensure a higher water quality . It is also recommended, as a complement to the above, the periodic addition of slow-dissolving calcium hypochlorite tables and/or City water manual additions to the cistern on an as needed basis. Periodic Cistern water pH control is also recommended.

#### 4.7.2.5 Zone 2 Access Path Requirements During O&M Activities

Should the mechanical, civil and instrumentation infrastructure located inside Zone 2 (fume fan, air intakes, blue roof monitoring equipment etc.) require servicing, all water accumulated in Zone 2 must be removed. Periodic and scheduled roof O&M activities should be coordinated with the blue roof scheduled discharged periods. Based on the above, there is no immediate need to design and install an emergency/maintenance access pathway inside Zone 2, as all activities will be conducted under non-ponding water conditions.

#### 4.7.2.6 Blue Roof Rainwater Monitoring Equipment Redundancy

As mentioned in Section 3.2 (System Design Considerations), a second level sensor should be in place so serve as a back up should the first one malfunction. Periodically checking the monitoring system and conducting the necessary preventative maintenance activities would help ensure its ongoing functioning. Additional temperature and water level sensors can be purchased and kept as spare parts.

#### 4.7.2.7 Basic Operation and Maintenance Schedule

Table 37 below outlines the main blue roof-associated activities requiring periodic O&M, in order to ensure that the accuracy of the monitoring and data recording system remains as per manufacturers' specifications. Additional O&M service must be performed according to the equipment manufacturer's guidelines.

**Table 37 Basic recommended O&M activities**

| O&M Activity Number | Component | Description | Purpose | Estimated O&M Annual Cost* |
|---|---|---|---|---|
| 1 | **Zone 2 flow control valves** | Valves to be left in fully open position and disconnected from PLC during winter months/freezing conditions. Visual observation of "OPEN" status required. | Prevent valves freezing/rupture of piping | CVC maintenance personnel |
| 2 | **Zone 2 flow control valves** | Ensure actuator free movement and positioning lever status by periodic visual inspection after winter. Perform monthly inspections during summer- spring months. Compare actual lever positioning on valve with PLC opening %. | Ensure valve opening % as per process requirement. | CVC maintenance personnel |
| 3 | **Zone 2 FPI water level and temperature sensors** | Remove sensors during winter months. | Sensors to be Removed during winter months when Blue Roof system is not operable. | CVC maintenance personnel. |
| 4 | **Zone 2 FPI water level and temperature sensors** | Clean sensors monthly during summer-spring months. Prevent dust/leaf/debris accumulation. Replace if damaged. | Ensure clean and free sensor operation during summer months | CVC maintenance personnel. $1,500/sensor plus labour for replacement. |
| 5 | **Zone 2 FPI water level and temperature sensors** | Calibrate sensors quarterly or as per manufacturer's guidelines. | Ensure accuracy of signals to primary PLC. | $1,200 |
| 6 | **Roof liner cleaning/ scrubbing** | Twice per year. Before and after the yearly Blue Roof Operating Cycle "June through September" | Prevent rainwater pollution due to dust and sediment accumulation on Zone 2. It is recommended to extend | $3,000 |

| O&M Activity Number | Component | Description | Purpose | Estimated O&M Annual Cost* |
|---|---|---|---|---|
| | | | this practice also to Zones 1 and 3. | |
| 7 | **Roof periodic visual general inspections** | Bi-weekly inspections during roof “non-ponding conditions” to remove excessive leaf accumulation and or other material observed in Zone 2. | Preventative general maintenance. | CVC maintenance personnel |
| 8 | **RWH system filters (50 micron and 5 micron)** | Replace non-back-washable filter media as required. Conduct periodic visual inspection and proper operation of associated filter head loss gauges. | Preventative general maintenance. | 4 x 5 micrometer filters @ $110 per filter plus $1,500 labour. |
| 9 | **RWH UV disinfection system** | Conduct periodic visual inspection and proper operation of associated UV system. Observe lamp scaling monthly. Replace lamp as per manufacturer’s recommendations. | Preventative general maintenance. | 1 x UV lamp @ $450 per lamp plus $800 labour. |
| 10 | **RWH solids removal tank** | Conduct periodic observation of the solids level accumulated inside the tank and bleed to sewer solids laden bottom as needed. | Preventative general maintenance. | CVC maintenance personnel |
| 11 | **Existing cistern water disinfection** | Weekly monitoring of pH and quality of the water inside the cistern. Add slow-dissolving Calcium Hypochlorite tablets. Frequency to be determined by trial and error during Blue Roof operation. Periodic City water manual addition to cistern is also recommended. | Preventative general maintenance. | $250/year |
| 12 | **RWH system water level control** | Monthly visual monitoring of water level signals and compare with PLC readings. | Preventative general maintenance. | CVC maintenance personnel |

| O&M Activity Number | Component | Description | Purpose | Estimated O&M Annual Cost* |
|---|---|---|---|---|
| 13 | **RWH system general preventative program** | Follow recommendations from supplier for all mechanical and electrical components. | Preventative general maintenance. | CVC maintenance personnel |
| 14 | **IT connectivity/PLC software calibration** | Input-output signal verification/Components performance verification | Preventative general maintenance. | $1,800 |

Note: * Cost based on $150/hr T&M third party contractor fee, including travel expenses, onsite preparation, work implementation and completion and decommissioning.

### 4.7.3 General Considerations for Blue Roof Application in ICI Sector

Designing a smart blue roof system for an ICI facility requires consideration of site-specific conditions. It is important to evaluate the activities surrounding the site, the drainage area to the system, identify potential contaminants and evaluate the risks the contaminants may pose to the intended non-potable water use application. By considering these elements in advance, the blue roof design and implementation process can proceed with minimal delays, costs and legal risks.

Understanding the end use of the rainwater dictates the level of treatment required, which influences the design. For example, using the rainwater for drip irrigation requires less disinfection/treatment than using the rainwater for vehicle washing. In general, the higher the potential to end use exposure by consumption, inhalation or dermal contact, the higher the level of disinfection required to protect human health.

Understanding potential contaminants that can get captured in the cistern is another very important consideration. When it comes to selecting treatment systems, one size does not fit all since treatment systems are selected based on the contaminants likely to be in the water. For example, if the site is located close to manufacturing activity and/or heavy traffic areas, there may be more organic and/or inorganic particulate on the roof. Water quality from a hard surface roof in an industrial area will likely see finer particulate matter than for the same building located in a suburb.

The peak flow rate required for all the fixtures is an important design detail that will heavily influence the configuration and size of a blue roof and RWH system. The peak flow can be calculated by adding up the number of fixtures and multiplying them by their respective water supply fixture units (WSFU), which can be found in your local plumbing code. If treatment is required, knowing your peak flowrate will help a designer strategize on treatment configuration to minimize cost.

If coupling with a RWH cistern to pump the non-potable rainwater to fixtures, it is essential to determine the total dynamic head (TDH) to the farthest fixture located at the highest elevation. If a rainwater treatment system is needed and TDH is not considered, the operability of the treatment system may be limited.

Determining the desired level of automation/controls required for the system is something else to consider, when designing a smart blue roof. Enhanced controls and communications capabilities can minimize day-to-day operational costs, while optimizing the overall system.

The age and condition of the roof liner is another important consideration, especially when considering costs. If the roof liner is near the end of its useful life, replacing it with a blue roof compatible liner would likely not incur significant extra costs. Related to this, waterproofing requirements and protection of existing rooftop equipment, such as mechanical systems (i.e. cooling towers, HVAC, vents), should also be taken into account.

Other considerations when designing a smart blue roof include:

- Overflow and safety
- Winter operability
- Operations and maintenance
- Commissioning the system and training
- Performance monitoring
- Data visualization dashboards

As part of this process, engaging appropriate professionals to assess the site is recommended, as they will be required for the design and implementation of such a system. Examples of these might include structural engineers, mechanical engineers, software designers, and water resource/environmental engineers, among others.

#### *4.7.4 General Smart Blue Roof Implementation Steps*

While designing and installing a smart blue roof system is a very site-specific endeavor, there are some general steps that should be taken into account when designing and installing a blue roof on any ICI facility.

Pre-purchasing stage:

- Engage professionals as needed for site assessment to evaluate existing infrastructure, determine system requirements and develop the design.
- Determine budget and required vendors and contractors.

Implementation stage:

- Tender and award contractor.
- Plan installation/fabrication/phasing schedule.
- Determine ideal time of year for implementation based on facility needs and regular activities.

Post-purchasing and post-implementation stages:

- Develop maintenance and monitoring schedule.
- Training of staff involved in maintenance/monitoring activities.
- Risk mitigation/system inspection.

## 4.8 Cost Accounting for the Landowner and Municipality

This section of the study analyzes the cost of implementing blue roof systems at the three different scales discussed in this report: the building or site scale, the street scale and the neighbourhood scale.

#### *4.8.1 Estimated Capital Costs at the Building Scale*

Costs associated with installing, operating, and maintaining a smart blue roof RWH system within an existing single building were evaluated along with associated benefits and savings and are described below. Costs related to installing a RWH system and passive blue roof are presented for comparison purposes.

#### *4.8.1.1 Rainwater Harvesting System*

Capital costs for a RWH were estimated based on the existing equipment at CVC's office building A. Actual costs were not available, as the system was designed and installed 20 years ago, so some assumptions and estimates were made. These are presented in **Table 38**:

**Table 38 Estimated RWH system capital and installation costs**

| Component | Quantity | Estimated Equipment Cost | Estimated Installation Cost |
|---|---|---|---|
| **5,000 litre Norwesco PE Tank (3 flanges 1 x 2" and 2 x 3")** | 1 | $3,500 | |
| **Dry contact float level control (HLL and LLL)** | 1 | $750 | |
| **JUDO Model JFXL Backwashable Filter 50 mm (100 USGPM)** | 1 | $5,500 | |
| **Multistage Centrifugal Pump** | 1 | $1,800 | |
| **Bladder Tank** | 1 | $800 | |
| **ELKSTER Flow Meter Model C 700** | 1 | $1,500 | |
| **24 Volts Solenoid Valve** | 1 | $250 | |
| **Variable Speed Drive** | 1 | $2,500 | |
| **Pressure Switch and Control Devices** | 2 | $750 | |
| **Mechanical - Valving** | 1 | $1,500 | $7,200 |
| **Electrical & Instrumentation** | 1 | $2,500 | $4,800 |
| **Skid Mounted Control Panel** | 1 | $4,500 | $2,500 |
| **Miscellaneous (strainers, couplings, etc)** | 1 | $1,500 | $2,500 |
| **5 m³ Concrete Base (Forming and Pouring)**** | 1 | $10,000 | $2,500 |
| **Site Commissioning & Decommissioning** | 1 | | $3,500 |
| **Existing Submersible Pump Interconnections/Electrical** | 1 | | $2,500 |
| **Software Programming** | 1 | | $1,200 |
| | | **$37,350** | **$26,700** |

**Total System Cost (includes 20% contingencies)** **$76,860**

Notes:
Concrete at $2,000/m³ installed
Electrical at $150/hr - 16 hrs
Mechanical at $150/hr - 48 hrs
Instrumentation at $150/hr - 16 hrs
Software programming at $150/hr - 8 hrs
Piping Install at $250/meter
** Labour at $50/hr
Total Cost does not include existing 4" dia. cast iron STM downpipe modifications or retrofitting
RWH System costs are project specific. No projections are recommended

#### *4.8.1.2 Passive Blue Roof*

Capital costs for a passive blue roof were estimated and are presented in **Table 39** below.

**Table 39 Passive blue roof estimated capital and installation costs**

| Component | Quantity | Estimated Equipment Cost | Estimated Installation Cost |
|---|---|---|---|
| **Site commissioning/decommissioning** | 1 | | $2,750 |
| **Raised roof fan decking & water proofing** | 1 | | $950 |
| **Roof fan duct water proofing** | 1 | | $1,695 |
| **Weather station removal/relocation** | 1 | | $1,200 |
| **Installation of new ZURN FLO-CONTROL drains**** | 7 | $1,750 | $2,500 |
| **Total Cost (includes 15% contingencies)** | | | **$10,459** |

### *4.8.1.3 Smart Blue Roof with RWH System*

Capital costs associated with retrofitting the existing CVC building and RWH system to have a smart blue roof were estimated by area (Zone 2, Zone 3 and the basement) and are presented in **Table 40** through **Table 42**. As mentioned previously, retrofitting Zone 3 to be part of the smart blue roof was deemed to have too high a cost for the increased benefits. Operating and maintenance costs are itemized in **Table 18**.

**Table 40 Zone 2 estimated capital and installation costs**

| Component | Quantity | Equipment Cost | Total Installed Cost | Expected Life (years) |
|---|---|---|---|---|
| **Site commissioning/decommissioning** | 1 | | $2,750 | |
| **Raised roof fan decking & water proofing** | 1 | | $950 | 15-25 |
| **Roof fan duct water proofing** | 1 | | $1,695 | 15-25 |
| **Weather station removal/relocation** | 1 | | $1,200 | |
| **Concrete precast roof core drilling for emergency overflows (using existing 4" diameter downpipes)** | 2 | | $2,450 | |
| **Emergency overflow sleeve/water proofing/sealing and covered top** | 2 | | $2,950 | 15-25 |
| **Accessing & retrofitting of existing 4" diameter CI horizontal rainwater leaders in 3rd floor attic** | 4 | | $2,100 | 15-25 |
| **Retrofitting existing 4" diameter rainwater CI downcomer** | 2 | | $2,100 | 15-25 |
| **Installation of 4" diameter metal solenoid valve in 3rd floor attic** | 2 | $23,000 | $31,100 | 10 |
| **Civil work required on 3rd floor office area to access pipes & restore to original*** | 2 | | $4,200 | |
| **Area 2 roof barrier installation and water proofing/hot sealing** | 1 | | $13,500 | 15-25 |

| Component | Quantity | Equipment Cost | Total Installed Cost | Expected Life (years) |
|---|---|---|---|---|
| **Installation of new ZURN FLO-CONTROL drains**** | 4 | $1,000 | $1,500 | 10 |
| **Installation of rainwater level & temperature meter-transmitter/roof fixed frame structure** | 1 | $2,800 | $5,250 | 3 |
| **Electrical work - I/O signal wiring to basement control room***** | 1 | | $6,500 | |
| **Miscellaneous HDPE fusing as required around retrofitted areas** | 1 | | $4,500 | |
| **ITC 8000 controller installation & I/O wiring connections****** | 1 | $4,500 | $5,500 | 10 |
| **Controller electrical control panel******* | 1 | $3,000 | $5,500 | 10 |
| **Total Cost Zone 2 (includes 15% contingencies)** | | | **$107,807** | |

| | | | | |
|---|---|---|---|---|
| Notes: | | | | |
| * Assumes access/repairs not required to 1st and 2nd floor ceiling | | | | |
| ** Cost for 2 additional Zurn Flow Control Roof Caps in Non-Blue Roof Zone 1 | 3 | $750 | $1,000 | |
| ***Assumes accessing & utilizing existing phone/computer wiring conduit | | | | |
| **** Rainwater flow provided by ITC PLC-controller - no separate flow meter required | | | | |
| ***** Master central PLC for additional I/O signals and computer peripherals not included | | | | |
| Costs do not include taxes | | | | |
| Cost for optional scuppers 3" diameter located in attic and across lateral walls | 2 | | $8,675 | |
| (No parapet intrusion/ modification required) | | | | |

**Table 41 Zone 3 estimated capital and installation costs**

| Component | Quantity | Equipment Cost | Total Installed Cost | Expected Life (years) |
|---|---|---|---|---|
| **Site commissioning/decommissioning** | 1 | | $1,500 | |
| **Concrete precast roof core drilling for emergency overflows** | 1 | | $1,500 | |
| **Emergency overflow sleeve/water proofing/sealing and covered top** | 1 | | $1,300 | 15-25 |
| **Accessing and retrofitting of existing 4" diameter CI horizontal rainwater leader in garage** | 1 | | $1,500 | 15-25 |
| **Installation of 4" diameter solenoid valve in garage area** | 1 | $11,500 | $15,500 | 10 |
| **Installation of new ZIRN FLO-CONTRAOL drain** | 1 | $220 | $500 | 10 |
| **Installation of rainwater level and temperature meter transmitter/roof fixed frame structure** | 1 | $2,800 | $5,250 | 3 |
| **Electrical work – I/O signal wiring to basement control room** | 1 | | $3,500 | |
| **Total Cost Zone 3 (includes 15% contingencies)** | | | **$35,133** | |

Notes:

- Assumes wiring route accessibility from garage to basement area control room
- Assumes wiring connection to basement RWH control panel
- Costs do not include taxes

**Table 42 Basement retrofit estimated capital and installation costs**

| Component | Quantity | Equipment Cost | Total Installed Cost | Expected Life (years) |
|---|---|---|---|---|
| **Site commissioning/decommissioning** | 1 | | $2,200 | |
| **Installation of new 3' diameter solids removal** | 1 | $2,500 | $5,200 | 15-25 |
| **Installation of manual city water addition line (chlorination)** | 1 | | $1,550 | 15-25 |
| **Retrofitting of 6" diameter CI inlet to accommodate 3" diameter restriction** | 1 | | $1,450 | 15-25 |
| **Mechanical and piping installation miscellaneous retrofitting** | 1 | | $3,525 | 15-25 |
| **Electrical/instrumentation/wiring** | 1 | | $3,500 | |
| **Viqua K model rainwater UV disinfection system*** | 1 | $5,300 | $7,500 | 15-25 |
| **Flow Max 5-micron filter assembly** | 1 | $1,950 | $3,500 | 15-25 |
| **Low-high water level control (ITM Instruments or equivalent pressure transducer/sheath type)** | 1 | $900 | $2,800 | 5 |
| **Total Cost Basement Retrofit (includes 15% contingencies)** | | | **$35,909** | |

Costs associated with the IoT part of the design are discussed below.

### 4.8.2 Summary of Estimated Benefits and Savings

Based on the multiple analyses conducted in this study, the benefits and savings of scaling up smart blue roof implementation up to the street and neighbourhood scales have been estimated and outlined in the following sections. Calculations were derived in extensive spreadsheets provided by the consultants and are not presented herein.

#### 4.8.2.1 Cost Savings Achieved via Blue Roof Implementation at the Site Scale

With a passive blue roof, benefits and savings at the site scale are minimal and generally limited to peak flow reduction and stormwater credits. Since the passive blue roof will earn stormwater credits of up to 40%, this makes the maximum savings for a passive blue roof at CVC's building A approximately $100 per year. Meanwhile, the benefits and savings associated with a RWH system on its own are limited to the savings associated with offsetting potable water use. This amounts to about $276 annually for CVC's Building A.

At the site scale, the total savings from a smart blue roof are approximately $100 from the stormwater credit, $510 from offsetting potable water use (see Table 15) and about $302 from energy savings. The active area of the blue roof system is about 317m$^2$ therefore the total savings by area are $0.32/m$^2$ from the stormwater credit, \$1.61/m$^2$ from offsetting potable water use and \$0.95/m$^2$ from energy savings or a total of \$2.88/m$^2$.

#### *4.8.2.2 Cost Savings Achieved via Blue Roof Implementation at the Street Scale*

Savings associated with water reuse and energy reductions for a smart blue roof and RWH system at the street scale have been discussed in Section 4.6.2 (see **Table 35** for energy savings), and **Table 43** below shows the potential cost savings, if all of the water collected in the street scale study area discussed in **Section 4.4** can be used. Full rainwater use may be achieved by sharing water between buildings (i.e. a higher water user can use the water off the roof of a neighbor who does not need it). The water savings use the Peel Region water rate of \$1.45 per m$^3$. Savings will change based on local water rates.

**Table 43 Cost savings associated with potable water offsets at the street scale**

| Street Sub-catchment ID | Rooftop Area (ha) | Average Annual Runoff Volume Reduction (m$^3$) | Foregone Water Purchasing Cost (\$/year) |
|---|---|---|---|
| **A1** | 1.14 | 7,923 | \$11,480.43 |
| **A2** | 0.85 | 5,908 | \$8,560.69 |
| **A3** | 0.57 | 3,962 | \$5,740.94 |
| **A4** | 0.67 | 4,657 | \$6,747.99 |
| **A5** | 0.71 | 4,935 | \$7,150.82 |
| **A6** | 1.08 | 7,506 | \$10,876.19 |
| **Column Totals** | | **34,891** | **\$50,557** |

#### *4.8.2.3 Cost Savings Achieved via Blue Roof Implementation at the Neighbourhood Scale*

When considering smart blue roof implementation at the neighbourhood scale, the cost savings of a smaller stormwater management pond in Matheson should also be accounted for. As per the analysis in Section 4.5.1.2, the reduction in the 100-year flood storage volume requirement by retrofitting the drainage area with blue roof is 59,011 m$^3$. The computed reduction in permanent pool and extended detention volumes is 20,048 m$^3$ and 5,346 m$^3$ respectively. This brings the total estimated volume reduction to 84,405 m$^3$ – approximately a 24% reduction compared to the proposed facility storage volume. Thus, given the facility's price of \$25.6 million (excluding land procurement costs), implementing blue roofs at the neighbourhood scale would translate into a proportional pond construction savings of \$6.2 million, based on the design volume of 350,438 m$^3$ from the 2015 Aquafor Beech report. Water conservation and energy saving costs are estimated based on Table 44, which summarizes the benefits of the application of smart blue roofs at the neighbourhood scale.

If land acquisition costs are also included in the assessment, the cost savings achieved through implementation of blue roofs in the CDA increase. Using standard industrial/commercial land values provided by the City (City of Mississauga 2018), the unit cost of commercial lands within the City is estimated to be \$3.694 million per ha. Aerial photography suggests that the Matheson facility occupies approximately 6.93 ha. This, in turn, equates to a total land cost of \$25.6million. The value of the land-use reduction associated with blue roof implementation can be estimated to be another \$6.2 million.

If foregone property tax revenues are also included in the above analysis, additional benefits may be computed. A nearby address was measured to be 140 m X 80 m (1.12 ha) in size. This parcel's property value, which includes both the land and building, accessed through the City of Mississauga website, was assessed to be $8.078 million (City of Mississauga, n.d.). The property tax bracket for such office building space is approximately 0.945% (City of Mississauga, 2019). As such, the increase in the prorated annual property tax revenue to the City resulting from the land saved via blue roof application equates to approximately $113,361 per year. Over a 25-year span, this equates to a net present loss of $2.83 million.

The application of blue roofs in existing ICI areas has the potential to reduce runoff volumes, flood severity, non-potable water demands and building energy consumption, while extending the useful life of existing infrastructure. Smart Blue Roof infrastructure can also be reasonably expected to provide an evaporative cooling benefit to surrounding environs. The above financial feasibility analysis suggests that blue roof application in pre-existing ICI areas could lead to $6.2 million in wetpond construction cost savings and an additional $6.2 million in land cost savings, for a total construction cost reduction of $12.4 million. If foregone property tax revenue is included in these calculations, the numbers climb to approximately $15.2 million. Such cost estimates do not include savings to property owners vis-à-vis water and sanitary sewer discharge savings, energy savings through evaporative cooling, reduced building material replacement costs, etc. As such, based on this simple analysis, neighbourhood-scale retrofit opportunities in flood-prone areas should be explored prior to investment being made in expensive public infrastructure projects.

## 4.9 Comparison and Cost of Scaling up of Smart Blue Roof Implementation

Table 44 below summarizes the costs and benefits (i.e. cost savings) associated with a smart blue roof and RWH system, as they apply to the site scale (CVC's Building A), the street scale, and the neighbourhood.

While the main benefits associated with the smart blue roof system are those related to stormwater reduction, avoided land acquisition and construction costs for stormwater management ponds, and avoided foregone property tax revenues – as demonstrated above – provide cost savings. Avoided flood damages to infrastructure and environment (e.g. erosion) and avoided storm sewer upgrade and replacement can also provide significant cost savings with large scale blue roof implementation. These avoided costs as they relate specifically to smart blue roofs are difficult to quantify and are very site specific. However, an initial effort has been made in the below table to quantify the known costs in order to illustrate the potential economic benefit of smart blue roofs. Costs were calculated at either the building, site or neighborhood scale and prorated for each scenario. A brief explanation of each row from Table 44 is provided here:

- Row 1: Reduction in Pond Storage Volume at Neighborhood Scale (see Section 0)
- Row 2: Stormwater Credit for reduced peak flow and for volume reduction
- Row 3: Savings from reduced potable water use due to rainwater storage on roof (Calculated for CVC head office in Section 4.3.2 and prorated for street and neighborhood scale)
- Row 4: Energy savings from evaporation cooling due to ponded water on roof (Calculated for CVC head office in Section 4.6.2 and prorated for street and neighborhood scale)
- Row 5: Property tax revenue from land made available by reduced pond size (Calculated for neighborhood scale in Section 4.8.2.3 and prorated for building and street scale)

- Row 6: Avoided cost of land for a stormwater management pond (Calculated for neighborhood scale in Section 4.8.2.3 and prorated for building and street scale)

- Row 7: Avoided flooding damages; A study carried out by the City of Markham and TMIG estimated that direct flood damages are about 10% of the MPAC value of a property (CHI, City of Markham and TMIG. 2019). Using an average land value of $3.694 million/hectare and estimating that 20% of a given area will flood during a 100-year event, the avoided flood damage values were calculated according to the building, street and neighborhood study site areas.

- Row 8: Avoided storm sewer pipe size increases; The calculations above (Section 4.4.1.2.2) show that the current storm sewer system would surcharge in the event of a 10-year storm. In order to avoid this a 20% increase in the size of the storm sewer pipes would be required. Using values provided by the City of Mississauga (City of Mississauga, 2013) to replace storm sewer pipes, the avoided costs of upgrading was estimated. The calculation was done based on the known size and length of pipes in the street scale and then this value was scaled down and up for the building and neighborhood scale.

- Row 9: Avoided Matheson Pond construction costs; The costs savings for a reduction in pond size were estimated based on the peak flow and reduction achieved by the smart blue roof system. (Calculated for neighborhood scale in section 4.8.2.3, and prorated for building and street scale)

- Row 10: Total avoided capital costs is a total of avoided land acquisition costs, avoided flooding damages, avoided storm sewer increases and avoided pond construction costs.

- Row 11: Total approximate annual costs savings is a sum of stormwater benefits, annual water savings and annual energy savings.

Note: There are several other costs associated with flooding that are much more difficult to quantify. For example, flooding can cause power outages, loss of the use of recreational spaces, and loss of animal habitat, among other things that would be very site specific. Further site-specific costs might include replacing/upgrading/expanding infrastructure, including retention ponds, watercourse and channel capacity upgrades, berm construction, and source and conveyance control programs. These costs can potentially all be reduced through wide scale implementation of blue roofs. This means that the true economic benefits are likely greater than quantified in this study.

With regard to Table 44 below, costs for the street scale and neighbourhood scale were based on the costs described in the previous sections. Each row of the costing portion of the table is described here:

- Row 12: Retrofits (scalable by building unit); Building unit related retrofit costs (commissioning, equipment relocation, waterproofing, etc.) for the blue roof and RWH system installation calculated for the CVC building were multiplied by the number of buildings in each area. The number of buildings at the street scale was estimated to be 44 and at the neighbourhood scale to be 150.

- Row 13: Retrofits (scalable by roof area); rainwater leader retrofits, solenoid valves, etc.) were scaled up by roof surface area.

- Row 14: Liner costs are estimated at $10 per square foot, and it is assumed that if several roofs were retrofitted at the same time that there would be economies of scale reducing liner costs by 20% at the street level and 25% at the neighbourhood level.

- Row 15: Smart system components were considered to be for the entire system include the controller, software, development and commissioning (detailed costs can be found in APPENDIX D). These components were assumed to be static no matter the size of the system. The input and output modules were scaled up based on the number of buildings in each system.

- Row 16: Total Capital Costs is a sum of retrofits that are scalable by building unit and retrofits scalable by roof area, plus roof line and smart system components. A range is estimated for total costs. The low end of the total cost range excludes the liner, as some buildings may have older roofs that are scheduled for replacement anyway, which means the liner cost would not be associated with the blue roof.

- Row 17: Annual Operation and Maintenance Costs: A range for O&M costs is provided. Operation and maintenance costs for the smart blue roof with RWH system outlined in this study have been estimated and were discussed previously in Section 4.7.2.7 above. The costs would be on a per building basis. This is considered a maximum annual cost, as some efficiencies may be found when operating such a system. Economies of scale may be found on the street and neighbourhood scales and are assumed to be 15% and 20%, respectively. (Calculated for CVC head office and prorated for street and neighborhood scale with economy of scale factor applied). The minimum operation and maintenance costs come from the Great Lakes pilot study where the O&M costs for a blue roof were assumed to be about the same as those for a traditional flat roof.

**Table 44 Summary of costs and benefits at building, street, and neighbourhood scales**

| | ITEM / SCALE | CVC Head Office  | Street Scale  | Neighbourhood Scale  |
|---|---|---|---|---|
| | **BENEFITS** | | | |
| 1 | **Reduction in Pond Storage Volume Requirement ($m^3$)** | - | - | 59,011 $m^3$ |
| 2 | **Stormwater Benefits & Savings to Landowner * (\$/yr)** | 645 $m^2$ <br> \$126 | 5.02 ha <br> \$9,780 | 133.6 ha <br> \$260,200 |
| 3 | **Annual Water Savings ($m^3$/yr) & Water Purchasing Cost Savings (\$/yr)** | 342 $m^3$ – 386 $m^3$ <br> \$504 - \$568 | 26,600 $m^3$ – 30,040 $m^3$ <br> \$39,200 - \$44,200 | 708,00 $m^3$ – 800,00 $m^3$ <br> \$1.04 million - \$1.18 million |
| 4 | **Annual Energy Savings (\$/yr)** | \$302 | \$47,800 - \$60,900 | \$1.28 million - \$1.62 million |
| | **Stormwater Benefits & Savings to Municipality** | | | |
| 5 | **Property Tax Revenue (\$/yr)** | \$117 | \$9,100 | \$242,000 |
| 6 | **Avoided Land Acquisition Costs** | \$2,990 | \$233,000 | \$6,200,000 |
| 7 | **Avoided Flooding Damages** | \$29,500 | \$2.30 million | \$61.1 million |
| 8 | **Avoided Storm Sewer Pipe Increases** | \$18,700 | \$1.45 million | \$38.7 million |
| 9 | **Avoided Matheson Pond Construction Cost** | \$2,990 | \$233,000 | \$6.2 million |
| 10 | **Total Avoided Capital Costs** | \$54,200 | \$4.2 million | \$112.2 million |
| 11 | **Total Approximate Annual Cost Savings ** (\$/yr)** | \$55,200 - \$55,300 | \$4.32 million - \$4.34 million | \$115,032,167.43- \$115,515,673.43 |

*Based on area divided by billing unit (267$m^2$), multiplied by annual rate per billing unit (\$104 in 2018 in Mississauga), divided by 2 (since the maximum stormwater credit is 50% of the stormwater charge).

** Calculated in a separate spreadsheet by consultant.

| | ITEM / SCALE | CVC Head Office  | Street Scale  | Neighbourhood Scale  |
|---|---|---|---|---|
| | **COSTS** | | | |
| 12 | **Retrofits (scalable by building unit)** | $83,900 | $3.70 million | $12.6 million |
| 13 | **Retrofits (scalable by roof area)** | $48,300 | $3.76 million | $100.1 million |
| 14 | **Liner** | - | $4.3 million | $107.9 million |
| 15 | **Smart system components (controller, software, development and commissioning) (scaling not required)** | $30,900 | $30,900 | $30,900 |
| 16 | **Total Capital Costs** | $177,000 | $7.92 million - $16.6 million | $150.3 million - $385 million |
| 17 | **Annual Operation & Maintenance ($/yr)** | $1,390- $9,400 | $108,000 - $353,000 | $1.13 million - $3.13 million |
| | **Return on Investment (ROI):** | **Negative** | **Negative** | **Positive** |

# 5. CONCLUSION

This study illustrates that, due to economy of scales, implementing the smart blue roof systems at the neighborhood scale will provide a positive return on investment. It is interesting to note that at the street scale a positive ROI of was not achieved. This is because the density of buildings is high compared to the density of buildings in the neighborhood site. As a result, when density is higher, the costs associated with each building results in a higher total cost per unit area, which makes the ROI unfavorable. As such, a factor to consider is the density of buildings in an area and the costs per building as this affects overall feasibility of blue roof implementation.

Because of the many unquantifiable benefits associated with the smart blue roof and RWH system as well as the preliminary nature of the cost and saving estimates outlined above, it is difficult at this time to make clear conclusions about financial feasibility at the different scales. However, with the increasing severity and frequency of storm events, it is possible that the avoided costs will only increase over time. Further research in the form of a pilot-scale implementation project at CVC is proposed as this will allow for real-life site-specific costs and benefits to be assessed more accurately. In addition, lessons learned from piloting building-scale implementation could help make larger-scale implementation easier and more cost effective.

While benefits to individual private landowners are limited, the benefits of blue roof installation for municipalities could be more substantial. Avoided land acquisition and construction costs for stormwater management-ponds and the resulting property tax revenues provide cost savings, while avoided flood damages to aging infrastructure and the environment (e.g. stream erosion) and avoided storm sewer pipe replacement can all be very significant with larger scale blue roof implementation, as noted above.

## 5.1 Private and Public Benefits and Incentives

Implementing smart blue roof systems on a large scale may be more cost-effective due to economies of scale from bulk purchases of materials and potential for rainwater capture and sharing between properties. The savings incurred are particularly significant for public agencies. Public agencies would do well to lead the implementation of this emerging stormwater management technology. To help gain public support for and action on this promising new stormwater management initiative, municipalities would need to write policies and pass standards to support smart blue roof implementation. For example, writing smart blue roof technology policies into construction regulations, as was done for green roofs with the City of Toronto Green Roof Bylaw and associated City of Toronto Green Standards. In order to raise public interest, confidence, and ability to install smart blue roof systems on a wide scale, it will also be imperative for governments to develop funding incentives and mechanisms for installation by private property owners. Comparable to conclusions reached in a 2013 article on a case study on green roofs "because the private benefits are not high enough to justify […] installation for a private decision-maker at the current cost level, the rate of implementation can be expected to stay low without corrective policy instruments. Policy instruments could include supportive policies that add incentives for private decision-makers to install [sustainable] roofs and/or administrative orders." (Nurmi et al, 2013). By extension, it is reasonable to expect that a similar conclusion could be reached for encouraging the implementation of smart blue roof technology across Canada.

## 5.2 Stakeholder Interest in Blue Roof Implementation

Are Canadian municipalities interested enough and ready to embrace this new smart technology? On February 7, 2019, CVC hosted a Smart Blue Roof Workshop event held at BraeBen Golf and Country Club in Mississauga. The purpose of the event was to introduce smart blue roof systems to private and public sector stakeholders, share technical and financial feasibility findings, as well as to obtain feedback from attendees about the applicability of smart blue roof systems. Feedback was obtained from the audience using Data on Spot (DOTS) clickers to answer a series of multiple-choice questions.

There were approximately 140 people in attendance from both the public and private sectors, with the former being the larger group. Notable attendees included: Orlando Corporation; Daniels; Mattamy; SMEs; regional and municipal governments; Ministry of the Environment, Conservation and Parks; and. conservation authorities. There were many other stakeholders from across Canada that were interested in attending the event; however, due to the lengthy travel distance, they were unable to attend and requested additional information related to the smart blue roof feasibility study results. The event spurred fruitful and thought-provoking discussions, with the majority of participants expressing interest in seeing CVC pilot a smart blue roof system. Highlights of specific feedback collected is featured below.

While most participants in the workshop had heard of blue roofs, far fewer were familiar with the IoT technology that can be coupled with blue roof systems for optimization. When polled about barriers to blue roof implementation, cost, followed by risk/liability, were the top reasons. These responses confirm that both more and more accurate information about the installation and performance of blue roof systems is required.

Given that more than 94 per cent of respondents stated that infrastructure regulators, owners, operators and investors should consider the impacts of climate change in the design, build and operation of all infrastructure assets, it is not surprising that 85 per cent also said that preparing infrastructure for a changing climate and adaptation of infrastructure should be led by a combination of the public and private sectors, with 87 per cent agreeing or strongly agreeing that guidelines — from, for example, City of Toronto's Green Roof Construction Standard and the Green Roof Bylaw — could be adapted to include blue roof systems. 85 per cent agreed or strongly agreed that smart IoT technology providing continuous monitoring and adaptive control of infrastructure is indeed the future and 76 per cent agreed or strongly agreed that blue, green or cool roof systems should be mandatory on new or retrofit buildings, especially in urban areas.

Financial concerns expressed with regard to implementing smart blue roof systems included ROI, which 58 per cent of respondents believed would take at least six years and possibly even more than 15 years to achieve, while security and data breach threats concerns were expressed by 70 per cent of respondents. Significantly, yet not surprisingly, 93 per cent felt that owners of blue roof systems should receive financial incentives, streamlined permitting or recognition (i.e. tax credits or reduced insurance premiums).

When asked "Who do you believe will be the most influential on the uptake of blue roof systems," the majority responded with "regulators (including insurers)" (at 49 per cent) or "building owners/facility managers" (at 25 per cent). Supporting the latter response, 90 per cent of respondents agreed or strongly agreed that they see the value in building a smart blue roof demonstration/pilot project at the CVC head office in Mississauga, stating the following points as being of interest to them (in order of importance):

- Performance monitoring
- Planning and design, tied with rooftop site visit
- Operation and maintenance, and
- Approvals and construction.

Given that 94 per cent of respondents agreed or strongly agreed that smart IoT technology optimizes infrastructure to obtain the most stormwater, water and energy efficiency benefits, there is notable interest in this emerging technology and CVC and interested stakeholders see substantial valuable in piloting a smart blue roof project on Building A to gain valuable lessons for wider scale application.

## 5.3 Concluding Remarks

In summary, this report concludes that further research in the form of a pilot-scale implementation project at CVC is warranted. Pilot implementation will be valuable to Canadian municipalities, as it will allow for real-life site-specific costs, performance and benefits to be assessed more accurately. While benefits to individual private landowners, such as CVC, are limited, it has been determined that the collective public benefits of smart blue roof installation for municipalities could be quite substantial. Avoided land acquisition and construction costs for stormwater management ponds and the resulting avoided foregone property tax revenues provide cost savings, while avoided flooding damages to infrastructure and environment (e.g. erosion) and avoided storm sewer replacement can all be very significant with larger scale smart blue roof implementation.

There are several other avoided costs associated with a smart blue roof's ability to manage stormwater, which are much more difficult to quantify. For example, flooding can cause power outages, loss of the use of recreational spaces, and loss of animal habitat, among other issues that would be very site specific. Additional site-specific avoided costs might include replacing, upgrading, or expanding infrastructure, including retention ponds; watercourse and channel capacity upgrades; berm construction; and, source and conveyance control programs.

Finally, as a type of green infrastructure, blue roofs can not only supplement gray stormwater infrastructure to reduce the risk of flooding, blue roofs can provide the co-benefits of reduced potable water use and improved energy efficiency through water use offset and evaporative cooling. Overall, blue roof systems can improve the resilience of highly urbanized industrial/commercial areas by enabling these areas to respond more intense rain events. The true economic benefits for municipalities may be far greater than could be quantified in this study. This suggests that catchment-scale retrofit opportunities in flood-prone and similar priority areas should be explored prior to investment being made in expensive conventional public infrastructure projects. It follows that a public and private sector integrated stormwater management approach has become necessary to reduce the pressures on aging municipal infrastructure and may, prove to be an effective method to address escalating flooding problems. To better refine costs and benefits of smart blue roof systems, a pilot project proof of concept is warranted. Given the ever-intensifying impacts of climate change on stormwater infrastructure, it appears that the benefits of smart blue roof technology should be further investigated in Canada as a potential wide-scale option for not only better controlling stormwater in urbanized communities, but also simultaneously saving costs in the process.

# ACRONYMS

| | |
|---|---|
| **AWS** | Amazon Web Services |
| **AoT** | Array of Things |
| **BMS** | Building Management System |
| **BR** | Blue Roof |
| **CDA** | Contributing Drainage Area |
| **CN** | Curve Number |
| **CVC** | Credit Valley Conservation Authority |
| **FCM** | Federation of Canadian Municipalities |
| **GHG** | Greenhouse Gas |
| **I/C** | Industrial/Commercial |
| **IDF** | Intensity - Duration - Frequency |
| **ICI** | Industrial, Commercial and Institutional |
| **IoT** | Internet of Things |
| **LAN** | Local Area Network |
| **LID** | Low Impact Development |
| **NASHYD** | Nash Instantaneous Unit Hydrograph |
| **NI** | National Instruments |
| **NBC** | National Building Code |
| **OBC** | Ontario Building Code |
| **PAC** | Programmable Automation Controller |
| **PLC** | Programmable Logic Controller |
| **PMR** | Protected Membrane Roofing |
| **RWH** | Rainwater Harvesting |
| **SCS** | Soil Conservation Service |
| **SDL** | Superimposed Dead Load |
| **SME** | Small-to-medium Enterprises |
| **STEP** | Sustainable Technologies Evaluation Program |
| **TDH** | Total Dynamic Head |
| **TIMP** | Total Impervious Area |
| **WSFU** | Water Supply Fixture Units |

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# APPENDIX A – Automated Real-time IoT Smart Blue Roof System Structural and Building Science

**SNOW LOADING TABLE**

| CODE Name | Article | Formula | Snow Loading (S) Toronto | Snow Loading (S) Mississauga | Remarks |
|---|---|---|---|---|---|
| OBC 2012 | 4.1.6.2 | $S=I_s[S_s(C_b.C_w.C_s.C_a)+S_r]$ | 23.4 (1.12kPa) | 26.7 (1.28kPa) | |
| NBC 2010 | 4.1.6.2 | $S=I_s[S_s(C_b.C_w.C_s.C_a)+S_r]$ | 23.4 (1.12kPa) | 26.7 (1.28kPa) | |
| OBC 2006 | 4.1.6.2 | $S=I_s[S_s(C_b.C_w.C_s.C_a)+S_r]$ | 23.4 (1.12kPa) | 26.7 (1.28kPa) | |
| NBC 2005 | 4.1.6.2 | $S=I_s[S_s(C_b.C_w.C_s.C_a)+S_r]$ | 23.4 (1.12kPa) (*) | 26.7 (1.28kPa) (*) | Snow load change |
| OBC 1997 | 4.1.7.1 | $S= S_s(C_b.C_w.C_s.C_a)+S_r$ | 21.7 (1.04kPa) | 25.1 (1.20kPa) | |
| NBC 1995 | 4.1.7.1 | $S= S_s(C_b.C_w.C_s.C_a)+S_r$ | 21.7 (1.04kPa) (*) | 25.1 (1.20kPa) (*) | |
| OBC 1990 | 4.1.7.1 | $S= S_s(C_b.C_w.C_s.C_a)+S_r$ | 21.7 (1.04kPa) | 25.1 (1.20kPa) | Snow load change |
| OBC 1986 | 4.1.7.1 | $S= S_0(C_b.C_w.C_s.C_a)$ | 32.0 (1.53kPa) | 32.0 (1.53kPa) | |
| NBC 1980 | 4.1.7 | $S= S_0.C_s$ | 32.0 (1.53kPa) (**) | 32.0 (1.53kPa) (**) | |
| OBC 1975 | 4.1.7 | $S= S_0.C_s$ | 32.0 (1.53kPa) | 32.0 (1.53kPa) | |
| NBC 1970 | 4.1.5 | $S= S_0.C_s$ | 32.0 (1.53kPa) | 32.0 (1.53kPa) | |
| NBC 1965 | 4.1.3.7 | $S= S_0.C_s$ | 32.0 (1.53kPa) | 32.0 (1.53kPa) | |
| NBC 1960 | 4.1.2.8.(1) | Tabulated | 32.0 (1.53kPa) | 32.0 (1.53kPa) | |
| NBC 1953 | 2.8 and 4.1.2.1 | Graphical | 32.0 (1.53kPa) (***) | 32.0 (1.53kPa) (***) | |
| City of Toronto Prior to 1970 | | Tabulated | 40.0 (1.91kPa) | | |

(*) Appendix C referenced for $S_s$ and $S_r$, but was not available. Indicated value is based on previous design notes.
(**) Appendix referenced value for $S_0$ was not available. Indicated value is based on previous design notes.
(***) Assumed value. Code article was not accessible as it was covered with Errata sheet.
Note: The above Snow loadings are for standalone flat roofs only. They do not account for snow accumulation due to shaped roofs, or near higher roofs.

**SYMBOL DEFINITIONS**

$C_a$ = Accumulation, or shape, factor = 1.0
$C_b$ = Basic snow load factor = 0.8
$C_s$ = Basic snow load coefficient = 0.8, Applicable to OBC 1975, NBC 1965, NBC 1970 and NBC 1980
$C_s$ = Slope factor = 1.0, Applicable to all Codes, except OBC 1975, NBC 1965, NBC 1970 and NBC 1980
$C_w$ = Wind exposure factor = 1.0
$I_s$ = Importance factor = 1.0 for "Normal" use buildings
$S$ = Design snow load in psf
$S_0$ = Ground snow load

$S_r$ = Associated rain load

$S_s$ = Ground snow load

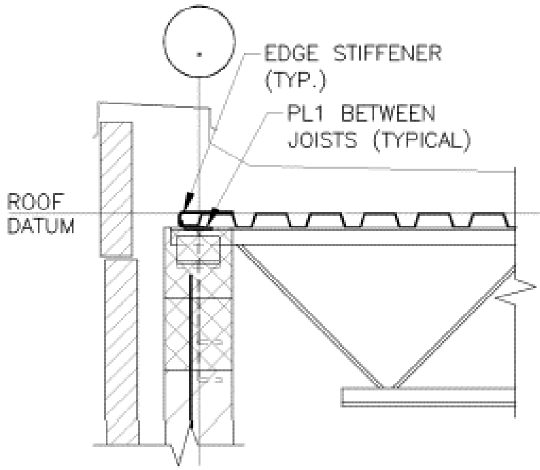


**Figure A 1 Steel deck on steel joists, roof without structural parapet**

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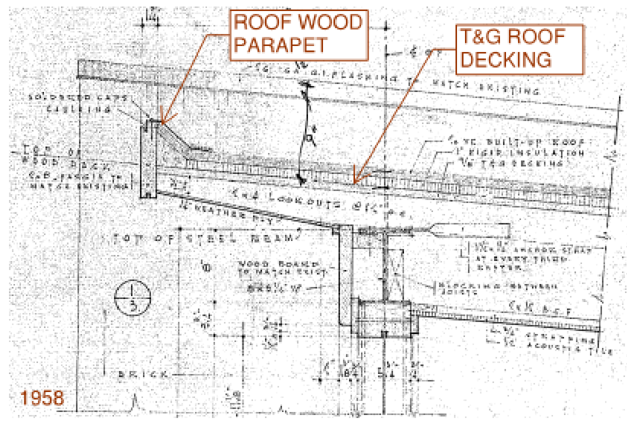



**Figure A 2 Roof detail with wood decking, 1958 Kitchener**

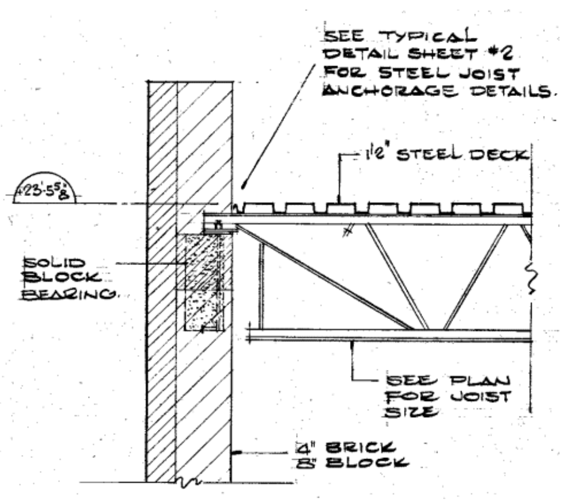



**Figure A 3 Steel deck on steel joists, roof with structural parapet, 1974 J.A. Turner SS, Brampton**

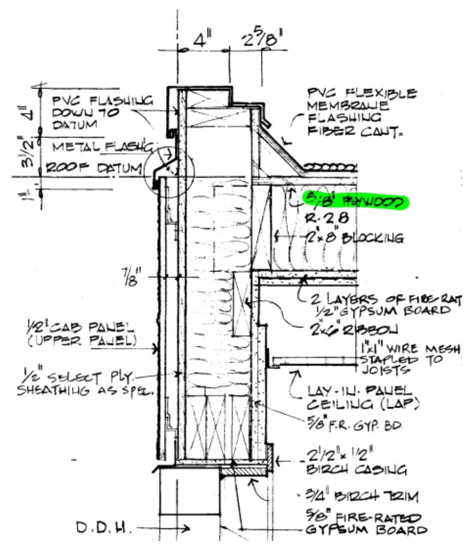



**Figure A 4 Plywood on wood joist, roof with structural parapet, 1982 Plum Tree JR. School, Mississauga**

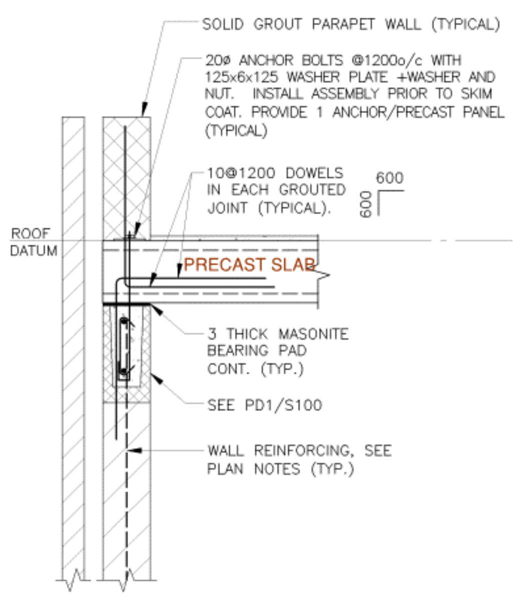



**Figure A 5 Hollow Core Precast roof with structural parapet, 2006 Turner Fenton SS, Brampton**

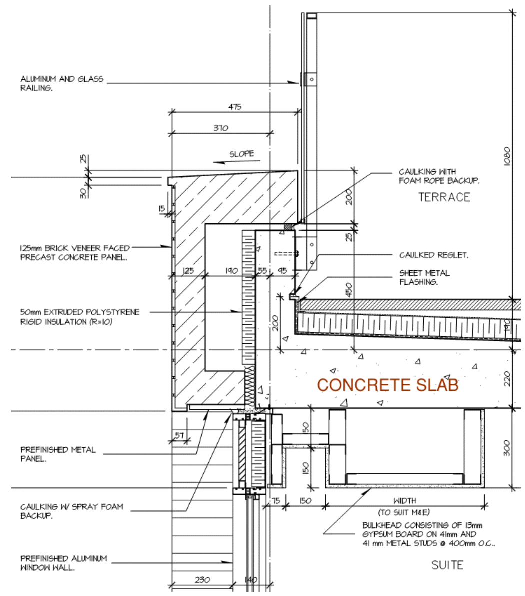



**Figure A 6 Concrete slab roof at with structural parapet, 2012 high-rise building, Toronto, 88 Davenport**

## APPENDIX B — Real-time Automated Components Products List

Appendix B includes all the specifications for the hardware referred to in the analysis of the real-time automated components of a smart blue roof system. The list of items is available in **Table 7** and **Table 4**.

SPECIFICATIONS

# NI cRIO-9030

## Embedded CompactRIO Controller with Real-Time Processor and Reconfigurable FPGA

This document lists the specifications for the National Instruments cRIO-9030. The following specifications are typical for the -20 °C to 55 °C operating temperature range unless otherwise noted.

**Caution** Do not operate the cRIO-9030 in a manner not specified in this document. Product misuse can result in a hazard. You can compromise the safety protection built into the product if the product is damaged in any way. If the product is damaged, return it to NI for repair.

## Processor

| | |
|---|---|
| CPU | Intel Atom E3825 |
| Number of cores | 2 |
| CPU frequency | 1.33 GHz |
| On-die L2 cache | 1 MB (shared) |

## Operating System

**Note** For minimum software support information, visit *ni.com/info* and enter the Info Code `swsupport`.

| | |
|---|---|
| Supported operating system | NI Linux Real-Time (64-bit) |

| | |
|---|---|
| Software requirements | |
| Application software | |
| LabVIEW | LabVIEW 2014 or later, LabVIEW Real-Time Module 2014 or later, LabVIEW FPGA Module 2014 or later[1], |
| C/C++ Development Tools for NI Linux Real-Time[2] | Eclipse Edition 2014 or later |
| Driver software | NI-RIO Device Drivers August 2014 or later |

# Network/Ethernet Port

| | |
|---|---|
| Number of ports | 2 |
| Network interface | 10Base-T, 100Base-TX, and 1000Base-T Ethernet |
| Compatibility | IEEE 802.3 |
| Communication rates | 10 Mbps, 100 Mbps, 1000 Mbps auto-negotiated |
| Maximum cabling distance | 100 m/segment |

# RS-232 Serial Port

| | |
|---|---|
| Maximum baud rate | 115,200 bps |
| Data bits | 5, 6, 7, 8 |
| Stop bits | 1, 2 |
| Parity | Odd, Even, Mark, Space |
| Flow control | RTS/CTS, XON/XOFF, DTR/DSR |
| RI wake maximum low level | 0.8 V |
| RI wake minimum high level | 2.4 V |
| RI overvoltage tolerance | ±24 V |

[1] LabVIEW FPGA Module is not required when using Scan Interface mode. To program the user-accessible FPGA on the cRIO-9030, LabVIEW FPGA Module is required.

[2] C/C++ Development Tools for NI Linux Real-Time is an optional interface for C/C++ programming of the cRIO-9030 processor. Visit *ni.com/info* and enter Info Code `RIOCdev` for more information about the C/C++ Development Tools for NI Linux Real-Time.

## RS-485/422 (DTE) Serial Port

| | |
|---|---|
| Maximum baud rate | 115,200 bps |
| Data bits | 5, 6, 7, 8 |
| Stop bits | 1, 2 |
| Parity | Odd, Even, Mark, Space |
| Flow control | XON/XOFF |
| Wire mode | 4-wire, 2-wire, 2-wire auto |
| Isolation voltage | 60 VDC continuous, port to earth ground |

**Note** The RS-485 serial port ground and shield are not connected to chassis ground. This isolation is intended to prevent ground loops and does not meet UL ratings for safety isolation.

| | |
|---|---|
| Cable requirement | Unshielded, 30 m maximum length (limited by EMC/surge) |

**Note** RS-485 is capable of 1.2 km (4,000 ft) length without surge limitation.

## USB Ports

| | |
|---|---|
| Number of ports | |
| Device ports | 1 standard B connector |
| Host ports | 2 standard A connectors |

**Note** The USB device port is intended for use in device configuration, application deployment, debugging, and maintenance.

| | |
|---|---|
| USB interface | USB 2.0, Hi-Speed |
| Maximum data rate | 480 Mb/s per port |
| Maximum current (USB host ports) | 1 A (aggregate) |

## Mini DisplayPort

| | |
|---|---|
| Maximum resolution | 2560 × 1600 at 60 Hz |

## SD Card Slot

| | |
|---|---|
| SD card support | SD and SDHC standards |

## Memory

| | |
|---|---|
| Nonvolatile[3] | |
| SD removable (user supplied) | Up to 32 GB |
| Solid-state drive | 4 GB |

**Note** Visit *ni.com/info* and enter the Info Code `ssdbp` for information about the life span of the nonvolatile memory and about best practices for using nonvolatile memory.

| | |
|---|---|
| Volatile | |
| Processor memory | |
| Density | 1 GB |
| Type | DDR3L |
| Maximum theoretical data rate | 8.533 GB/s |
| Data throughput | |
| System memory to SD removable storage[4] | 10 MB/s |
| Module slots to system memory | 20 MB/s, application- and system-dependent |

## Reconfigurable FPGA

| | |
|---|---|
| FPGA type | Xilinx Kintex-7 7K70T |
| Number of flip-flops | 82,000 |
| Number of 6-input LUTs | 41,000 |
| Number of DSP slices (18 × 25 multipliers) | 240 |
| Available block RAM | 4,860 kbits |
| Number of DMA channels | 16 |
| Number of logical interrupts | 32 |

[3] 1 MB is equal to 1 million bytes. 1 GB is equal to 1 billion bytes. The actual formatted capacity might be less.

[4] Consult the manufacturer specifications of your SD removable storage.

## Internal Real-Time Clock

| | |
|---|---|
| Accuracy | 200 ppm; 40 ppm at 25 °C |

## CMOS Battery

| | |
|---|---|
| Typical battery life with power applied to power connector | 10 years |
| Typical battery life when stored at temperatures up to 25 °C | 7.8 years |
| Typical battery life when stored at temperatures up to 85 °C | 5.4 years |

## Power Requirements

**Note** Some C Series modules have additional power requirements. For more information about C Series module power requirements, refer to the C Series module(s) documentation.

| | |
|---|---|
| Voltage input range (measured at the cRIO-9030 power connector) | |
| V1 | 9 V to 30 V |
| V2 | 9 V to 30 V |
| Maximum power consumption | 40 W |

**Note** The maximum power consumption specification is based on a fully populated system running a high-stress application at elevated ambient temperature and with all C Series modules and USB devices consuming the maximum allowed power.

| | |
|---|---|
| Typical standby power consumption | 3.4 W at 24 VDC input |
| Recommended power supply | 100 W, 24 VDC |
| Typical leakage current from secondary power input (V2) while system is powered from primary power input (V1) | |
| At 9 V | 0.4 mA |
| At 30 V | 1.93 mA |

**Caution** Do not connect V2 to a DC mains supply or to any supply that requires a connecting cable longer than 3 m (10 ft). A DC mains supply is a local DC electricity supply network in the infrastructure of a site or building.

| | |
|---|---|
| EMC ratings for inputs as described in IEC 61000 | |
| V1 | Short lines, long lines, and DC distributed networks |
| V2 | Short lines only |
| Power input connector | 4-position, 3.5 mm pitch, pluggable screw terminal with screw locks, Sauro CTF04BV8-AN000A |

# Physical Characteristics

If you need to clean the cRIO-9030, wipe it with a dry towel.

**Tip** For two-dimensional drawings and three-dimensional models of the cRIO-9030, visit *ni.com/dimensions* and search by module number.

| | |
|---|---|
| Weight (unloaded) | 1,800 g (3 lbs, 15 oz) |
| Dimensions (unloaded) | 219.5 mm × 88.1 mm × 109.2 mm (8.64 in. × 3.47 in. × 4.30 in.) |
| Screw-terminal wiring | |
| Gauge | 0.5 mm $^2$ to 2.1 mm$^2$ (20 AWG to 14 AWG) copper conductor wire |
| Wire strip length | 6 mm (0.24 in.) of insulation stripped from the end |
| Temperature rating | 85 °C |
| Torque for screw terminals | 0.20 N · m to 0.25 N · m (1.8 lb · in. to 2.2 lb · in.) |
| Wires per screw terminal | One wire per screw terminal |
| Connector securement | |
| Securement type | Screw flanges provided |
| Torque for screw flanges | 0.20 N · m to 0.25 N · m (1.8 lb · in. to 2.2 lb · in.) |

# Safety Voltages

Connect only voltages that are below these limits.

| | |
|---|---|
| V1 terminal to C terminal | 30 VDC maximum, Measurement Category I |
| V2 terminal to C terminal | 30 VDC maximum, Measurement Category I |
| Chassis ground to C terminal | 30 VDC maximum, Measurement Category I |

Measurement Category I is for measurements performed on circuits not directly connected to the electrical distribution system referred to as *MAINS* voltage. MAINS is a hazardous live electrical supply system that powers equipment. This category is for measurements of voltages from specially protected secondary circuits. Such voltage measurements include signal levels, special equipment, limited-energy parts of equipment, circuits powered by regulated low-voltage sources, and electronics.

**Caution** Do not connect the cRIO-9030 to signals or use for measurements within Measurement Categories II, III, or IV.

**Note** Measurement Categories CAT I and CAT O are equivalent. These test and measurement circuits are not intended for direct connection to the MAINS building installations of Measurement Categories CAT II, CAT III, or CAT IV.

# Environmental

| | |
|---|---|
| Temperature (IEC-60068-2-1 and IEC-60068-2-2) | |
| Operating | -20 °C to 55 °C |
| Storage | -40 °C to 85 °C |

**Caution** Failure to follow the mounting instructions in the user manual can cause temperature derating. Visit *ni.com/info* and enter Info Code `criomounting` for more information about mounting configurations and temperature derating.

| | |
|---|---|
| Ingress protection | IP20 |
| Operating humidity (IEC 60068-2-56) | 10% RH to 90% RH, noncondensing |
| Storage humidity (IEC 60068-2-56) | 5% RH to 95% RH, noncondensing |
| Pollution Degree (IEC 60664) | 2 |
| Maximum altitude | 5,000 m |

Indoor use only.

# Hazardous Locations

| | |
|---|---|
| U.S. (UL) | Class I, Division 2, Groups A, B, C, D, T4;<br>Class I, Zone 2, AEx nA IIC T4 |
| Canada (C-UL) | Class I, Division 2, Groups A, B, C, D, T4;<br>Class I, Zone 2, Ex nA IIC T4 |
| Europe (ATEX) and International (IECEx) | Ex nA IIC T4 Gc |

# Shock and Vibration

To meet these specifications, you must mount the cRIO-9030 system directly on a flat, rigid surface as described in the user manual, affix ferrules to the ends of the terminal wires, install an SD card cover (SD Door Kit, 783660-01), and use retention accessories for the USB host ports (NI Industrial USB Extender Cable, 152166-xx), USB device port (NI Locking USB Cable, 157788-01), and mini DisplayPort connector (NI Retention Accessory for Mini DisplayPort, 156866-01). All cabling should be strain-relieved near input connectors. Take care to not directionally bias cable connectors within input connectors when applying strain relief.

| | |
|---|---|
| Operating vibration | |
| Random (IEC 60068-2-64) | 5 $g_{rms}$, 10 Hz to 500 Hz |
| Sinusoidal (IEC 60068-2-6) | 5 g, 10 Hz to 500 Hz |
| Operating shock (IEC 60068-2-27) | 30 g, 11 ms half sine; 50 g, 3 ms half sine;<br>18 shocks at 6 orientations |

# Safety and Hazardous Locations Standards

This product is designed to meet the requirements of the following electrical equipment safety standards for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1
- EN 60079-0:2012, EN 60079-15:2010
- IEC 60079-0: Ed 6, IEC 60079-15; Ed 4
- UL 60079-0; Ed 5, UL 60079-15; Ed 3
- CSA 60079-0:2011, CSA 60079-15:2012

**Note** For UL and other safety certifications, refer to the product label or the *Online Product Certification* section.

## Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326-1 (IEC 61326-1): Class A emissions; Industrial immunity
- EN 61000-6-2: Immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- EN 55022 (CISPR 22): Class A emissions
- EN 55024 (CISPR 24): Immunity
- AS/NZS CISPR 11: Group 1, Class A emissions
- AS/NZS CISPR 22: Class A emissions
- FCC 47 CFR Part 15B: Class A emissions
- ICES-001: Class A emissions

**Note** In the United States (per FCC 47 CFR), Class A equipment is intended for use in commercial, light-industrial, and heavy-industrial locations. In Europe, Canada, Australia and New Zealand (per CISPR 11) Class A equipment is intended for use only in heavy-industrial locations.

**Note** Group 1 equipment (per CISPR 11) is any industrial, scientific, or medical equipment that does not intentionally generate radio frequency energy for the treatment of material or inspection/analysis purposes.

**Note** For EMC declarations and certifications, and additional information, refer to the *Online Product Certification* section.

## CE Compliance CE

This product meets the essential requirements of applicable European Directives, as follows:

- 2014/35/EU; Low-Voltage Directive (safety)
- 2014/30/EU; Electromagnetic Compatibility Directive (EMC)
- 94/9/EC; Potentially Explosive Atmospheres (ATEX)

## Online Product Certification

Refer to the product Declaration of Conformity (DoC) for additional regulatory compliance information. To obtain product certifications and the DoC for this product, visit *ni.com/certification*, search by model number or product line, and click the appropriate link in the Certification column.

# Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *Minimize Our Environmental Impact* web page at *ni.com/environment*. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

# Waste Electrical and Electronic Equipment (WEEE)

**EU Customers** At the end of the product life cycle, all NI products must be disposed of according to local laws and regulations. For more information about how to recycle NI products in your region, visit *ni.com/environment/weee*.

# Battery Replacement and Disposal

**Battery Directive** This device contains a long-life coin cell battery. If you need to replace it, use the Return Material Authorization (RMA) process or contact an authorized National Instruments service representative. For more information about compliance with the EU Battery Directive 2006/66/EC about Batteries and Accumulators and Waste Batteries and Accumulators, visit *ni.com/environment/batterydirective*.

# 电子信息产品污染控制管理办法（中国 RoHS）

**中国客户** National Instruments 符合中国电子信息产品中限制使用某些有害物质指令 (RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 `ni.com/environment/rohs_china`。(For information about China RoHS compliance, go to `ni.com/environment/rohs_china`.)

# Worldwide Support and Services

The National Instruments website is your complete resource for technical support. At *ni.com/support*, you have access to everything from troubleshooting and application development self-help resources to email and phone assistance from NI Application Engineers.

Visit *ni.com/services* for NI Factory Installation Services, repairs, extended warranty, and other services.

Visit *ni.com/register* to register your National Instruments product. Product registration facilitates technical support and ensures that you receive important information updates from NI.

A Declaration of Conformity (DoC) is our claim of compliance with the Council of the European Communities using the manufacturer's declaration of conformity. This system affords the user protection for electromagnetic compatibility (EMC) and product safety. You can obtain the DoC for your product by visiting *ni.com/certification*. If your product supports calibration, you can obtain the calibration certificate for your product at *ni.com/calibration*.

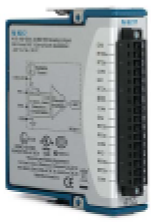
National Instruments corporate headquarters is located at 11500 North Mopac Expressway, Austin, Texas, 78759-3504. National Instruments also has offices located around the world. For telephone support in the United States, create your service request at *ni.com/support* or dial 1 866 ASK MYNI (275 6964). For telephone support outside the United States, visit the *Worldwide Offices* section of *ni.com/niglobal* to access the branch office websites, which provide up-to-date contact information, support phone numbers, email addresses, and current events.

376260A-02 Oct15

DATASHEET

# NI 9217

## 4 RTD, 0 Ω to 400 Ω, 24 Bit, 400 S/s Aggregate, PT100



- Screw-terminal connectivity
- 50 Hz/60 Hz noise rejection
- 250 Vrms, CAT II, channel-to-earth isolation

The NI 9217 is an RTD analog input module for NI CompactDAQ and CompactRIO systems. The NI 9217 features four channels and 24 bits of resolution for PT100 RTD measurements. The NI 9217, compatible with 3- and 4-wire RTD measurements, automatically detects the type of RTD (3- or 4-wire) connected to the channel and configures each channel for the appropriate mode. The module provides 1 mA of current excitation per channel and has less than a 1 °C accuracy error over its entire operating temperature range. NI provides calibration services for the NI 9217.

| | |
|---|---|
| Kit Contents | • NI 9217<br>• NI 9217 Getting Started Guide |
| Accessories | • NI 9939 Backshell Connector Kit<br>• NI 9975 Screw-Terminal Block |

| Product Name | Module Type | Signal Ranges | Channels | Max Sample Rate | Simultaneous | Resolution | Connectivity |
|---|---|---|---|---|---|---|---|
| NI 9216 | PT100 RTD | 0 to 400 Ω | 8 | 400 S/s | No | 24-Bit | Spring-Terminal and DSUB |
| NI 9217 | PT100 RTD | 0 to 400 Ω | 4 | 400 S/s | No | 24-Bit | Screw-Terminal |
| NI 9219 | Universal | 0 to 10000 Ω | 4 | 100 S/s | Yes | 24-Bit | Spring-Terminal |
| NI 9226 | PT1000 RTD | 0 to 4000 Ω | 8 | 400 S/s | No | 24-Bit | Spring-Terminal and DSUB |

# NI C Series Overview

NI provides more than 100 C Series modules for measurement, control, and communication applications. C Series modules can connect to any sensor or bus and allow for high-accuracy measurements that meet the demands of advanced data acquisition and control applications.

- Measurement-specific signal conditioning that connects to an array of sensors and signals
- Isolation options such as bank-to-bank, channel-to-channel, and channel-to-earth ground
- -40 °C to 70 °C temperature range to meet a variety of application and environmental needs
- Hot-swappable

The majority of C Series modules are supported in both CompactRIO and CompactDAQ platforms and you can move modules from one platform to the other with no modification.

## CompactRIO

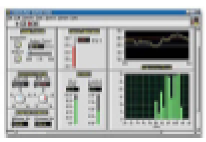
CompactRIO combines an open-embedded architecture with small size, extreme ruggedness, and C Series modules in a platform powered by the NI LabVIEW reconfigurable I/O (RIO) architecture. Each system contains an FPGA for custom timing, triggering, and processing with a wide array of available modular I/O to meet any embedded application requirement.

## CompactDAQ

CompactDAQ is a portable, rugged data acquisition platform that integrates connectivity, data acquisition, and signal conditioning into modular I/O for directly interfacing to any sensor or signal. Using CompactDAQ with LabVIEW, you can easily customize how you acquire, analyze, visualize, and manage your measurement data.

## Software

### LabVIEW Professional Development System for Windows

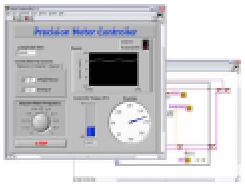


- Use advanced software tools for large project development
- Generate code automatically using DAQ Assistant and Instrument I/O Assistant
- Use advanced measurement analysis and digital signal processing
- Take advantage of open connectivity with DLLs, ActiveX, and .NET objects
- Build DLLs, executables, and MSI installers

### NI LabVIEW FPGA Module

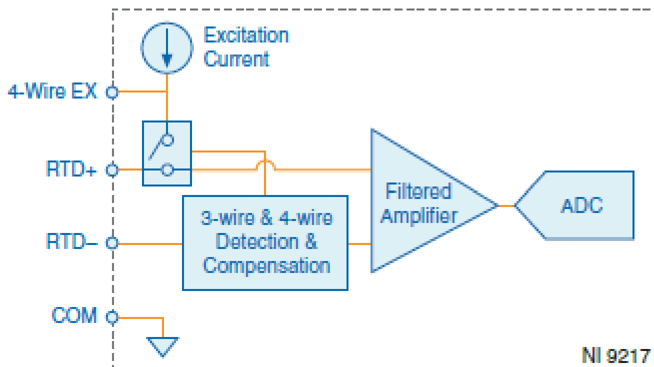
- Design FPGA applications for NI RIO hardware
- Program with the same graphical environment used for desktop and real-time applications
- Execute control algorithms with loop rates up to 300 MHz
- Implement custom timing and triggering logic, digital protocols, and DSP algorithms
- Incorporate existing HDL code and third-party IP including Xilinx IP generator functions
- Purchase as part of the LabVIEW Embedded Control and Monitoring Suite

**NI LabVIEW Real-Time Module**



- Design deterministic real-time applications with LabVIEW graphical programming
- Download to dedicated NI or third-party hardware for reliable execution and a wide selection of I/O
- Take advantage of built-in PID control, signal processing, and analysis functions
- Automatically take advantage of multicore CPUs or set processor affinity manually
- Take advantage of real-time OS, development and debugging support, and board support
- Purchase individually or as part of a LabVIEW suite

# Input Circuitry




- RTD channels share a common ground that is isolated from other modules in the system.
- Each RTD channel is filtered and then sampled by a 24-bit analog-to-digital converter (ADC).

# NI 9217 Specifications

The following specifications are typical for the range -40 °C to 70 °C unless otherwise noted.

All specifications given in °C are specific to 100 Ω platinum RTDs.

**Caution** Do not operate the NI 9217 in a manner not specified in this document. Product misuse can result in a hazard. You can compromise the safety protection built into the product if the product is damaged in any way. If the product is damaged, return it to NI for repair.

## Input Characteristics

| | |
|---|---|
| Number of channels | 4 analog input channels |
| ADC resolution | 24 bits |
| Type of ADC | Delta-sigma |
| Sampling mode | Scanned |
| Measurement range | |
| Temperature | -200 °C to 850 °C |
| Resistance | 0 Ω to 400 Ω |
| Common-mode range | |
| COM-to-earth ground | ±250 Vrms |
| Channel-to-COM | 50 mV |
| Conversion time | |
| High-resolution mode | 200 ms per channel, 800 ms total for all channels |
| High-speed mode | 2.5 ms per channel, 10 ms total for all channels |

Temperature accuracy (including noise)[1], 4-wire mode

| Measured Value | Typical (25 °C) | Maximum (-40 to 70 °C) |
|---|---|---|
| -200 °C to 150 °C | 0.15 °C | 0.35 °C |
| 150 °C to 850 °C | 0.20 °C | 1.0 °C |

Temperature accuracy (including noise)[1], 3-wire mode

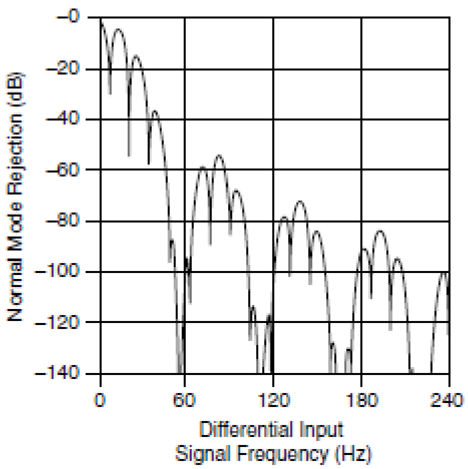
| Measured Value | Typical (25 °C) | Maximum (-40 to 70 °C) |
|---|---|---|
| -200 °C to 150 °C | 0.20 °C | 0.50 °C |
| 150 °C to 850 °C | 0.30 °C | 1.0 °C |

| | |
|---|---|
| Noise | |
| High-resolution mode | 0.003 °C |
| High-speed mode | 0.02 °C |

[1] For high-speed mode, add a 0.1 °C error.

| | |
|---|---|
| Excitation current | 1 mA per channel |
| Noise rejection | |
| Normal mode (50/60 Hz) | |
| High-resolution mode | 85 dB minimum |
| High-speed mode | None |
| Common-mode rejection, channel to earth ground (50/60 Hz) | |
| High-resolution mode | 170 dB minimum |
| High-speed mode | 155 dB |
| Input bandwidth (high-resolution mode) | 3.3 Hz |

High-resolution filter response[2], [3]




| | |
|---|---|
| Overvoltage protection | ±30 V between inputs |
| MTBF | 891,597 hours at 25 °C; Bellcore Issue 2, Method 1, Case 3, Limited Part Stress Method |

## Power Requirements

| | |
|---|---|
| Power consumption from chassis | |
| Active mode | 350 mW maximum |
| Sleep mode | 1 mW maximum |

[2] This image is provided courtesy of Linear Technology Corp.
[3] High-speed filter response has the same characteristics as the high-resolution filter response except that the first notch is at 14 kHz.

| | |
|---|---|
| Thermal dissipation (at 70 °C) | |
| Active mode | 350 mW maximum |
| Sleep mode | 1 mW maximum |

## Physical Characteristics

| | |
|---|---|
| Screw-terminal wiring | |
| Gauge | 0.05 mm$^2$ to 1.5 mm$^2$ (30 AWG to 14 AWG) copper conductor wire |
| Wire strip length | 6 mm (0.24 in.) of insulation stripped from the end |
| Temperature rating | 90 °C minimum |
| Torque for screw terminals | 0.22 N · m to 0.25 N · m (1.95 lb · in. to 2.21 lb · in.) |
| Wires per screw terminal | One wire per screw terminal; two wires per screw terminal using a 2-wire ferrule |
| Ferrules | 0.25 mm$^2$ to 1.5 mm$^2$ |
| Connector securement | |
| Securement type | Screw flanges provided |
| Torque for screw flanges | 0.2 N · m (1.80 lb · in.) |

## Safety

### Safety Voltages

Connect only voltages that are within the following limits.

### Maximum Voltage

Connect only voltages that are within the following limits.[4]

| | |
|---|---|
| All terminals-to-COM | ±30 V |

### Isolation Voltages

| | |
|---|---|
| Channel-to-channel | None |

[4] The maximum voltage that can be applied between any channel or Vsup terminal and a COM terminal without damaging the module or other devices.

| | |
|---|---|
| Channel-to-earth ground | |
| Continuous | |
| up to 2,000 m | 250 Vrms, Measurement Category II |
| up to 5,000 m | 60 VDC, Measurement Category I |
| Withstand | |
| up to 2,000 m | 2,300 Vrms, verified by a 5 s dielectric withstand test |
| up to 5,000 m | 1,000 Vrms, verified by a 5 s dielectric withstand test |

Measurement Category II is for measurements performed on circuits directly connected to the electrical distribution system. This category refers to local-level electrical distribution, such as that provided by a standard wall outlet, for example, 115 V for U.S. or 230 V for Europe.

**Note** Measurement Categories CAT I and CAT O are equivalent. These test and measurement circuits are not intended for direct connection to the MAINS building installations of Measurement Categories CAT II, CAT III, or CAT IV.

**Caution** Do not connect the NI 9217 to signals or use for measurements within Measurement Categories III or IV.

## Hazardous Locations

| | |
|---|---|
| U.S. (UL) | Class I, Division 2, Groups A, B, C, D, T4; Class I, Zone 2, AEx nA IIC T4 |
| Canada (C-UL) | Class I, Division 2, Groups A, B, C, D, T4; Class I, Zone 2, Ex nA IIC T4 |
| Europe (ATEX) and International (IECEx) | Ex nA IIC T4 Gc |

## Safety and Hazardous Locations Standards

This product is designed to meet the requirements of the following electrical equipment safety standards for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1
- EN 60079-0:2012, EN 60079-15:2010
- IEC 60079-0: Ed 6, IEC 60079-15; Ed 4
- UL 60079-0; Ed 5, UL 60079-15; Ed 3
- CSA 60079-0:2011, CSA 60079-15:2012

**Note** For UL and other safety certifications, refer to the product label or the *Online Product Certification* section.

## Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326-1 (IEC 61326-1): Class A emissions; Industrial immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- CE, C-Tick, ICES, and FCC Part 15; Class A emissions

**Note** For EMC declarations and certifications, and additional information, refer to the *Online Product Certification* section.

## CE Compliance

This product meets the essential requirements of applicable European Directives, as follows:

- 2014/35/EU; Low-Voltage Directive (safety)
- 2014/30/EU; Electromagnetic Compatibility Directive (EMC)
- 94/9/EC; Potentially Explosive Atmospheres (ATEX)

## Online Product Certification

Refer to the product Declaration of Conformity (DoC) for additional regulatory compliance information. To obtain product certifications and the DoC for this product, visit *ni.com/certification*, search by model number or product line, and click the appropriate link in the Certification column.

## Shock and Vibration

To meet these specifications, you must panel mount the system.

| | |
|---|---|
| Operating vibration | |
| Random (IEC 60068-2-64) | 5 $g_{rms}$, 10 Hz to 500 Hz |
| Sinusoidal (IEC 60068-2-6) | 5 g, 10 Hz to 500 Hz |
| Operating shock (IEC 60068-2-27) | 30 g, 11 ms half sine; 50 g, 3 ms half sine; 18 shocks at 6 orientations |

## Environmental

Refer to the manual for the chassis you are using for more information about meeting these specifications.

| | |
|---|---|
| Operating temperature (IEC 60068-2-1, IEC 60068-2-2) | -40 °C to 70 °C |
| Storage temperature (IEC 60068-2-1, IEC 60068-2-2) | -40 °C to 85 °C |

| | |
|---|---|
| Ingress protection (with power plug attached) | IP 40 |
| Operating humidity (IEC 60068-2-78) | 10% RH to 90% RH, noncondensing |
| Storage humidity (IEC 60068-2-78) | 5% RH to 95% RH, noncondensing |
| Pollution Degree | 2 |
| Maximum altitude | 5,000 m |

Indoor use only.

## Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *Minimize Our Environmental Impact* web page at *ni.com/environment*. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

## Waste Electrical and Electronic Equipment (WEEE)

**EU Customers** At the end of the product life cycle, all NI products must be disposed of according to local laws and regulations. For more information about how to recycle NI products in your region, visit *ni.com/environment/weee*.

## 电子信息产品污染控制管理办法（中国 RoHS）

**中国客户** National Instruments 符合中国电子信息产品中限制使用某些有害物质指令 (RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 `ni.com/environment/rohs_china`。(For information about China RoHS compliance, go to `ni.com/environment/rohs_china`.)

## Calibration

You can obtain the calibration certificate and information about calibration services for the NI 9217 at *ni.com/calibration*.

| | |
|---|---|
| Calibration interval | 1 year |

374187A-02 Mar16

DATASHEET

# NI 9381

## 8 AI/8 AO/4 DIO, 0 V to 5 V, 12 Bit, 20 kS/s Aggregate

- DSUB connectivity
- 4 LVTTL lines with a 1 MHz update rate

The NI 9381 multifunction I/O module for CompactRIO systems. The NI 9381 combines common I/O circuitry into a single module to help system designers fit more functionality into a single system.

| | |
|---|---|
| Kit Contents | • NI 9381<br>• NI 9381 Getting Started Guide |
| Accessories | **Front-Mount**<br>• NI 9923 Screw-Terminal Block<br><br>**Cable**<br>• DSUB Cable, 1 m (778621-01)<br>• Din-Rail Spring-Terminal Block (778676-01) |

| NI 9381 MODULE COMPARISON | | | | | |
|---|---|---|---|---|---|
| Product Name | Measurement Type | Channels | Range | Resolution | Connectivity |
| NI 9201 | AI | 8 | ±10 V | 12 Bit | Screw-terminal, Spring-terminal, DSUB |
| NI 9263 | AO | 4 | ±10 V | 16 Bit | Screw-terminal, Spring-terminal |
| NI 9381 | AI, AO, DIO | 8 AI, 8 AO, 4 DIO | 0 V to 5 V, 3 V TTL | 12 Bit | DSUB |
| NI 9401 | DIO | 8 | 5 V TTL | — | DSUB |

# NI C Series Overview

NI provides more than 100 C Series modules for measurement, control, and communication applications. C Series modules can connect to any sensor or bus and allow for high-accuracy measurements that meet the demands of advanced data acquisition and control applications.

- Measurement-specific signal conditioning that connects to an array of sensors and signals
- Isolation options such as bank-to-bank, channel-to-channel, and channel-to-earth ground
- -40 °C to 70 °C temperature range to meet a variety of application and environmental needs
- Hot-swappable

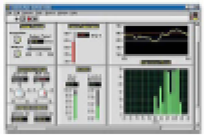
The majority of C Series modules are supported in both CompactRIO and CompactDAQ platforms and you can move modules from one platform to the other with no modification.

## CompactRIO

CompactRIO combines an open-embedded architecture with small size, extreme ruggedness, and C Series modules in a platform powered by the NI LabVIEW reconfigurable I/O (RIO) architecture. Each system contains an FPGA for custom timing, triggering, and processing with a wide array of available modular I/O to meet any embedded application requirement.

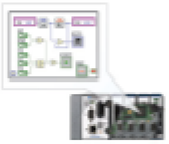
## Software

**LabVIEW Professional Development System for Windows**



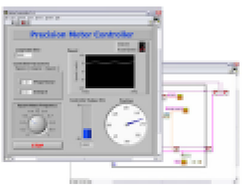
- Use advanced software tools for large project development
- Use advanced measurement analysis and digital signal processing
- Take advantage of open connectivity with DLLs, ActiveX, and .NET objects
- Build DLLs, executables, and MSI installers

**NI LabVIEW FPGA Module**



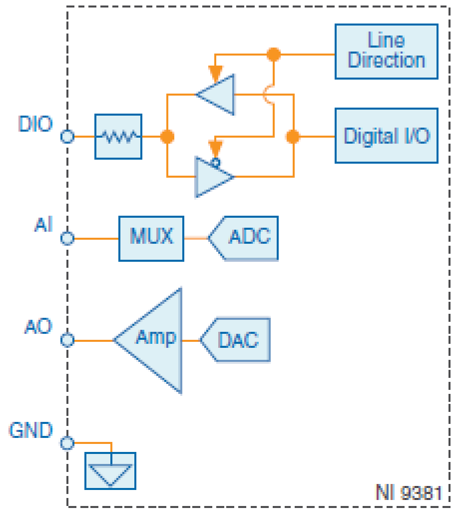
- Design FPGA applications for NI RIO hardware
- Program with the same graphical environment used for desktop and real-time applications
- Execute control algorithms with loop rates up to 300 MHz
- Implement custom timing and triggering logic, digital protocols, and DSP algorithms
- Incorporate existing HDL code and third-party IP including Xilinx IP generator functions
- Purchase as part of the LabVIEW Embedded Control and Monitoring Suite

**NI LabVIEW Real-Time Module**



- Design deterministic real-time applications with LabVIEW graphical programming
- Download to dedicated NI or third-party hardware for reliable execution and a wide selection of I/O
- Take advantage of built-in PID control, signal processing, and analysis functions
- Automatically take advantage of multicore CPUs or set processor affinity manually
- Take advantage of real-time OS, development and debugging support, and board support
- Purchase individually or as part of a LabVIEW suite

# NI 9381 Circuitry




- The module provides an analog-to-digital converter (ADC), eight digital-to-analog converters (DAC), and four digital lines.
- Line direction logic enables/disables the line input and output transceiver.

# NI 9381 Specifications

The following specifications are typical for the range -40 °C to 70 °C unless otherwise noted.

**Caution** Do not operate the NI 9381 in a manner not specified in this document. Product misuse can result in a hazard. You can compromise the safety protection built into the product if the product is damaged in any way. If the product is damaged, return it to NI for repair.

## Analog Input

| | |
|---|---|
| Number of channels | 8 single-ended channels |
| ADC resolution | 12 bits |
| Type of ADC | Successive approximation register (SAR) |
| Input range | 0 V to 5 V ±1% |
| DNL | ±1.25 LSB |
| Conversion time | 50 µs (20 kS/s) |
| Input coupling | DC |

| | |
|---|---|
| Input impedance | 1 MΩ in parallel with 50 pF |
| Bandwidth | 1 kHz |
| Stability | |
| Gain drift | 80 ppm/°C |
| Offset drift | 85 μV/°C |

**Table 1.** Accuracy[1]

| Measurement Conditions | | Percent of Reading (Gain Error) | Percent of Range (Offset Error) |
|---|---|---|---|
| Calibrated | Maximum (-40 °C to 70 °C) | ±0.70% | ±13 mV |
| | Typical (23 °C, ±5 °C) | ±0.15% | ±6.5 mV |
| Uncalibrated[2] | Maximum (-40 °C to 70 °C) | ±1.00% | ±16 mV |
| | Typical (23 °C, ±5 °C) | ±0.50% | ±7.5 mV |

## Analog Output

| | |
|---|---|
| Number of channels | 8 channels |
| DAC resolution | 12 bits |
| Type of DAC | String |
| Startup voltage | 0 V |
| Output range | 0 V to 5 V ±1% |
| Current drive | ±1 mA |
| Output impedance | 5 Ω |
| Update time | 50 μs (20 kS/s) |
| Short-circuit protection | Indefinitely |
| Slew rate | 30 V/ms |
| Settling time | 900 μs |
| DNL | ±1 LSB |
| Capacitive drive | 1,500 pF |

1 Accuracy is impacted for AC signals by an amount equal to 4.0*f* μV, where f is the signal frequency in hertz

2 Uncalibrated accuracy refers to the accuracy achieved when acquiring in raw or unscaled modes where the calibration constants stored in the module are not applied to the data.

| | |
|---|---|
| Stability | |
| Gain drift | 85 ppm/°C |
| Offset drift | 180 µV/°C |

**Table 2.** Accuracy[3]

| Measurement Conditions | | Percent of Reading (Gain Error) | Percent of Range (Offset Error) |
|---|---|---|---|
| Calibrated | Maximum (-40 °C to 70 °C) | ±1.02% | ±23.5 mV |
| | Typical (23 °C, ±5 °C) | ±0.19% | ±5 mV |
| Uncalibrated[4] | Maximum (-40 °C to 70 °C) | ±1.9% | ±50 mV |
| | Typical (23 °C, ±5 °C) | ±0.6% | ±10 mV |

## Digital Input/Output

| | |
|---|---|
| Number of channels | 4 channels |
| Default power-on line direction | Input |
| Input/output type | LVTTL, single-ended |
| Digital logic levels | |
| Maximum input voltage | 5.2 V |
| Input high, $V_{IH}$ | 2 V |
| Input low, $V_{IL}$ | 0.8 V |
| Output high, $V_{OH}$ | |
| Sourcing 100 µA | 2.7 V |
| Output low, $V_{OL}$ | |
| Sinking 100 µA | 0.2 V |
| Maximum I/O switching frequency | 1 MHz |
| Capacitive drive | 100 pF |

3 Accuracy is impacted for AC signals by an amount equal to 4.0*f* µV, where f is the signal frequency in hertz

4 Uncalibrated accuracy refers to the accuracy achieved when acquiring in raw or unscaled modes where the calibration constants stored in the module are not applied to the data.

## Physical Characteristics

If you need to clean the module, wipe it with a dry towel.

**Tip** For two-dimensional drawings and three-dimensional models of the C Series module and connectors, visit *ni.com/dimensions* and search by module number.

| | |
|---|---|
| Weight | 145 g (5.1 oz) |

## Power Requirements

| | |
|---|---|
| Power consumption from chassis | |
| Active mode | 600 mW maximum |
| Sleep mode | 1 mW maximum |
| Thermal dissipation (at 70 °C) | |
| Active mode | 600 mW maximum |
| Sleep mode | 1 mW maximum |

## Safety Voltages

| | |
|---|---|
| Isolation | |
| Channel-to-channel | None |
| Channel-to-earth ground | None |

## Hazardous Locations

| | |
|---|---|
| U.S. (UL) | Class I, Division 2, Groups A, B, C, D, T4;<br>Class I, Zone 2, AEx nA IIC T4 |
| Canada (C-UL) | Class I, Division 2, Groups A, B, C, D, T4;<br>Class I, Zone 2, Ex nA IIC T4 |
| Europe (ATEX) and International (IECEx) | Ex nA IIC T4 Gc |

## Safety and Hazardous Locations Standards

This product is designed to meet the requirements of the following electrical equipment safety standards for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1

- EN 60079-0:2012, EN 60079-15:2010
- IEC 60079-0: Ed 6, IEC 60079-15; Ed 4
- UL 60079-0; Ed 5, UL 60079-15; Ed 3
- CSA 60079-0:2011, CSA 60079-15:2012

**Note** For UL and other safety certifications, refer to the product label or the *Online Product Certification* section.

## Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326-1 (IEC 61326-1): Class A emissions; Industrial immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- AS/NZS CISPR 11: Group 1, Class A emissions
- FCC 47 CFR Part 15B: Class A emissions
- ICES-001: Class A emissions

**Note** In the United States (per FCC 47 CFR), Class A equipment is intended for use in commercial, light-industrial, and heavy-industrial locations. In Europe, Canada, Australia and New Zealand (per CISPR 11) Class A equipment is intended for use only in heavy-industrial locations.

**Note** Group 1 equipment (per CISPR 11) is any industrial, scientific, or medical equipment that does not intentionally generate radio frequency energy for the treatment of material or inspection/analysis purposes.

**Note** For EMC declarations and certifications, and additional information, refer to the *Online Product Certification* section.

## CE Compliance CE

This product meets the essential requirements of applicable European Directives, as follows:

- 2014/35/EU; Low-Voltage Directive (safety)
- 2014/30/EU; Electromagnetic Compatibility Directive (EMC)
- 94/9/EC; Potentially Explosive Atmospheres (ATEX)

## Online Product Certification

Refer to the product Declaration of Conformity (DoC) for additional regulatory compliance information. To obtain product certifications and the DoC for this product, visit *ni.com/*

*certification*, search by model number or product line, and click the appropriate link in the Certification column.

## Shock and Vibration

To meet these specifications, you must panel mount the system.

| | |
|---|---|
| Operating vibration | |
| Random (IEC 60068-2-64) | 5 $g_{rms}$, 10 Hz to 500 Hz |
| Sinusoidal (IEC 60068-2-6) | 5 g, 10 Hz to 500 Hz |
| Operating shock (IEC 60068-2-27) | 30 g, 11 ms half sine; 50 g, 3 ms half sine; 18 shocks at 6 orientations |

## Environmental

Refer to the manual for the chassis you are using for more information about meeting these specifications.

| | |
|---|---|
| Operating temperature (IEC 60068-2-1, IEC 60068-2-2) | -40 °C to 70 °C |
| Storage temperature (IEC 60068-2-1, IEC 60068-2-2) | -40 °C to 85 °C |
| Ingress protection | IP40 |
| Operating humidity (IEC 60068-2-78) | 10% RH to 90% RH, noncondensing |
| Storage humidity (IEC 60068-2-78) | 5% RH to 95% RH, noncondensing |
| Pollution Degree | 2 |
| Maximum altitude | 2,000 m |

Indoor use only.

## Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *Minimize Our Environmental Impact* web page at *ni.com/environment*. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

# Waste Electrical and Electronic Equipment (WEEE)

**EU Customers** At the end of the product life cycle, all NI products must be disposed of according to local laws and regulations. For more information about how to recycle NI products in your region, visit *ni.com/environment/weee*.

# 电子信息产品污染控制管理办法（中国 RoHS）

**中国客户** National Instruments 符合中国电子信息产品中限制使用某些有害物质指令 (RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 `ni.com/environment/rohs_china`。(For information about China RoHS compliance, go to `ni.com/environment/rohs_china`.)

# Calibration

You can obtain the calibration certificate and information about calibration services for the NI 9381 at *ni.com/calibration*.



375983A-02 Mar16

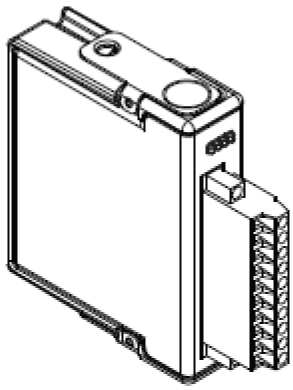
USER MANUAL AND SPECIFICATIONS

# NI 9482

## 4-Channel SPST Electromechanical Relay Module

Français Deutsch 日本語 한국어 简体中文

ni.com/manuals



This document describes how to use the National Instruments 9482 and includes specifications and pin assignments for the NI 9482.

**Note** The safety guidelines and specifications in this document are specific to the NI 9482. The other components in the system might not meet the same safety ratings and specifications. Refer to the documentation for each component in the system to determine the safety ratings and specifications for the entire system.

## Related Information

**NI CompactDAQ & NI CompactRIO Documentation**
ni.com/info ⇨ cseriesdoc

**Chassis Compatibility**
ni.com/info ⇨ compatibility

**Software Support**
ni.com/info ⇨ softwareversion

**Services**
ni.com/services

## Safety Guidelines

Operate the NI 9482 only as described in these operating instructions.

**Hot Surface** This icon denotes that the component may be hot. Touching this component may result in bodily injury.

**Warning** This icon denotes a warning advising you to take precautions to avoid electrical shock.

**Caution** Do not operate the NI 9482 in a manner not specified in this user manual. Product misuse can result in a hazard. You can compromise the safety protection built into the product if the product is damaged in any way. If the product is damaged, return it to National Instruments for repair.

### Safety Guidelines for Hazardous Voltages

If hazardous voltages are connected to the module, take the following precautions. A hazardous voltage is a voltage greater than 42.4 $V_{pk}$ or 60 VDC to earth ground.

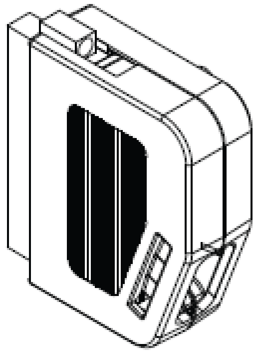
**Caution** Ensure that hazardous voltage wiring is performed only by qualified personnel adhering to local electrical standards.

**Caution** Do not mix hazardous voltage circuits and human-accessible circuits on the same module.

**Caution** Make sure that devices and circuits connected to the module are properly insulated from human contact.

**Caution** When module terminals are hazardous voltage LIVE (>42.4$V_{pk}$/60 VDC), you must ensure that devices and circuits connected to the module are properly insulated from human contact. You must use the NI 9927 connector backshell kit to ensure that the terminals are not accessible.

**Figure 1.** NI 9927



## Electromagnetic Compatibility Guidelines

This product was tested and complies with the regulatory requirements and limits for electromagnetic compatibility (EMC) as stated in the product specifications. These requirements and limits are designed to provide reasonable protection against harmful interference when the product is operated in its intended operational electromagnetic environment.

This product is intended for use in industrial locations. There is no guarantee that harmful interference will not occur in a particular installation, when the product is connected to a test object, or if the product is used in residential areas. To minimize the potential for the product to cause interference to radio and television reception or to experience unacceptable performance degradation, install and use this product in strict accordance with the instructions in the product documentation.

Furthermore, any changes or modifications to the product not expressly approved by National Instruments could void your authority to operate it under your local regulatory rules.

**Caution** To ensure the specified EMC performance, operate this product only with shielded cables and accessories.

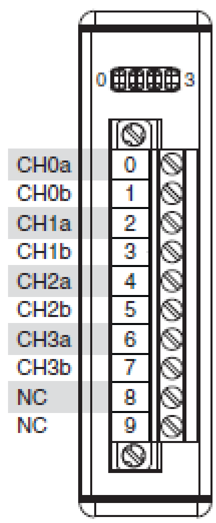
**Caution** The I/O port pins of this product can be damaged if subjected to Electrostatic Discharge (ESD). To prevent damage, industry-standard ESD prevention measures must be employed during installation, maintenance, and operation.

**Caution** The I/O port of this product is rated for Measurement Category II; however, it is neither designed nor tested for compliance with the transient immunity requirements for Electrical Fast Transients or lightning Surge, which are normally applied to ports intended for connection to the electrical distribution system. For applications where connection to the electrical distribution system is desired, ensure that the I/O port is provided with appropriate transient protection.

## Connecting the NI 9482

The NI 9482 provides connections for four electromechanical relay channels.

**Figure 2.** NI 9482 Pinout



### Connector

The NI 9482 has a 10-terminal, detachable screw-terminal connector.

### Signals

Each channel has two interchangeable pins, CHa and CHb, to which you can connect a load.

**Note** You must use 2-wire ferrules to create a secure connection when connecting more than one wire to a single terminal on the NI 9482.

### LEDs

Each channel has an LED that indicates the state of the channel. A channel LED is lit when the channel is on and dark when the channel is off. The LEDs are disabled when the chassis is in sleep mode.

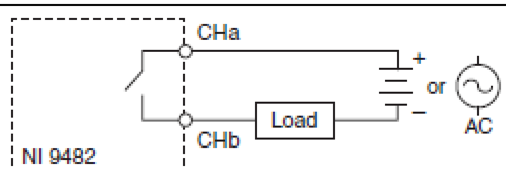
#### Related Information

*Sleep Mode* on page 12

### Connecting a Load

You can connect loads to the NI 9482. Connect the positive lead of the load to CHa or CHb, the ground of the load to the power supply, and the remaining CHa or CHb to the other lead of the power supply.

**Figure 3.** Connecting a Load

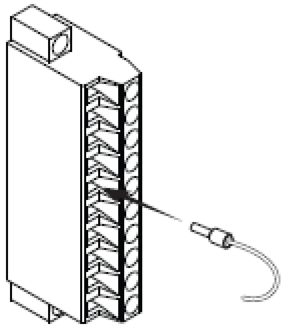



When the channel is turned on, the terminal connected to the load drives current or applies voltage to the load. When the channel is off, the terminal does not drive current or apply voltage to the load.

## Wiring for High-Vibration Applications

If an application using the NI 9482 is subject to high vibration, National Instruments recommends that you either use ferrules to terminate wires to the detachable screw-terminal connector or use the NI 9927 backshell kit to protect the connections.

**Figure 4.** Wiring a Screw-Terminal Connector with a Ferrule



## Sleep Mode

This module supports a low-power sleep mode. Support for sleep mode at the system level depends on the chassis that the module is plugged into. Refer to the chassis manual for information about support for sleep mode. If the chassis supports sleep mode, refer to the software help for information about enabling sleep mode.

Typically, when a system is in sleep mode, you cannot communicate with the modules. In sleep mode, the system consumes minimal power and may dissipate less heat than it does in normal mode.

### Related Information

*Power Requirements* on page 14

## Specifications

The following specifications are typical for the range -40 °C to 70 °C unless otherwise noted.

**Caution** Using the NI 9482 in a manner not described in this document may impair the protection the NI 9482 provides.

### Output Characteristics

Number of channels ........................ 4 electromechanical relay channels

Relay type ........................ Single pole single throw (SPST)

Power-on output state ........................ Channels off

Switching capacity (resistive load)

- Switching voltage ........................ 60 VDC max, 250 $V_{rms}$ max
- Switching current, per channel
  - One channel on ........................ 2.5 A max at 30 VDC, 1 A max at 60 VDC, 2.5 A max at 250 $V_{rms}$
  - Two channels on ........................ 2 A max at 30 VDC, 1 A max at 60 VDC, 2 A max at 250 $V_{rms}$
  - All channels on ........................ 1.5 A max at 30 VDC, 1 A max at 60 VDC, 1.5 A max at 250 $V_{rms}$

Resistance per channel, channel on ........................ 0.2 Ω

Switching rate ........................ 1 operation per second

Relay release time ........................ 10 ms max

Relay operate time ........................ 15 ms max

Relay bounce time ........................ 3 ms

Off state leakage ........................ 10 µA max

Life expectancy

- Mechanical (no load) ........................ 20,000,000 operations
- Electrical (connecting to load) ... 100,000 operations

MTBF ........................ Contact NI for Bellcore MTBF or MIL-HDBK-217F specifications

### Power Requirements

Power consumption from chassis

- Active mode ........................ 580 mW max
- Sleep mode ........................ 10 mW max

Thermal dissipation (at 70 °C)

- Active mode ........................ 1.5 W max
- Sleep mode ........................ 10 mW max

## Physical Characteristics

If you need to clean the module, wipe it with a dry towel.

**Tip** For two-dimensional drawings and three-dimensional models of the C Series module and connector, visit `ni.com/dimensions` and search by the module number.

| | |
|---|---|
| Screw-terminal wiring | 0.511 mm diameter (24 AWG) to 2.053 mm diameter (12 AWG) copper conductor wire with 10 mm (0.39 in.) of insulation stripped from the end |
| Torque for screw terminals | 0.5 N · m to 0.6 N · m (4.4 lb · in. to 5.3 lb · in.) |
| Ferrules | 0.25 $mm^2$ to 2.5 $mm^2$ |
| Weight | 150 g (5.3 oz) |

## Safety Voltages

Connect only voltages that are within the following limits.

| | |
|---|---|
| CHa-to-CHb | 250 $V_{rms}$ max, Measurement Category II |
| Isolation | |
| Channel-to-channel | |
| Continuous | 250 $V_{rms}$ |
| Withstand | 1,400 $V_{rms}$, verified by a 5 s dielectric withstand test |
| Channel-to-earth ground | |
| Continuous | 250 $V_{rms}$ |
| Withstand | 2,300 $V_{rms}$, verified by a 5 s dielectric withstand test |

Measurement Category II is for measurements performed on circuits directly connected to the electrical distribution system. This category refers to local-level electrical distribution, such as that provided by a standard wall outlet, for example, 115 V for U.S. or 230 V for Europe.

**Caution** Do *not* connect the NI 9482 to signals or use for measurements within Measurement Categories III or IV.

### Safety Standards

This product meets the requirements of the following standards of safety for electrical equipment for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1

**Note** For UL and other safety certifications, refer to the product label or the *Online Product Certification* section.

### Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326 (IEC 61326): Class A emissions; Basic immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- AS/NZS CISPR 11: Group 1, Class A emissions
- FCC 47 CFR Part 15B: Class A emissions
- ICES-001: Class A emissions

**Note** In the United States (per FCC 47 CFR), Class A equipment is intended for use in commercial, light-industrial, and heavy-industrial locations. In Europe, Canada, Australia and New Zealand (per CISPR 11) Class A equipment is intended for use only in heavy-industrial locations.

**Note** Group 1 equipment (per CISPR 11) is any industrial, scientific, or medical equipment that does not intentionally generates radio frequency energy for the treatment of material or inspection/analysis purposes.

**Note** For EMC declarations and certifications, refer to the *Online Product Certification* section.

### CE Compliance CE

This product meets the essential requirements of applicable European Directives as follows:

- 2006/95/EC; Low-Voltage Directive (safety)
- 2004/108/EC; Electromagnetic Compatibility Directive (EMC)

## Online Product Certification

To obtain product certifications and the Declaration of Conformity (DoC) for this product, visit ni.com/certification, search by module number or product line, and click the appropriate link in the Certification column.

## Shock and Vibration

To meet these specifications, you must panel mount the system.

Operating vibration,
sinusoidal (IEC 60068-2-6) ............. 5 g, 40 Hz to 500 Hz; 0.062 in. double amplitude, 10 Hz to 40 Hz

**Note** The shock and vibration rating for the NI 9482 is limited, in comparison to other NI CompactDAQ and CompactRIO devices, due to the mechanical relays on the module.

## Environmental

Refer to the manual for the chassis you are using for more information about meeting these specifications.

Operating temperature
(IEC 60068-2-1, IEC 60068-2-2) ..... -40 °C to 70 °C

Storage temperature
(IEC 60068-2-1, IEC 60068-2-2) ..... -40 °C to 85 °C

Ingress protection

NI 9482....................................... IP 30

NI 9482 with screw-terminal
connector attached...................... IP 40

Operating humidity
(IEC 60068-2-56).............................. 10% to 90% RH, noncondensing

Storage humidity
(IEC 60068-2-56).............................. 5% to 95% RH, noncondensing

Pollution Degree ............................... 2

Maximum altitude............................. 5,000 m

Indoor use only.

## Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *Minimize Our Environmental Impact* Web page at `ni.com/environment`. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

## Waste Electrical and Electronic Equipment (WEEE)

**EU Customers** At the end of the product life cycle, all products *must* be sent to a WEEE recycling center. For more information about WEEE recycling centers, National Instruments WEEE initiatives, and compliance with WEEE Directive 2002/96/EC on Waste and Electronic Equipment, visit `ni.com/environment/weee`.

## 电子信息产品污染控制管理办法（中国 RoHS）

**中国客户** National Instruments 符合中国电子信息产品中限制使用某些有害物质指令 (RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 `ni.com/environment/rohs_china`。(For information about China RoHS compliance, go to `ni.com/environment/rohs_china`.)

## Worldwide Support and Services

The National Instruments website is your complete resource for technical support. At ni.com/support you have access to everything from troubleshooting and application development self-help resources to email and phone assistance from NI Application Engineers.

Visit ni.com/services for NI Factory Installation Services, repairs, extended warranty, and other services.

Visit ni.com/register to register your National Instruments product. Product registration facilitates technical support and ensures that you receive important information updates from NI.

A Declaration of Conformity (DoC) is our claim of compliance with the Council of the European Communities using the manufacturer's declaration of conformity. This system affords the user protection for electromagnetic compatibility (EMC) and product safety. You can obtain the DoC for your product by visiting ni.com/certification. If your product supports calibration, you can obtain the calibration certificate for your product at ni.com/calibration.



373948B-01 Dec13

# FPI SENSORS INTERNATIONAL

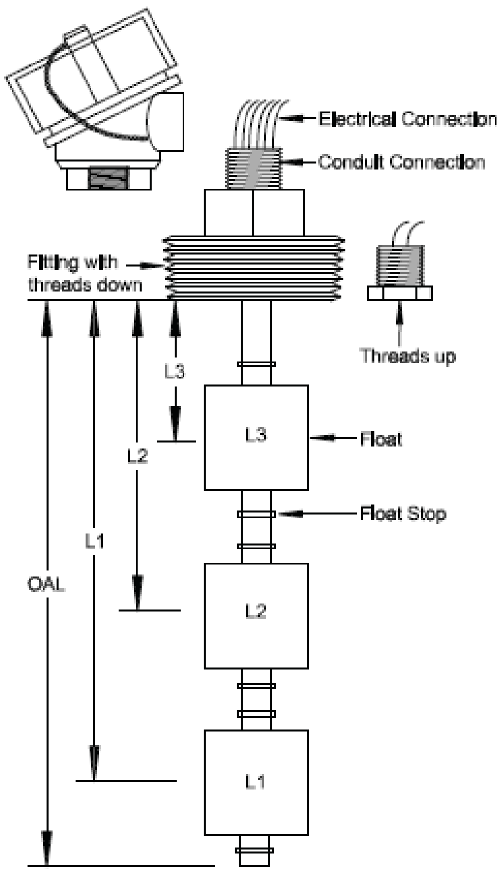
A HIGHER LEVEL OF SATISFACTION

## Three Level Configurator – Build to Order

**We excel in LOW COST » HIGH QUALITY » 72 HOUR MFG TIME**

WE SHIP IN 72 HOURS

**MANY OTHER VARIATIONS AND OPTIONS ARE AVAILABLE**




**HOUSING:**
❑ Nema 4X Explosion Proof ❑ Watertight ❑ NA

**ELECTRICAL CONNECTION:**
❑ Wire ❑ Cable ❑ Connector (specify) ___________

**CONDUIT CONNECTION:**
❑ ½" NPT ❑ Other ___________ ❑ NA

**FITTING AND STEM MATERIAL:**
❑ SS ❑ Brass ❑ PVC ❑ Poly ❑ Teflon

**FITTING SIZE (NPT):**
❑ ¼" ❑ ½" ❑ ¾" ❑ 1" ❑ 1¼" ❑ 1½" ❑ 2"
❑ Flange ___________ ❑ Other ___________

**THREAD ORIENTATION:**
❑ Threads down *(threads from outside of the tank)*
❑ Threads up *(threads from inside of the tank)*

**LEAD LENGTH:** ___________"

**FLOAT STOPS:**
❑ Retaining ring ❑ Set collar

**FLOAT MATERIAL:**
❑ SS ❑ Buna ❑ Poly ❑ Teflon ❑ PVC

**SWITCH TYPE:**
❑ SPST ❑ SPDT

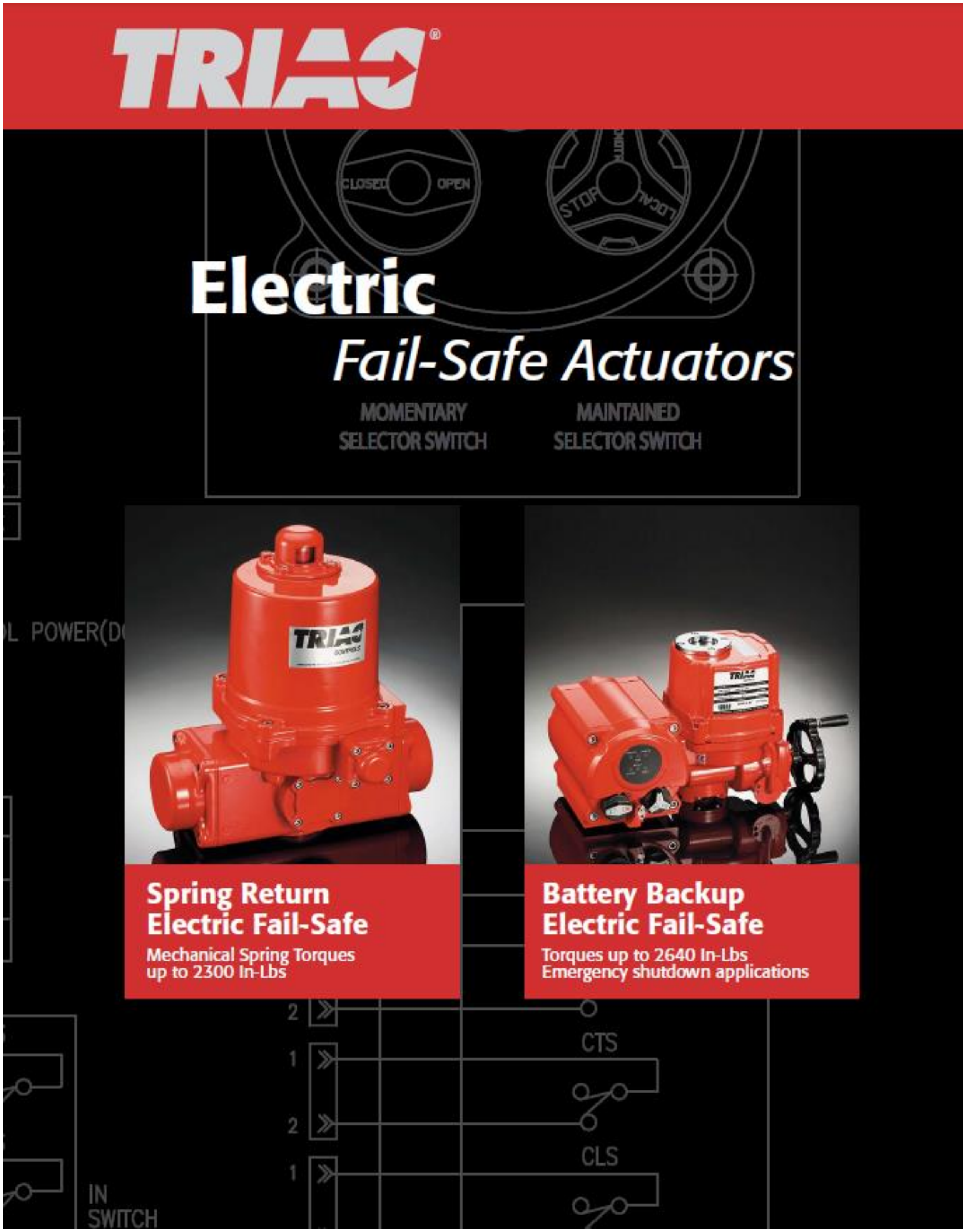
**SWITCH RATING:**
❑ 10 watt (500ma) ❑ 50 watt (1 amp) ❑ 100 watt (3 amp)

| ACTUATION: | OPERATION: | SPECIFIC GRAVITY: |
|---|---|---|
| L3 ___________" | ❑ N.O. ❑ N.C. | ❑ .60sg ❑ .93sg |
| L2 ___________" | ❑ N.O. ❑ N.C. | ❑ .60sg ❑ .93sg |
| L1 ___________" | ❑ N.O. ❑ N.C. | ❑ .60sg ❑ .93sg |

Minimum actuation is 1" Maximum actuation is 235"

**OPTIONS:**
❑ Shroud
❑ Field Adjustable Length
❑ Thermocouple ___________
❑ Temp Switch ❑ N.O. or ❑ N.C. ___________ °F set point
❑ Centering Disk
❑ Compression Union
❑ Thermistor ___________

**1.800.852.9984** www.FPIsensors.com
info@FPIsensors.com Fax 651.681.1888


TRIAC
Electric
Fail-Safe Actuators
MOMENTARY SELECTOR SWITCH
MAINTAINED SELECTOR SWITCH
Spring Return Electric Fail-Safe
Mechanical Spring Torques up to 2300 In-Lbs
Battery Backup Electric Fail-Safe
Torques up to 2640 In-Lbs
Emergency shutdown applications
CTS
CLS
IN SWITCH

# Spring Return
# Electric Fail-Safe Actuators

## FSE Series

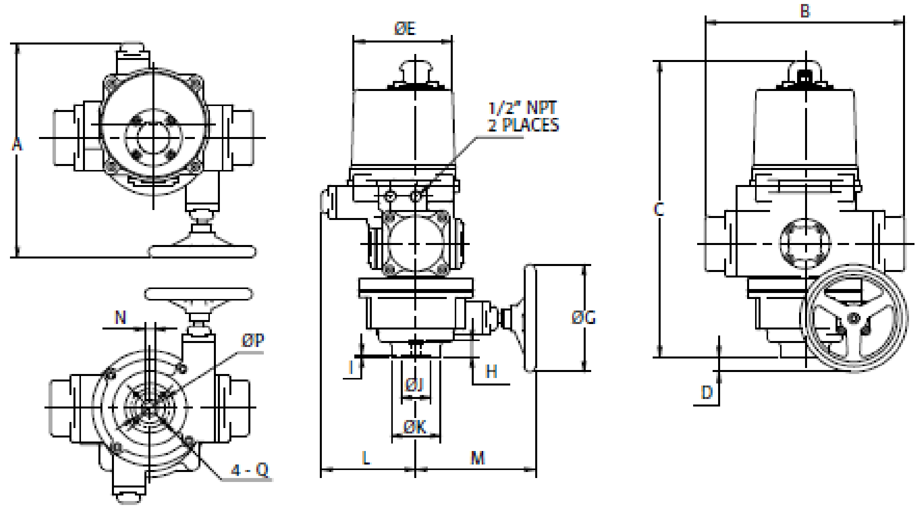

CE

### Features and General Information

- Corrosion resistant IP67, Type 4X construction
- Die cast aluminum housing and cover
- Powder polyurethane coated
- Four internal switches (2-Indication; 2-Motor Control)
- Stainless steel fasteners
- Visual position indicator
- Spring engagement mechanism design for extended cycle life
- Four models, 440 In-Lbs to 2300 In-Lbs
- 24VDC, 24VAC, 110/120VAC, 220/240VAC
- Heater and thermostat
- Optional manual override
- 50% Duty Cycle
- Standard Temperature Range (-22°F to 149°F) (Low Temp option to -40°F)

# Technical and Dimensional Information

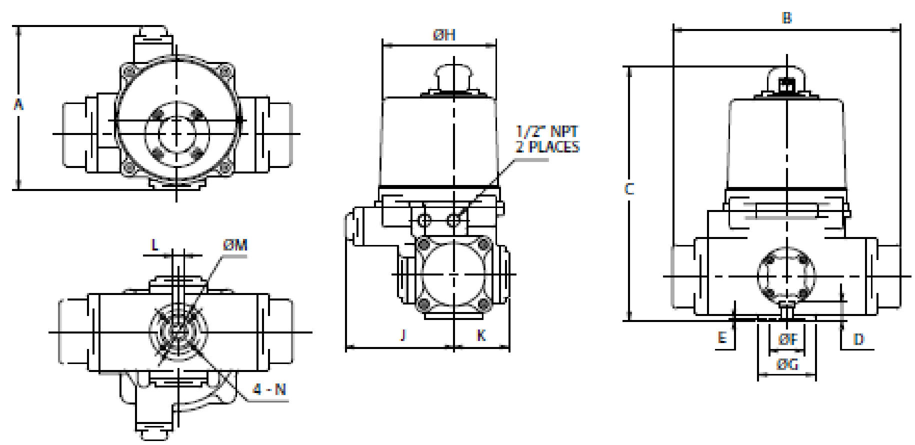
## FSE Series with Manual Override




### DIMENSIONS (IN)

| SIZE | A | B | C | D | E | G | H | I | J | K | L | M | N | P | Q | ISO 5211 | LBS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FSE-440MO | 15.24 | 14.17 | 21.06 | 1.38 | 7.01 | 7.64 | 1.18 | 0.16 | 2.17 | 3.54 | 6.73 | 8.50 | 0.669 | 2.756 | M8-1.25 | F07 | 82 |
| FSE-1150MO | 19.06 | 18.19 | 25.12 | 2.68 | 10.31 | 11.61 | 1.61 | 0.20 | 2.76 | 4.92 | 9.72 | 9.33 | 0.866 | 4.016 | M10-1.5 | F10 | 163 |
| FSE-1770MO | 23.19 | 23.62 | 28.94 | 4.29 | 11.97 | 15.67 | 1.77 | 0.20 | 3.35 | 5.91 | 12.01 | 11.18 | 1.063 | 4.921 | M12-1.75 | F12 | 298 |
| FSE-2300MO | 23.19 | 23.62 | 28.94 | 4.29 | 11.97 | 15.67 | 1.77 | 0.20 | 3.35 | 5.91 | 12.01 | 11.18 | 1.063 | 4.921 | M12-1.75 | F12 | 298 |

## FSE Series without Manual Override



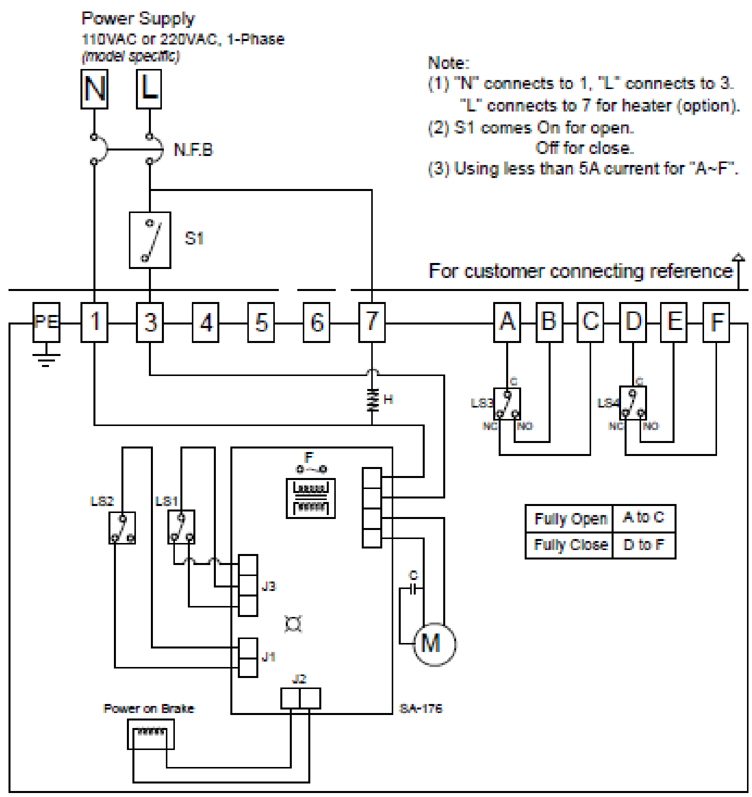

### DIMENSIONS (IN)

| SIZE | A | B | C | D | E | F | G | H | J | K | L | M | N | ISO 5211 | LBS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FSE-440 | 10.16 | 14.17 | 16.73 | 1.22 | 0.20 | 2.17 | 3.94 | 7.01 | 6.73 | 3.43 | 0.669 | 2.756 | M8-1.25 | F07 | 60 |
| FSE-1150 | 14.37 | 18.19 | 19.80 | 1.61 | 0.20 | 2.76 | 5.51 | 10.43 | 9.72 | 4.33 | 0.866 | 4.016 | M10-1.5 | F10 | 126 |
| FSE-1770 | 17.24 | 23.62 | 22.72 | 1.81 | 0.24 | 3.35 | 6.69 | 12.01 | 12.01 | 5.24 | 1.063 | 4.921 | M12-1.75 | F12 | 209 |
| FSE-2300 | 17.24 | 23.62 | 22.72 | 1.81 | 0.24 | 3.35 | 6.69 | 12.01 | 12.01 | 5.24 | 1.063 | 4.921 | M12-1.75 | F12 | 209 |

# Wiring Diagram

## FSE Series 110VAC 1 Phase, On/Off

**SE 1201**




**110/120 VAC, 1 Phase**

| Model | Max Torque | | Motor Power | Operating Time (Sec/90°) | | Current Ratings (60Hz/50Hz) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 110VAC / 1 Phase | | 120VAC / 1 Phase | |
| | N.m | In. lbs. | | Motor (60Hz/50Hz) | Spring | Run | Lock | Run | Lock |
| FSE-440 | 50 | 443 | 50W | 7/9 | 3 | 1.0A / 1.3A | 2.0A / 2.2A | 1.0A / 1.3A | 2.0A / 2.2A |
| FSE-1150 | 130 | 1151 | 130W | 7/9 | 8 | 2.6A / 4.5A | 10A / 10.5A | 3.8A / 6.9A | 11A / 11.5A |
| FSE-1770 | 200 | 1771 | 130W | 11/13 | 12 | 2.6A / 4.5A | 10A / 10.5A | 3.8A / 6.9A | 11A / 11.5A |
| FSE-2300 | 260 | 2302 | 130W | 14/17 | 12 | 2.6A / 4.5A | 10A / 10.5A | 3.8A / 6.9A | 11A / 11.5A |

**24V DC/AC, 1 Phase**

| Model | Max Torque | | Motor Power | Operating Time (Sec/90°) | | Current Ratings | |
|---|---|---|---|---|---|---|---|
| | | | | Motor | Spring | 24V DC/AC 1 Phase | |
| | N.m | In. lbs. | | | | Run | Lock |
| FSE-440 | 50 | 443 | 50W | 7 | 3 | 3.0A | 4.0A |
| FSE-1150 | 130 | 1151 | 130W | 8 | 8 | 9.0A | 19.0A |
| FSE-1770 | 200 | 1771 | 130W | 11 | 12 | 9.0A | 19.0A |
| FSE-2300 | 260 | 2302 | 130W | 17 | 12 | 9.0A | 19.0A |

**220/240 VAC, 1 Phase**

| Model | Max Torque | | Motor Power | Operating Time (Sec/90°) | | Current Ratings (60Hz/50Hz) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 220VAC / 1 Phase | | 240VAC / 1 Phase | |
| | N.m | In. lbs. | | Motor (60Hz/50Hz) | Spring | Run | Lock | Run | Lock |
| FSE-440 | 50 | 443 | 50W | 7/9 | 3 | 0.6A / 0.7A | 1.0A / 1.2A | 0.7A / 0.8A | 1.3A / 1.5A |
| FSE-1150 | 130 | 1151 | 130W | 7/9 | 8 | 1.5A / 2.2A | 5.0A / 5.1A | 2.1A / 3.8A | 5.6A / 5.7A |
| FSE-1770 | 200 | 1771 | 130W | 11/13 | 12 | 1.5A / 2.2A | 5.0A / 5.1A | 2.1A / 3.8A | 5.6A / 5.7A |
| FSE-2300 | 260 | 2302 | 130W | 14/17 | 12 | 1.5A / 2.2A | 5.0A / 5.1A | 2.1A / 3.8A | 5.6A / 5.7A |

**Weight**

| Model | Weight (Lbs) | |
|---|---|---|
| | Standard | w/ Manual Override |
| FSE-440 | 60 | 82 |
| FSE-1150 | 126 | 163 |
| FSE-1770 | 209 | 298 |
| FSE-2300 | 209 | 298 |

# Backup Battery Electric Fail-Safe Actuators

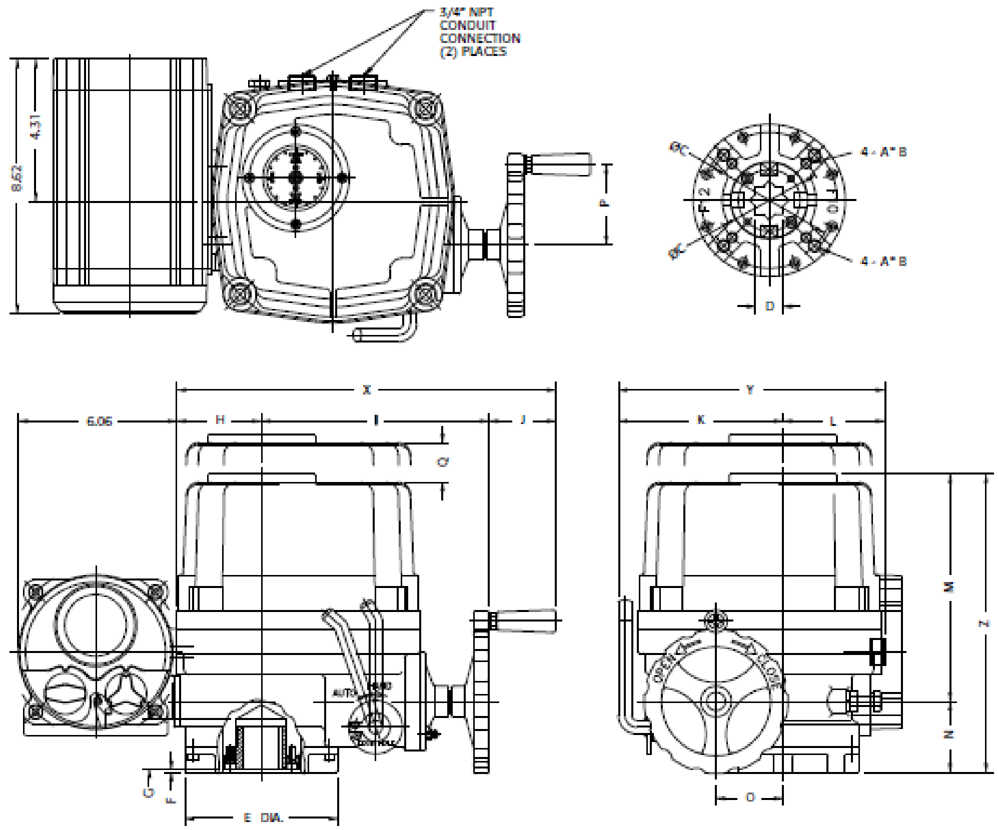
## *BFS Series*


### *Features and General Information*

- Corrosion resistant housing and enclosure Type 4, 4X, and 6, IP65
- Four internal switches (2-Indication; 2-Motor Control)
- Heater and thermostat standard
- Sealed, maintenance-free, rechargable battery
- 110 VAC, 220 VAC *(model specific)*
- Local or Remote Control
- Battery power level indication
- LED indication for Power Supply/Open and Close/Fault
- Manual override with handwheel
- Standard ambient temperature range: -4°F to 140°F

# Technical and Dimensional Information

## BFS Series




| LED LAMP SIGNAL | |
|---|---|
| WHITE | POWER |
| GREEN/BLACK/RED | BATTERY LEVEL |
| BLUE | REMOTE |
| YELLOW | FAULT |
| RED | OPEN |
| GREEN | CLOSE |

- Configurable to fail close or fail open on loss of power supply
- VRLA battery capacity for 5 cycles after loss of power
- Battery recharges automatically when re-energized

**BFS Motor Data (110VAC)**

| Model | Torque (In-Lbs) | Speed (Quarter-Turn) | Full Load Current |
|---|---|---|---|
| BFS-690 | 690 | 13 | 1 AMP |
| BFS-1350 | 1350 | 21 | 1.3 AMPS |
| BFS-1700 | 1700 | 21 | 1.5 AMPS |
| BFS-2640 | 2640 | 26 | 1.9 AMPS |

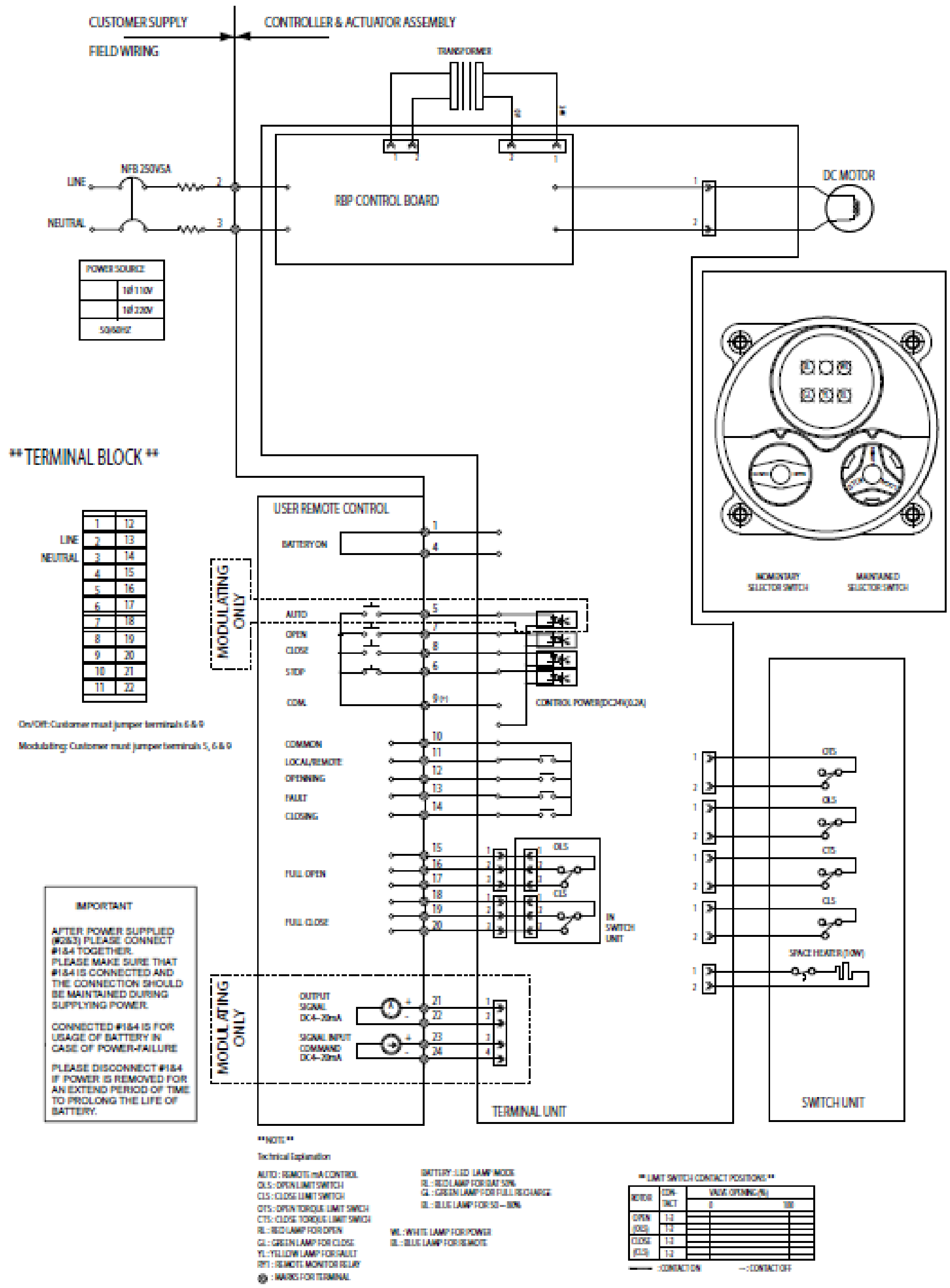
### DIMENSIONS (IN)

| SIZE | A | B | C | D sq | E | F | G | H | I | J | K | L | M | N | O | P | Q | X | Y | Z | ISO 5211 | LBS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BFS-690 | M8 | 0.47 | 2.756 | 0.669 | 3.46 | 0.12 | 1.26 | 1.97 | 6.18 | 2.01 | 3.94 | 2.76 | 6.57 | 2.09 | 1.57 | 2.36 | 4.72 | 10.16 | 6.69 | 9.25 | F07 | 35 |
| BFS-1350 | M8/M10 | 0.47/0.59 | 2.756/4.016 | 0.748 | 4.92 | 0.12 | 1.65 | 2.87 | 7.87 | 2.56 | 5.59 | 3.43 | 7.56 | 2.68 | 2.13 | 3.07 | 6.30 | 13.31 | 9.02 | 10.55 | F07/F10 | 49 |
| BFS-1700 | M8/M10 | 0.47/0.59 | 2.756/4.016 | 0.748 | 4.92 | 0.12 | 1.65 | 2.87 | 7.87 | 2.56 | 5.59 | 3.43 | 7.56 | 2.68 | 2.13 | 3.07 | 6.30 | 13.31 | 9.02 | 10.55 | F07/F10 | 52 |
| BFS-2640 | M10/M12 | 0.59/0.71 | 4.016/4.921 | 1.063 | 5.83 | 0.12 | 1.93 | 3.23 | 8.70 | 2.56 | 6.30 | 3.90 | 8.70 | 2.72 | 2.56 | 3.07 | 7.09 | 14.49 | 10.20 | 11.42 | F10/F12 | 62 |

# Wiring Diagram

## BFS Series On/Off or Modulating

**ON/OFF - SE1231**
**MODULATING - SE1253**



TRIAC

## TRIAC® Fail-Safe Actuator Series
## Part Number Reference

| Model | |
|---|---|
| FSE | Fail-Safe Electric Spring Return Actuator |
| BFS | Battery Backup Fail-Safe Electric Actuator |

| Control | |
|---|---|
| Blank | (2) Position Control (Open / Close) |
| M | Standard Modulating Control Card |

| Actuator Sizes (FSE) | |
|---|---|
| Size | |
| -440 | 440 In-Lbs |
| -1150 | 1150 In-Lbs |
| -1770 | 1770 In-Lbs |
| -2300 | 2300 In-Lbs |

| Actuator Sizes (BFS) | |
|---|---|
| Size | |
| -690 | 690 In-Lbs |
| -1350 | 1350 In-Lbs |
| -1700 | 1700 In-Lbs |
| -2640 | 2640 In-Lbs |

| Motor | | |
|---|---|---|
| X | 110/120VAC/1PH | (*blank* on BFS Series) |
| C | 24VDC | FSE On/Off only |
| D | 24VAC/1PH | FSE On/Off only |
| E | 220VAC/1PH | |

| Action | Note: Add all miscellaneous options to end of part number |
|---|---|
| Blank | No options |
| MO | Manual Override *(standard on BFS)* |
| FC | Fail Close *(must be determined at time of order for FSE Series)* |
| FO | Fail Open *(must be determined at time of order for FSE Series)* |

### Examples

**FSE-440XMO-FC**
Triac Spring Return Electric Fail clockwise, Fail-Safe Actuator, 440 In-Lbs Torque Output, 7 Sec Cycle Speed, Two Position Control, 115VAC/1PH, 2 Amps LR, (2) Auxiliary Limit Switches, Thermosat and Heater, 70mm bolt circle, 17mm female drive, Weight-82 Lbs, with 200mm dia handwheel manual override
***** FAIL CLOCKWISE *****

**BFSM-2640**
Triac Battery Failsafe System Electric Actuator, 2640 In-Lbs, 26 Second Operation, 115VAC/1PH, Modulating Control, Type 4 & 6, Compartment Heater & Thermostat, (2) Auxilary Limit Switches, (2) Torque Switches, Diecast Anodized Aluminum Polyester Coated Construction, Class F Extended Duty Fan Motor, Manual Overide, (2) 3/4" NPT Conduit Connections, F10/F12 ISO Mounting Pad, 27MM (1.063) Star Output Drive, Local / Remote Control
*****Fail Clockwise on Loss of Power*****

A-T Controls reserves the right to change product designs and technical/dimensional specifications without notice.


A-T Controls, Inc.
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FSE-BFS-20180312

LIT0025

# Thermocouple and RTD Sensors

### Thermocouples
- J, K, T, and E types

**RTDs**
- Platinum 100 Ω at 0 °C
- Conform to DIN 43760-1980 (alpha = 0.00385)
- 3-wire

**Configuration Options**
- Field-cuttable probes
- Ready-made sensors
- Thermocouple wire
- Thermocouple extension wire

**Accessories**
- Thermocouple plugs (J, K, T, E)
- Spring-loaded fittings (probes only)
- Tubing cutters (probes only)

## Overview
NI offers thermocouples and RTDs for your measurement and automation systems. These sensors are available in versatile configurations – field-cuttable probes and ready-made sensors. NI also offers spools of thermocouple wire and extension wire.

## Thermocouples
Thermocouples are the most popular temperature measurement transducers available. Because of their low cost and wide temperature acceptance range, you can use thermocouples for a wide variety of applications in all industries. All NI thermocouples and extension wires are available in J, K, T, and E types and follow ANSI color coding specifications.

### Field-Cuttable Thermocouples
NI field-cuttable thermocouples suit a wide variety of temperature applications. With field-cuttable thermocouples, you can cut the metal sheathed probe to the desired length – from 8.9 to 61 cm (3.5 to 24 in.)

### Ready-Made Thermocouples
For cost-sensitive applications, NI offers ready-made thermocouples – individual packets of thermocouple wire with the measuring junction provided at one end. Ready-made thermocouples are ideal for starter or educational applications.

### Thermocouple and Extension Wire
For large-scale or custom temperature measurement applications, NI offers spools of thermocouple and extension wire. You are responsible for making the thermocouple junction.

### Thermocouple Miniconnector Plugs
For applications requiring fast, easy connection and disconnection of thermocouples, we suggest thermocouple miniconnectors. These plugs work with any standard thermocouple miniconnector jack, including those available with the TC-2095, SCXI-1112, SC-2311, SC-2345, and CA-1000 Series connector panelettes. Thermocouple miniconnector plugs come in quantities of 10, and are available for J, K, T, and E types.



### RTDs
RTDs are popular for high-accuracy temperature measurement applications. NI offers 3-wire, 100 Ω platinum RTDs that conform to the DIN 43760-1980 (European) standard curve (a = 0.00385). These RTDs are available as field-cuttable metal sheathed probes and ready-made element configurations.

### Field-Cuttable RTDs
NI field-cuttable RTDs are ideal for a wide variety of temperature applications. With field-cuttable RTDs, you can cut the metal sheathed probe to the desired length – from 8.9 to 61 cm (3.5 to 24 in.).

### Ready-Made RTDs
Ready-made RTDs offer solutions for cost-sensitive temperature measurement applications. Each RTD element is sealed in an Alumina tube, with three Teflon-coated leads, and can measure up to 204 °C (400 °F).

# Thermocouple and RTD Sensors





## Ordering Information

### Field-Cuttable Thermocouples

J-type
- Grounded ........ 745685-J01
- Ungrounded ........ 745685-J02

K-type
- Grounded ........ 745685-K01
- Ungrounded ........ 745685-K02

T-type
- Grounded ........ 745685-T01
- Ungrounded ........ 745685-T02

E-type
- Grounded ........ 745685-E01
- Ungrounded ........ 745685-E02

### Ready-Made Thermocouples

J-type
- 1 m ........ 745690-J001
- 2 m ........ 745690-J002

K-type
- 1 m ........ 745690-K001
- 2 m ........ 745690-K002

T-type
- 1 m ........ 745690-T001
- 2 m ........ 745690-T002

E-type
- 1 m ........ 745690-E001
- 2 m ........ 745690-E002

### Thermocouple Wire

J-type
- 30 m ........ 745687-J030
- 300 m ........ 745687-J300

K-type
- 30 m ........ 745687-K030
- 300 m ........ 745687-K300

T-type
- 30 m ........ 745687-T030
- 300 m ........ 745687-T300

E-type
- 30 m ........ 745687-E030
- 300 m ........ 745687-E300

### Thermocouple Extension Wire

Jx-type
- 30 m ........ 745689-J030
- 300 m ........ 745689-J300

Kx-type
- 30 m ........ 745689-K030
- 300 m ........ 745689-K300

Tx-type
- 30 m ........ 745689-T030
- 300 m ........ 745689-T300

Ex-type
- 30 m ........ 745689-E030
- 300 m ........ 745689-E300

### Accessories

Thermocouple Miniconnector Plugs (Quantity 10)
- J type ........ 745688-J10
- K type ........ 745688-K10
- T type ........ 745688-T10
- E type ........ 745688-E10

Uncompensated ........ 745688-U10
Spring-loaded fitting ........ 745688-32
Tubing cutter ........ 745688-37

### RTDs

Field-Cuttable RTD
- 100 Ω, Pt, 3-wire ........ 745686-01

Ready-Made RTDs
- 1 m ........ 745691-01
- 2 m ........ 745691-02

## Specifications

### Thermocouple Characteristics

**Extension Wire**

Temperature range ........ -20 to 221 °F (-6.7 to 105 °C)

**RTD Characteristics**

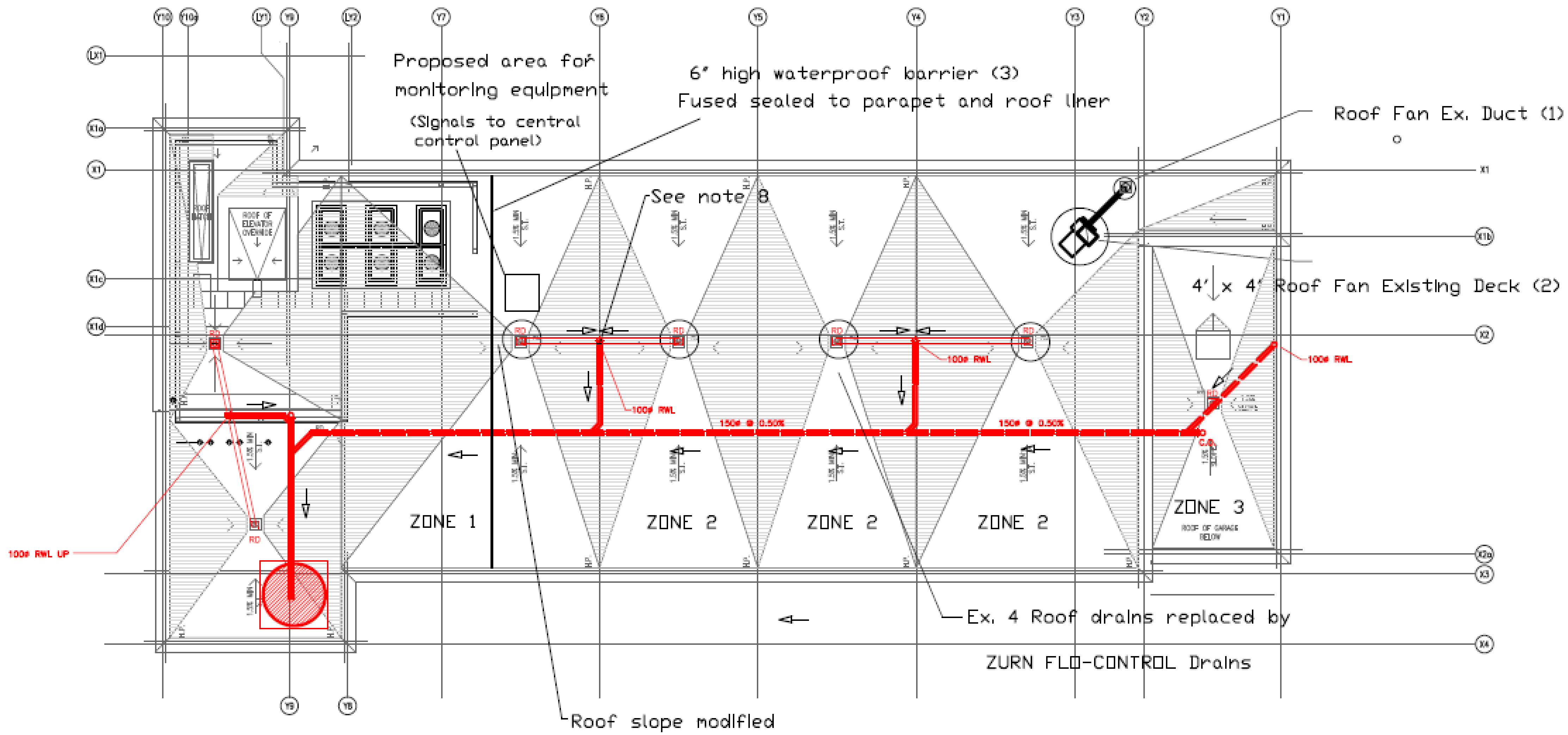
Type ........ Platinum
Resistance ........ 100 Ω at 0 °C
Probe range ........ -58 to 900 °F (-50 to 482 °C)
Ready-made range ........ -58 to 400 °F (-50 to 204 °C)
Calibration ........ DIN 43760-1980 (European) Standard Curve (a = 0.00385)
Accuracy ........ ±(0.3+0.005 |t|) °C (where t is the absolute valueof the temperature being measured in °C)
Configuration ........ 3-wire

Probe and Ready-Made Thermocouple Calibrations

| Calibration | Conductor | | Temp. Range | Limits of Error[1] (whichever is greater) |
|---|---|---|---|---|
| | Positive | Negative | | |
| J-type | Iron (White) | Constantan (Red) | 32 to 900 °F (0 to 482 °C) | ±2.2 °C (4.0 °F) or ±0.75% |
| K-type | Chromel (Yellow) | Alumel (Red) | 32 to 900 °F (0 to 482 °C) | ±2.2 °C (4.0 °F) or ±0.75% |
| T-type (probe only) | Copper (Blue) | Constantan (Red) | -328 to 32 °F (-200 to 0 °C)<br>32 to 500 °F (0 to 260 °C) | ±2.2 °C (4.0 °F) or ±0.75%<br>±1.0 °C (2.0 °F) or ±0.75% |
| T-type (ready-made only) | Copper (Blue) | Constantan (Red) | 32 to 500 °F (0 to 260 °C) | ±1.0 °C (2.0 °F) or ±0.75% |
| E-type | Chromel (Purple) | Constantan (Red) | 32 to 900 °F (0 to 482 °C) | ±1.7 °C (2.0 °F) or ±0.75% |

[1]Where error is given in percent, the percentage applies to the temperature being measured, not the range.

# APPENDIX C- CVC Building A Blue Roof Project Drawings




NOTES:

1. Fan duct to be framed and waterproof with Liner up to 6" above roof liner level
2. Fan deck to be waterproof with liner up to 6" above roof liner level
3. Controlled Zones 1 and non-controlled Zone 2 separated by 6" high fixed water proof barrier
4. Weather station to be relocated to non-controlled Zone 1
5. All new slab core drilled perforations for emergency overflows to be water proof
6. All seals to existing liner to be heat fused
7. 2 x 4"Ø North side roof drains in non-controlled Zone 1 and 1 x 4"Ø roof drain in non-controlled Zone 3 are not equipped with control discharge valves
8. New Emergency overflow (typical of 2) located directly above existing 4"Ø sewer downpipe

General Notes:

This design package is solely intended for the Credit Valley Conservation Authority (CVC). The selections and recommendations made in this design package are in accordance with Enviro-Stewards understanding of the project, the current site infrastructure and the information provided by CVC.

The contractor shall in addition field-verify all dimensions, geotechnical parameters and data provided in these drawings. The contractor shall report all alleged discrepancies to CVC before any bidding process and the commencement of all related construction activities. The drawings do not indicate, nor include, all offsets fittings and accessories, which may be required for the successful implementation of the work.

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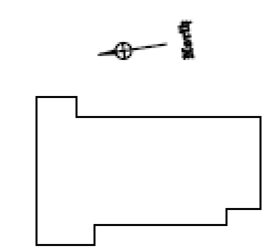



| DATE | NO. | REVISIONS |
|---|---|---|
| | 02 | REVISIONS |
| | 00 | REVISIONS |

CREDIT VALLEY CONSERVATION AUTHORITY
1255 OLD DERRY ROAD, MISSISSAUGA, L5N 6R4
RAINWATER MANAGEMENT PLAN

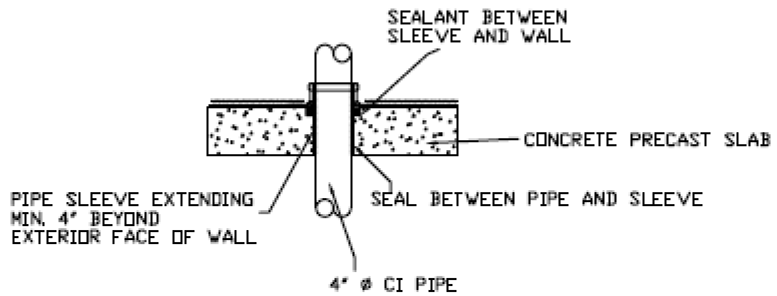
TITLE: DRAWING ONE
BLUE ROOF AREA SEGREGATION
AND
PROPOSED LAYOUT

STAMP

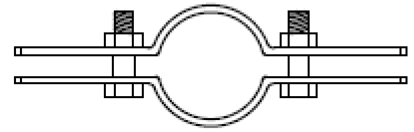
1 Union Street, Elmira, On. N3B 3J9
www.enviro-stewards.com

| SIZE | JOB NO. | DWG NO. | REV | DATE |
|---|---|---|---|---|
| | | | | JANUARY 2019 |

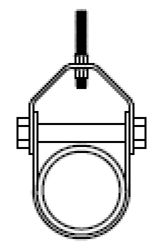
SCALE ( as noted ) DRAWN BY:



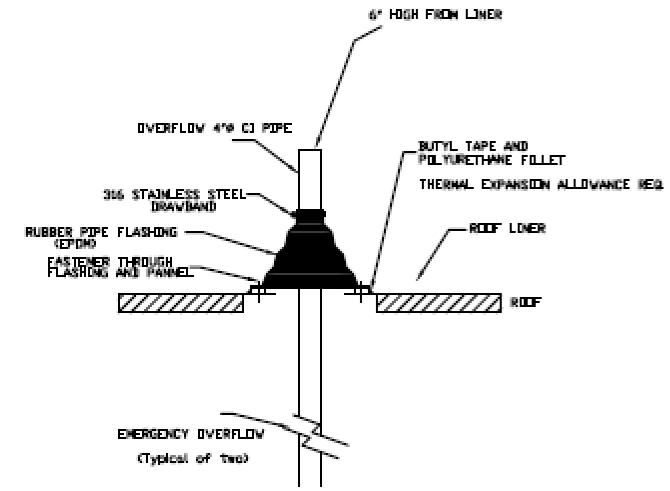

CONCRETE PENETRATION DETAIL (TYP)

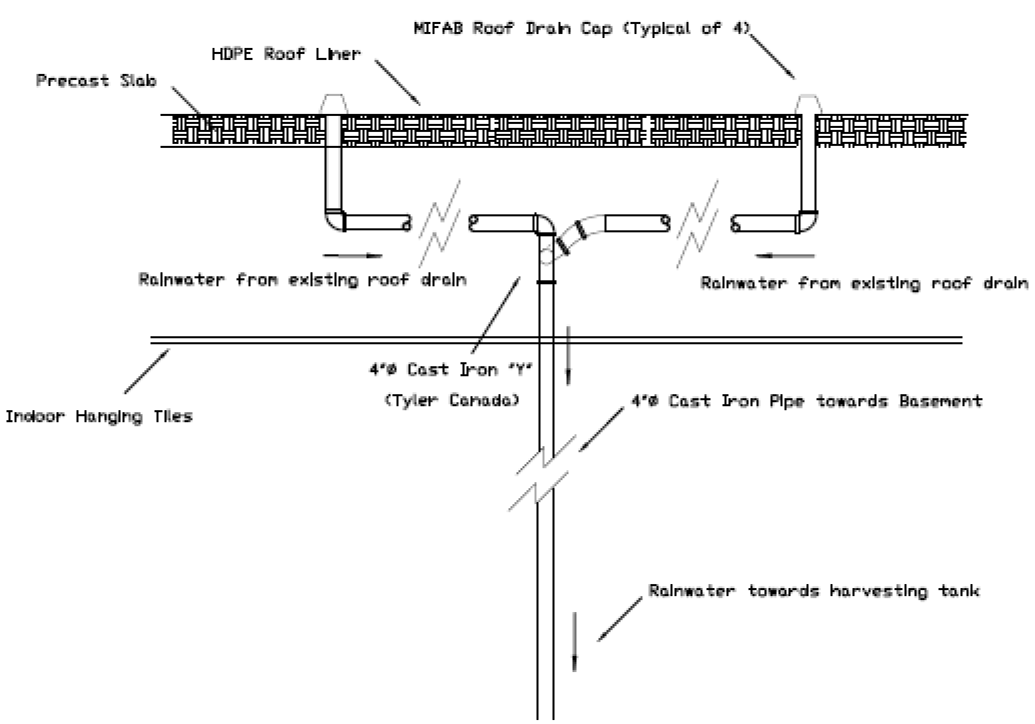


304 SS 3/16" THICK CI PIPE SUPPORT DETAIL

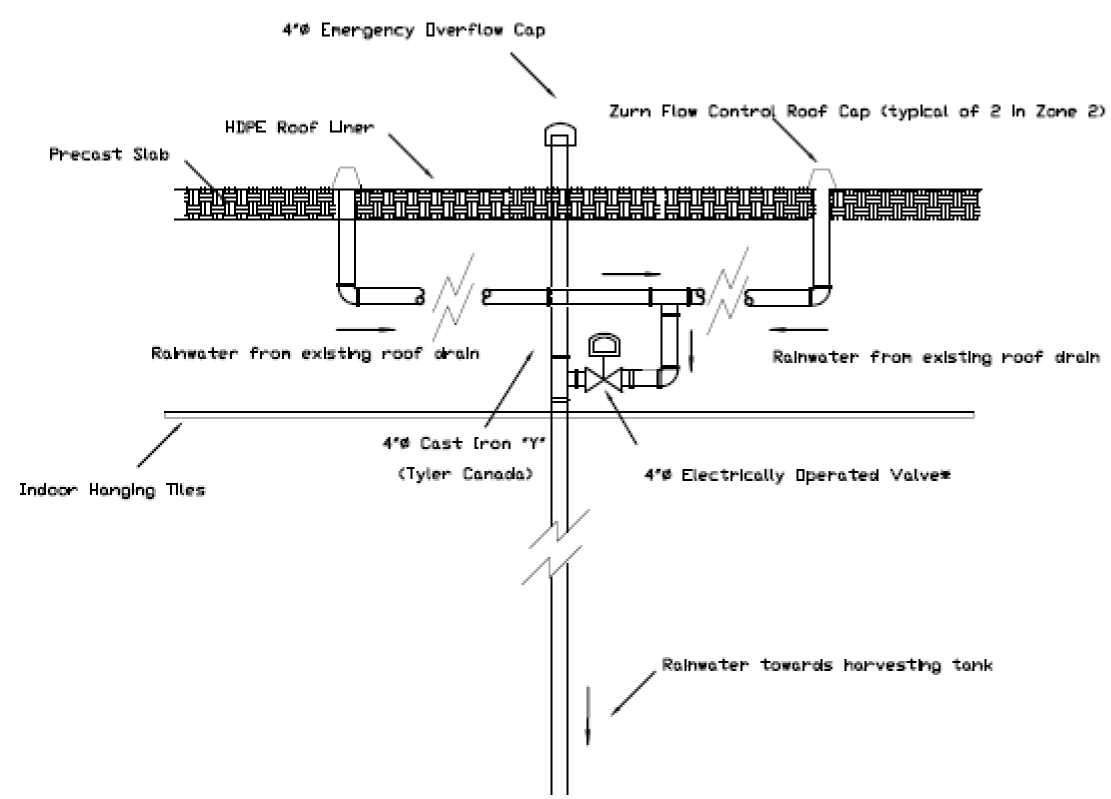


3/16" x 304 SS CI PIPE HANGERS DETAIL(TYP)




EXISTING RAINWATER ROOF LEADER LAYOUT




PROPOSED RAINWATER ROOF LEADER LAYOUT

(Typical of two)

NOTES

Roof Fan Platform 3" high

Roof vent boots 5" high max.

Anchoring Pole boots 6.25" high

Vertical Liner under parapet below sheet metal cover 7" high

NOTES

Zone 1 and 3 remain uncontrolled. Zone 2 only controlled area (See DWG 3)

All Zones equipped with Zurn Flow Control Roof Drain Caps

* 110 Volts - Single Phase Solenoid Valve (typical of 2 only in Zone 2)

Valve Operation paced on 4 - 20 mA signal from level - temp. transmitter

Concrete Slab to be core-drilled to allow 4"ø overflow (Typical of two only in Zone 2)

General Notes:

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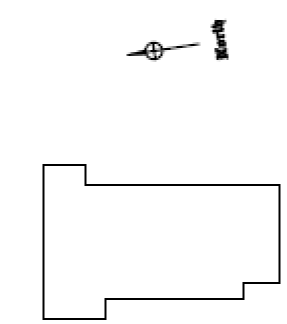



| | | |
|---|---|---|
| | 02 | REVISIONS |
| | 00 | REVISIONS |
| DATE | NO. | REVISIONS |

CREDIT VALLEY CONSERVATION AUTHORITY
1255 OLD DERRY ROAD, MISSISSAUGA, L5N 6R4
RAINWATER MANAGEMENT PLAN

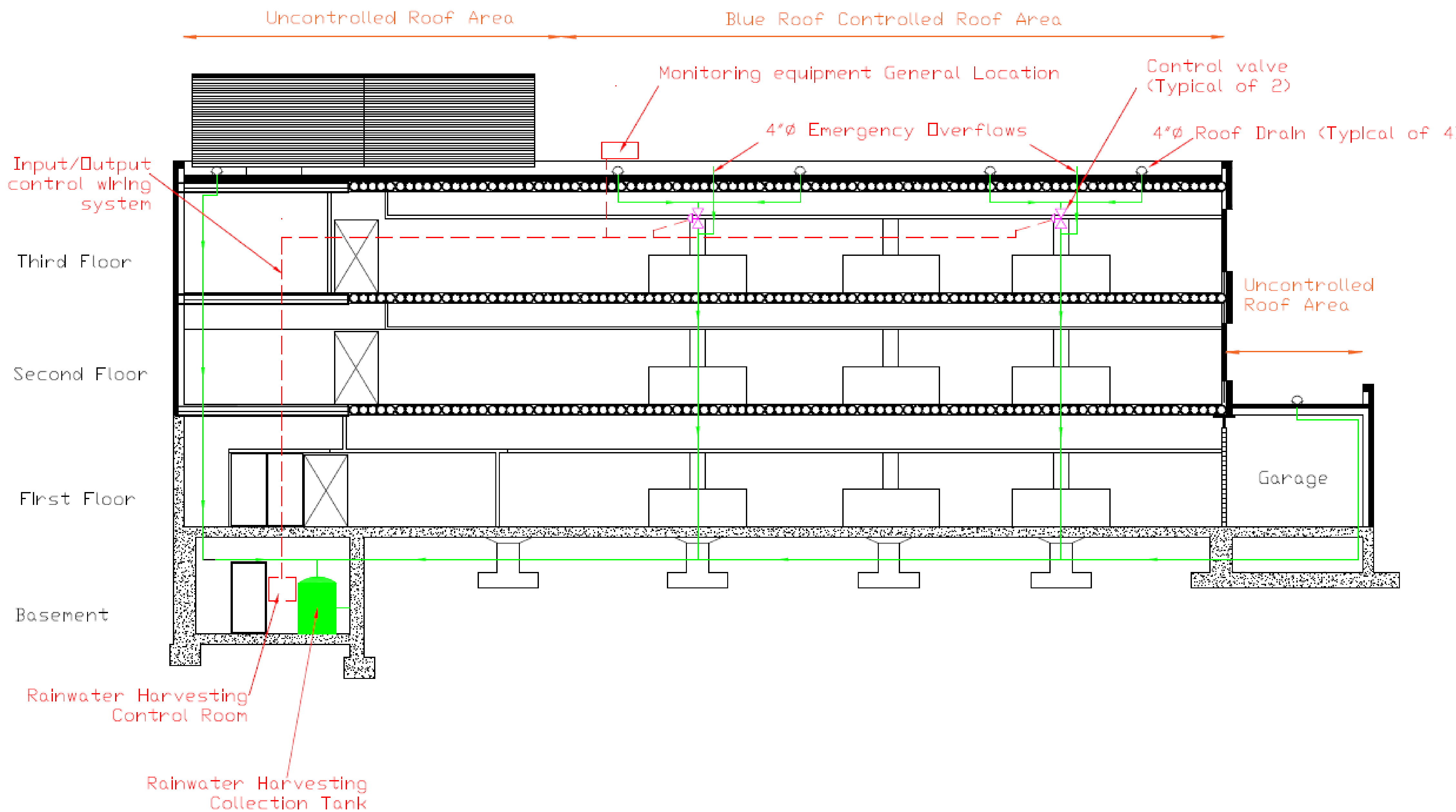
TITLE

DRAWING TWO
EXISTING & PROPOSED
ROOF DRAIN PIPING LAYOUT

STAMP

1 Union Street, Elmira, On. N3B 3J9
www.enviro-stewards.com

| SIZE | JOB NO. | DWG NO. | REV | DATE |
|---|---|---|---|---|
| | | | | January 2019 |

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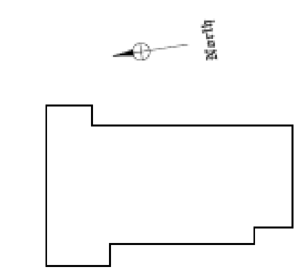
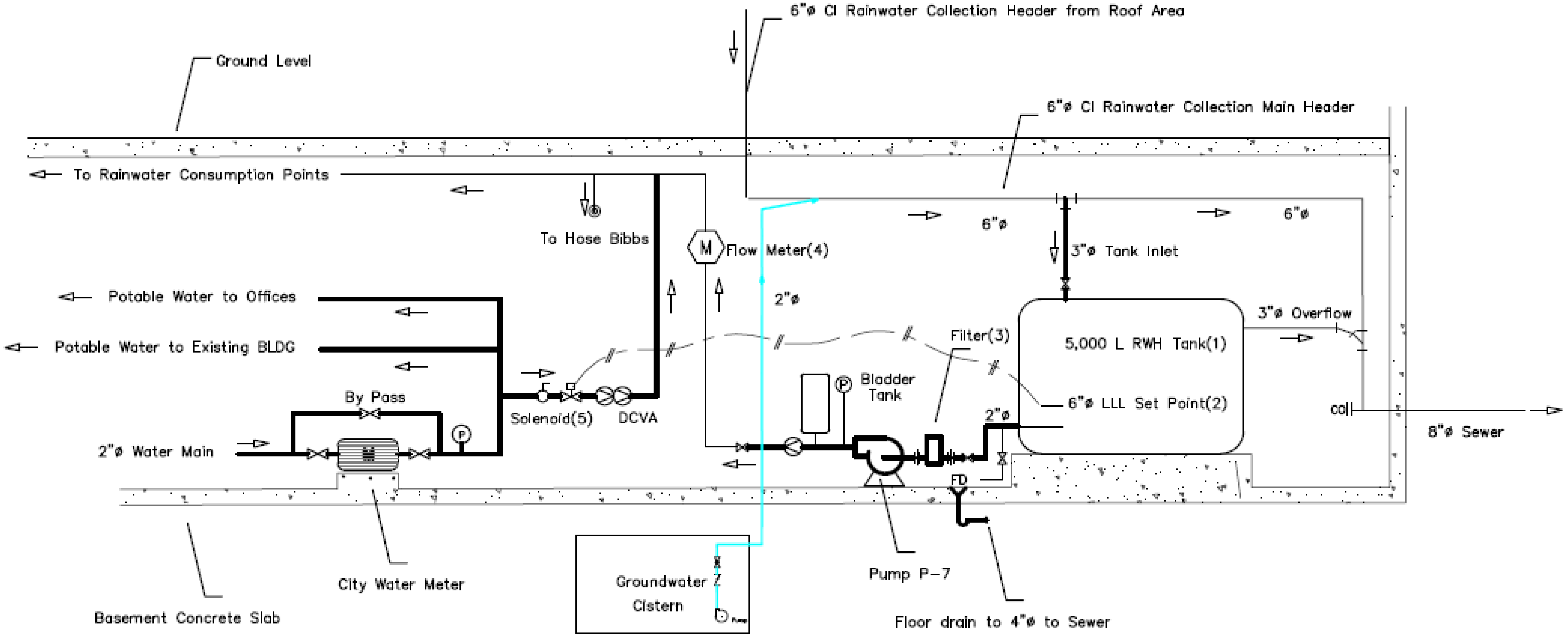



| | | |
|---|---|---|
| | 02 | REVISIONS |
| | 00 | REVISIONS |
| DATE | NO. | REVISIONS |

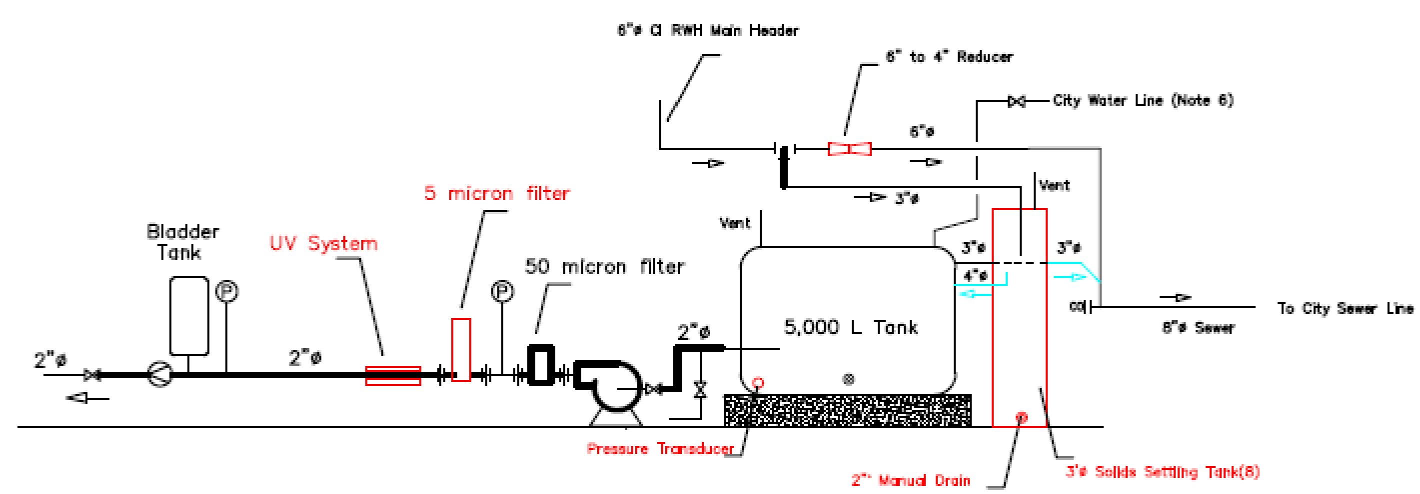
CREDIT VALLEY CONSERVATION AUTHORITY
1255 OLD DERRY ROAD, MISSISSAUGA, L5N 6R4
RAINWATER MANAGEMENT PLAN

TITLE
DRAWING THREE
STORM SEWER GENERAL LAYOUT
BUILDING CROSS SECTION

STAMP




Existing Rainwater Harvesting System (Basement)




RWH System Proposed Retrofitting

Solids Removal Tank – Disinfection System – Flow Restriction

Conceptual Diagram

NOTES:

1. Norwesco Tank
2. Low Liquid Level Set Point
3. JUDO Model JFXL–T 50 mm Backwashable Filter
4. ELSTER C 700 Model Flow Meter
5. 24Volts Solenoid Paced to open on LLL in Tank. NC
6. City Water Line Manually Operated to add Cl2
7. Pump 7 to deactivate upon LLL.
8. Conceptual Sketch Only. Detail Design Required

General Notes:

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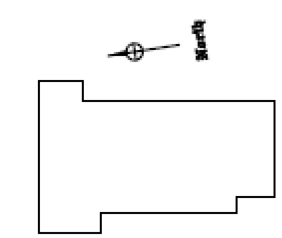

| DATE | NO. | REVISIONS |
|---|---|---|
| | 02 | REVISIONS |
| | 00 | REVISIONS |

CREDIT VALLEY CONSERVATION AUTHORITY
1255 OLD DERRY ROAD, MISSISSAUGA, L5N 6R4
RAINWATER MANAGEMENT PLAN

TITLE
DRAWING FOUR
PROPOSED RAIN WATER HARVESTING TANKAGE RETROFIT
BASEMENT AREA

STAMP

1 Union Street, Elmira, On. N3B 3J9
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| SIZE | JOB NO. | DWG NO. | REV | DATE |
|---|---|---|---|---|
| | | | | JANUARY 2019 |

SCALE ( as noted ) | DRAWN BY:

## APPENDIX D – Supporting Calculation Tables for Technical and Financial Feasibility Assessment of the Smart Blue Roof System

Volume stored at end of day with potential daily usage and evaporation

| Date | Potential volume stored ($m^3$) | Daily consumption ($m^3$) 1.58 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 5.68 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 7.33 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 10.42 | Volume Stored ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 01-Apr-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 02-Apr-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 03-Apr-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 04-Apr-17 | 6.15 | 1.58 | 3.91 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 05-Apr-17 | 0.00 | 1.58 | 1.66 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 06-Apr-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 07-Apr-17 | 10.27 | 1.58 | 8.03 | 5.68 | 3.93 | 7.33 | 2.28 | 10.42 | 0.00 |
| 08-Apr-17 | 0.00 | 0.00 | 7.36 | 0.00 | 3.26 | 0.00 | 1.62 | 0.00 | 0.00 |
| 09-Apr-17 | 0.00 | 0.00 | 6.70 | 0.00 | 2.60 | 0.00 | 0.95 | 0.00 | 0.00 |
| 10-Apr-17 | 0.00 | 1.58 | 4.45 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 11-Apr-17 | 1.40 | 1.58 | 3.60 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 12-Apr-17 | 0.00 | 1.58 | 1.35 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 13-Apr-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 14-Apr-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 15-Apr-17 | 1.46 | 0.00 | 0.79 | 0.00 | 0.79 | 0.00 | 0.79 | 0.00 | 0.79 |
| 16-Apr-17 | 0.00 | 0.00 | 0.13 | 0.00 | 0.13 | 0.00 | 0.13 | 0.00 | 0.13 |
| 17-Apr-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 18-Apr-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 19-Apr-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 20-Apr-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 21-Apr-17 | 7.93 | 1.58 | 5.68 | 5.68 | 1.58 | 7.33 | 0.00 | 10.42 | 0.00 |
| 22-Apr-17 | 0.00 | 0.00 | 5.02 | 0.00 | 0.92 | 0.00 | 0.00 | 0.00 | 0.00 |
| 23-Apr-17 | 0.00 | 0.00 | 4.35 | 0.00 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24-Apr-17 | 0.00 | 1.58 | 2.10 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 25-Apr-17 | 1.40 | 1.58 | 1.25 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 26-Apr-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 27-Apr-17 | 1.08 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 28-Apr-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 29-Apr-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 30-Apr-17 | 0.89 | 0.00 | 0.22 | 0.00 | 0.22 | 0.00 | 0.22 | 0.00 | 0.22 |
| 01-May-17 | 10.27 | 1.58 | 8.25 | 5.68 | 4.15 | 7.33 | 2.50 | 10.42 | 0.00 |
| 02-May-17 | 0.00 | 1.58 | 6.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 03-May-17 | 0.00 | 1.58 | 3.76 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 04-May-17 | 0.00 | 1.58 | 1.51 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 05-May-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 06-May-17 | 13.32 | 0.00 | 12.65 | 0.00 | 12.65 | 0.00 | 12.65 | 0.00 | 12.65 |

Volume stored at end of day with potential daily usage and evaporation

| Date | Potential volume stored ($m^3$) | Daily consumption ($m^3$) 1.58 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 5.68 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 7.33 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 10.42 | Volume Stored ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 07-May-17 | 0.00 | 0.00 | 11.99 | 0.00 | 11.99 | 0.00 | 11.99 | 0.00 | 11.99 |
| 08-May-17 | 0.00 | 1.58 | 9.74 | 5.68 | 5.64 | 7.33 | 3.99 | 10.42 | 0.90 |
| 09-May-17 | 0.00 | 1.58 | 7.49 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 10-May-17 | 0.00 | 1.58 | 5.25 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 11-May-17 | 0.00 | 1.58 | 3.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 12-May-17 | 0.00 | 1.58 | 0.76 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 13-May-17 | 0.00 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14-May-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15-May-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 16-May-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 17-May-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 18-May-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 19-May-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 20-May-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 21-May-17 | 5.52 | 0.00 | 4.85 | 0.00 | 4.85 | 0.00 | 4.85 | 0.00 | 4.85 |
| 22-May-17 | 0.00 | 1.58 | 2.61 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 23-May-17 | 0.00 | 1.58 | 0.36 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 24-May-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 25-May-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 26-May-17 | 10.53 | 1.58 | 8.28 | 5.68 | 4.18 | 7.33 | 2.54 | 10.42 | 0.00 |
| 27-May-17 | 0.00 | 0.00 | 7.62 | 0.00 | 3.52 | 0.00 | 1.87 | 0.00 | 0.00 |
| 28-May-17 | 0.00 | 0.00 | 6.95 | 0.00 | 2.85 | 0.00 | 1.20 | 0.00 | 0.00 |
| 29-May-17 | 0.00 | 1.58 | 4.70 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 30-May-17 | 0.00 | 1.58 | 2.46 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 31-May-17 | 2.47 | 1.58 | 2.69 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 01-Jun-17 | 0.00 | 1.58 | 0.44 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 02-Jun-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 03-Jun-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 04-Jun-17 | 1.97 | 0.00 | 1.30 | 0.00 | 1.30 | 0.00 | 1.30 | 0.00 | 1.30 |
| 05-Jun-17 | 0.89 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 06-Jun-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 07-Jun-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 08-Jun-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 09-Jun-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 10-Jun-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 11-Jun-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12-Jun-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 13-Jun-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 14-Jun-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |

Volume stored at end of day with potential daily usage and evaporation

| Date | Potential volume stored ($m^3$) | Daily consumption ($m^3$) 1.58 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 5.68 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 7.33 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 10.42 | Volume Stored ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 15-Jun-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 16-Jun-17 | 2.85 | 1.58 | 0.61 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 17-Jun-17 | 1.14 | 0.00 | 1.08 | 0.00 | 0.48 | 0.00 | 0.48 | 0.00 | 0.48 |
| 18-Jun-17 | 0.89 | 0.00 | 1.31 | 0.00 | 0.70 | 0.00 | 0.70 | 0.00 | 0.70 |
| 19-Jun-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 20-Jun-17 | 0.82 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 21-Jun-17 | 1.20 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 22-Jun-17 | 0.70 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 23-Jun-17 | 9.39 | 1.58 | 7.14 | 5.68 | 3.04 | 7.33 | 1.39 | 10.42 | 0.00 |
| 24-Jun-17 | 0.00 | 0.00 | 6.47 | 0.00 | 2.37 | 0.00 | 0.73 | 0.00 | 0.00 |
| 25-Jun-17 | 0.95 | 0.00 | 6.76 | 0.00 | 2.66 | 0.00 | 1.01 | 0.00 | 0.29 |
| 26-Jun-17 | 1.71 | 1.58 | 6.23 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 27-Jun-17 | 0.00 | 1.58 | 3.98 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 28-Jun-17 | 0.00 | 1.58 | 1.73 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 29-Jun-17 | 1.52 | 1.58 | 1.01 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 30-Jun-17 | 1.90 | 1.58 | 0.67 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 01-Jul-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 02-Jul-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 03-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 04-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 05-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 06-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 07-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 08-Jul-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 09-Jul-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 11-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 12-Jul-17 | 0.76 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 13-Jul-17 | 1.08 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 14-Jul-17 | 4.19 | 1.58 | 1.94 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 15-Jul-17 | 0.00 | 0.00 | 1.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16-Jul-17 | 0.00 | 0.00 | 0.61 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 17-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 18-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 19-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 20-Jul-17 | 4.57 | 1.58 | 2.32 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 21-Jul-17 | 0.00 | 1.58 | 0.07 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 22-Jul-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 23-Jul-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Volume stored at end of day with potential daily usage and evaporation

| Date | Potential volume stored ($m^3$) | Daily consumption ($m^3$) 1.58 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 5.68 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 7.33 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 10.42 | Volume Stored ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 24-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 25-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 26-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 27-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 28-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 29-Jul-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 30-Jul-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 31-Jul-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 01-Aug-17 | 4.44 | 1.58 | 2.19 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 02-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 03-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 04-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 05-Aug-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 06-Aug-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 07-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 08-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 09-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 10-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 11-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 12-Aug-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 13-Aug-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 15-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 16-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 17-Aug-17 | 4.12 | 1.58 | 1.88 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 18-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 19-Aug-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20-Aug-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 21-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 22-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 23-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 24-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 25-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 26-Aug-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 27-Aug-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 28-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 29-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 30-Aug-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 31-Aug-17 | 1.40 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |

Volume stored at end of day with potential daily usage and evaporation

| Date | Potential volume stored ($m^3$) | Daily consumption ($m^3$) 1.58 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 5.68 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 7.33 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 10.42 | Volume Stored ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 01-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 02-Sep-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 03-Sep-17 | 2.54 | 0.00 | 1.87 | 0.00 | 1.87 | 0.00 | 1.87 | 0.00 | 1.87 |
| 04-Sep-17 | 1.52 | 1.58 | 1.15 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 05-Sep-17 | 1.71 | 1.58 | 0.61 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 06-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 07-Sep-17 | 0.82 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 08-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 09-Sep-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10-Sep-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 11-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 12-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 13-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 14-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 15-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 16-Sep-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 17-Sep-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 19-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 20-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 21-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 22-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 23-Sep-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24-Sep-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 25-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 26-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 27-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 28-Sep-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 29-Sep-17 | 0.89 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 30-Sep-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 01-Oct-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 02-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 03-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 04-Oct-17 | 2.09 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 05-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 06-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 07-Oct-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 08-Oct-17 | 1.14 | 0.00 | 0.48 | 0.00 | 0.48 | 0.00 | 0.48 | 0.00 | 0.48 |
| 09-Oct-17 | 3.93 | 1.58 | 2.16 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |

Volume stored at end of day with potential daily usage and evaporation

| Date | Potential volume stored ($m^3$) | Daily consumption ($m^3$) | Volume Stored ($m^3$) | Daily consumption ($m^3$) | Volume Stored ($m^3$) | Daily consumption ($m^3$) | Volume Stored ($m^3$) | Daily consumption ($m^3$) | Volume Stored ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | 1.58 | | 5.68 | | 7.33 | | 10.42 | |
| 10-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 11-Oct-17 | 0.89 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 12-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 13-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 14-Oct-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15-Oct-17 | 5.01 | 0.00 | 4.34 | 0.00 | 4.34 | 0.00 | 4.34 | 0.00 | 4.34 |
| 16-Oct-17 | 0.00 | 1.58 | 2.10 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 17-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 18-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 19-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 20-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 21-Oct-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 22-Oct-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 23-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 24-Oct-17 | 2.79 | 1.58 | 0.54 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 25-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 26-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 27-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 28-Oct-17 | 1.08 | 0.00 | 0.41 | 0.00 | 0.41 | 0.00 | 0.41 | 0.00 | 0.41 |
| 29-Oct-17 | 1.14 | 0.00 | 0.89 | 0.00 | 0.89 | 0.00 | 0.89 | 0.00 | 0.89 |
| 30-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 31-Oct-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 01-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 02-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 03-Nov-17 | 4.31 | 1.58 | 2.07 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 04-Nov-17 | 1.46 | 0.00 | 2.86 | 0.00 | 0.79 | 0.00 | 0.79 | 0.00 | 0.79 |
| 05-Nov-17 | 5.20 | 0.00 | 7.39 | 0.00 | 5.33 | 0.00 | 5.33 | 0.00 | 5.33 |
| 06-Nov-17 | 0.00 | 1.58 | 5.15 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 07-Nov-17 | 0.00 | 1.58 | 2.90 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 08-Nov-17 | 0.00 | 1.58 | 0.66 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 09-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 10-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 11-Nov-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12-Nov-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 13-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 14-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 15-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 16-Nov-17 | 1.14 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 17-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |

Volume stored at end of day with potential daily usage and evaporation

| Date | Potential volume stored ($m^3$) | Daily consumption ($m^3$) 1.58 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 5.68 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 7.33 | Volume Stored ($m^3$) | Daily consumption ($m^3$) 10.42 | Volume Stored ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 18-Nov-17 | 5.14 | 0.00 | 4.47 | 0.00 | 4.47 | 0.00 | 4.47 | 0.00 | 4.47 |
| 19-Nov-17 | 0.00 | 0.00 | 3.81 | 0.00 | 3.81 | 0.00 | 3.81 | 0.00 | 3.81 |
| 20-Nov-17 | 0.00 | 1.58 | 1.56 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 21-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 22-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 23-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 24-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 25-Nov-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 26-Nov-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 27-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 28-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 29-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 30-Nov-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 01-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 02-Dec-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 03-Dec-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 04-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 05-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 06-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 07-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 08-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 09-Dec-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10-Dec-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 11-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 12-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 13-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 14-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 15-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 16-Dec-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 17-Dec-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 19-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 20-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 21-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 22-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 23-Dec-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24-Dec-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 25-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 26-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |

| | | Volume stored at end of day with potential daily usage and evaporation | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Potential volume stored | Daily consumption ($m^3$) | Volume Stored ($m^3$) | Daily consumption ($m^3$) | Volume Stored ($m^3$) | Daily consumption ($m^3$) | Volume Stored ($m^3$) | Daily consumption ($m^3$) | Volume Stored ($m^3$) |
| Date | ($m^3$) | 1.58 | | 5.68 | | 7.33 | | 10.42 | |
| 27-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 28-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 29-Dec-17 | 0.00 | 1.58 | 0.00 | 5.68 | 0.00 | 7.33 | 0.00 | 10.42 | 0.00 |
| 30-Dec-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 31-Dec-17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Energy Savings Calculations Table

| white roof | black roof | |
|---|---|---|
| 5.6 | 8.1 | delta T into building in summer |
| 21.34 | 30.86 | GJ/y heat transfer into building in summer no pooled water |
| 3.5 | | delta T out of building in summer |
| 13.34 | 13.34 | GJ/y heat transfer out of building in summer with pooled water |
| 34.67 | 44.20 | GJ/y Total heat transfer savings |
| 11.56 | 14.73 | GJ/y energy required to move that heat by air conditioner |
| 3 | | CoP of air conditioner |
| 3,210.43 | 4,092.42 | kWh saved by air conditioner |
| $301.78 | $384.69 | annual cost savings |
| 0.16 | 0.20 | annual GHG savings |
| 317.10 | | Surface area (m2) |
| $0.95 | $1.21 | Cost savings per m2 |
| 0.000506 | 0.000645 | GHG savings per m2 |
| 10.12 | 12.91 | kWh savings per m2 |