Sustainable Technologies
EVALUATION PROGRAM

Automated Real-time IoT Smart Blue Roof Systems for the IC&I Sector for Flood and Drought Resilience and Adaptation: A Literature Review

Prepared by:
Credit Valley Conservation

November 2018
Version 2.0

www.sustainabletechnologies.ca

PUBLICATION INFORMATION

This document was prepared by the Credit Valley Conservation through the Sustainable Technologies Evaluation Program.

Citation: Credit Valley Conservation. 2018. *Smart Blue Roof Project Literature Review Report*. Credit Valley Conservation, Mississauga, Ontario.

Report Contributors from Credit Valley Conservation:

Bernadeta Szmudrowska	Phil James	Kyle Vander Linden	Graeme MacDonald	Aloma Jonker
Kyle Menken	Bill Trenouth	Jacqueline Demchuk	Paul Kennedy	Erin Curtis

Documents prepared by the Sustainable Technologies Evaluation Program (STEP) are available at www.sustainabletechnologies.ca. For more information about this or other STEP publications, please contact:

Bernadeta Szmudrowska
Specialist, Integrated Water Management
Credit Valley Conservation Authority
1255 Old Derry Road,
Mississauga, Ontario
L5N 6R4
Tel: 905-670-1615 ext 535
E-mail: bernadeta.szmudrowska@cvc.ca

Cassie Schembri
Program Manager, Integrated Water Management
Credit Valley Conservation Authority
1255 Old Derry Road,
Mississauga, Ontario
L5N 6R4
Tel: 905-670-1615 ext 277
E-mail: cassie.schembri@cvc.ca

THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The water component of the Sustainable Technologies Evaluation Program (STEP) is a partnership between Toronto and Region Conservation Authority (TRCA), Credit Valley Conservation and Lake Simcoe Region Conservation Authority. STEP supports broader implementation of sustainable technologies and practices within a Canadian context by:

- Carrying out research, monitoring and evaluation of clean water and low carbon technologies;
- 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.

ACKNOWLEDGEMENTS

Funding support for this document was generously provided by the Federation of Canadian Municipalities and the Region of Peel.

We would also like to thank the many individuals and organizations who contributed to this report by providing data, technical review and expert advice:

- Michael Cleland, City of Mississauga
- Julius Lindsay, City of Mississauga
- Tim Van Seters, Toronto and Region Conservation Authority
- Angela Murphy, Ryerson University
- Daniel Caunter, George Brown College
- Amir Shabani, George Brown College
- Chris LeConte, Smart Watering Systems
- Chantelle-Brittany Jacob-Okorn, Credit Valley Conservation
- Carol Chaput, Region of Peel
- Jeremy Harris, Region of Peel
- Jeremy Schembri, Region of Peel
- Iris Tufa, Region of Peel
- Eric Meliton, Toronto and Region Conservation Authority
- Patrick Fung, Toronto and Region Conservation Authority
- Bruce Taylor, Enviro-Stewards
- Alicia Wind, Enviro-Stewards
- Edward Del Rosso, Enviro-Stewards
- Moheb Ekladios, Credit Valley Conservation
- Alex Fitzgerald, Credit Valley Conservation
- Kevin Mercer, RainGrid
- Igor Yeremin, RainGrid
- John Silvestri, WSP
- Miomir Brzakovic, WSP

NOTICE

While support was received from the above noted individuals and agencies to prepare this document, such support does not indicate their endorsement of its contents. Although every reasonable effort has been made to ensure the integrity of the contents of this document, the supporting individuals and agencies do not make any warranty or representation, expressed or implied, with respect to the accuracy or completeness of the information contained herein. Mention of trade names or commercial products does not constitute endorsement or recommendation of those products. The purpose of this communication is to provide general information of a legal nature. It does not contain a full analysis of the law nor does it constitute an opinion on the points of law discussed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Overview of stormwater challenges facing municipalities

Stormwater management across Canada and in the Region of Peel faces growing challenges. While each municipality has its own set of unique circumstances, these issues can generally be grouped into five broad but inter-related categories: climate change, aging infrastructure, underserviced urban areas, a growing urban footprint and financial obstacles.

Climate change: The intensity of rain events is expected to rise with the increase in global temperatures. Longer drought periods are also expected. Urban planners used to rely on intense rain events having a certain recurrence period: a one-in-five-year storm, a one-in-one-hundred year storm, etc. Climate change introduces uncertainty into our ability to plan for the future and will likely increase the number of rain events that overwhelm existing stormwater infrastructure.

Underserviced urban areas: Urban areas built before the 1970s have little or no stormwater controls. In the Toronto and Region Conservation Authority's (TRCA) jurisdiction, 65 per cent of the urban area lacks adequate stormwater quantity controls (e.g. pipes sized to convey a ten-year storm)[1]. While the percentage of underserviced area varies from municipality to municipality, this means that much of Canada's urban space is threatened by flooding, especially flash flooding.

The stormwater infrastructure deficit: Canada's stormwater assets are degrading faster than they are being repaired or upgraded. Current reinvestment rates are only at 24 per cent of the level required to maintain these assets[2].

A growing urban footprint: As Canada's population grows its urban centres will experience necessary expansion and intensification. Replacing fields, forests and meadows with roads, houses and parking lots creates more runoff, exacerbating stormwater quality and quantity issues locally and downstream.

Financial obstacles: The cost of upgrading infrastructure on public lands and in underserviced areas is prohibitive. Addressing these issues in a cost-effective manner requires looking at private property for stormwater control purposes. A recent Sustainable Technologies Evaluation Program (STEP) analysis uncovered several financial obstacles to the uptake of lot-level stormwater management practices by the private sector[3]. Coupled with the right incentive programs, blue roofs have the potential to help overcome these challenges and to provide value to both the public and the private sectors.

Blue roofs, smart blue roofs and potential benefits

Well-designed roofs are impervious to water and keep the structures they protect dry. In so doing they produce an amount of stormwater runoff proportional to their size. In most Canadian municipalities, the Region of Peel included, this runoff is conveyed as quickly as possible to municipally-owned stormwater infrastructure, from where it drains into lakes, rivers or streams.

[1] Credit Valley Conservation. (2018). Economic Instruments to Facilitate Stormwater Management on Private Property. Retrieved from: https://sustainabletechnologies.ca/app/uploads/2018/07/Economic-Instruments-for-SWM-CVC-STEP-format3.pdf

[2] Credit Valley Conservation. (2018). Economic Instruments to Facilitate Stormwater Management on Private Property. Retrieved from: https://sustainabletechnologies.ca/app/uploads/2018/07/Economic-Instruments-for-SWM-CVC-STEP-format3.pdf

[3] Credit Valley Conservation. (2018). Economic Instruments to Facilitate Stormwater Management on Private Property. Retrieved from: https://sustainabletechnologies.ca/app/uploads/2018/07/Economic-Instruments-for-SWM-CVC-STEP-format3.pdf

Blue roofs, as the term is used throughout project, operate differently. Rather than immediately conveying stormwater to the municipal system, they attenuate runoff at the rooftop level, often operating in conjunction with a rainwater harvesting system (RWHS). These systems have the potential to provide many stormwater management benefits for municipalities:

- **Peak flow reduction:** retaining or detaining stormwater on rooftops during storms keeps water from municipal stormwater systems during intense rainfall events, mitigating (downstream) flood risk. This also mitigates combined sewer overflows and erosion in receiving streams.
- **Runoff volume reduction:** by reusing stormwater or allowing it to evaporate from a rooftop, less water reaches the municipal system than would from a traditional system, extending municipal infrastructure's life span and helping to restore the natural water balance.
- **Stormwater use:** by using stormwater for non-potable purposes – flushing toilets, irrigating lawns and gardens, for example – municipally-supplied drinking water is conserved and the cost of filtering and pumping it avoided.
- **Evaporative cooling:** allowing water stored on a rooftop to evaporate mitigates the urban heat-island effect and reduces the need for air-conditioning (and the energy it requires).
- **Potential cost savings:** compared to other stormwater management techniques, whether traditional or low impact development, CVC expects that blue roofs will have relatively low life-cycle costs.
- **Retrofit scenarios:** blue roofs can be used to utilize space in underserviced, crowded urban areas, especially legacy Industrial, Commercial and Institutional (IC&I) zones which lack adequate stormwater infrastructure.

Blue roofs also have the potential to save businesses and institutions money on air conditioning and water-use costs. Those residing in municipalities with stormwater charge and credit programs, such as the City of Mississauga, also stand to benefit financially in the form of reduced charges.

Much like buildings in the Industrial, Commercial and Institutional (IC&I) sector, CVC's head office has a large, flat roof, making it an ideal place to build and test a smart blue roof for technical and financial feasibility. If it works on CVC's roof, it could work across Canada.

The Smart Blue Roof Project

While all blue roofs attenuate runoff at the rooftop level, smart blue roofs optimize stormwater management by using the internet of things (IoT) and by integration with building management systems (BMSs). These stormwater systems have the potential to become an important part of the municipal toolkit for addressing the challenges noted above. Credit Valley Conservation (CVC) received a grant from the Federation of Canadian Municipalities (FCM) to conduct a feasibility study on blue roofs in 2018, and the Region of Peel has also contributed financially to the project.

The Smart Blue Roof Project comprises three phases for testing the potential for smart blue roofs to improve stormwater management across Canada. **Phase One** (represented in this report) conducts a literature review and initial analysis of the suitability of CVC's head office building for a smart blue roof. **Phase Two** will perform technical and financial feasibility assessments of smart blue roof implementation, both for CVC's head office and for the industrial, commercial and institutional sector (IC&I) generally. **Phase Three** will conduct a stakeholder workshop and produce guidance documents to help the IC&I sector build blue roofs of their own.

After completion of the first three phases of the Smart Blue Roof Project, CVC hopes to extend the project to **Phase Four** – implementation - by applying for funding.

Methodology

This literature survey provides background information necessary to conduct a thorough technical and financial feasibility analysis. In order of presentation:

- Structural details about CVC's head office and its current stormwater and rainwater harvesting systems
- The study area and policy context: CVC head office, the City of Mississauga, and policies relevant to blue roofs from Canada and around the world
- A general survey of the components necessary for both passive and active blue roof systems – waterproofing membranes, flow control orifices, the sensors, actuators and flow measurement devices necessary for a smart blue roof, etc.
- Necessary safety features for storing water on rooftops
- Considerations for developing an operations and maintenance plan
- How to build an IoT-enabled smart blue roof system and integrate it with building management and rainwater harvesting systems
- Examples of blue roof systems from around the world
- Opportunities for and constraints on a smart blue roof system at CVC head office

Key Results

Little information is publically available about blue roofs. However, several businesses are beginning to offer services for building and operating blue roofs across the world; this indicates that the private sector is indeed interested in smart blue roof systems and technology. The review was only able to identify one example of a "smart" blue roof, and this example used smart technology for monitoring only.

Building an IoT integrated smart blue roof system seems to be relatively uncharted territory. This is a challenge for designing a smart blue roof, since it will have to be done without relying on previous experience or examples. But it is also an opportunity. As this literature review makes clear, there are many possible configurations between the sensors, actuators, building management systems, the internet, user interfaces, alarm systems, etc., that could compose a functioning smart blue roof. A careful tackling of the design challenges identified in phase one of this project – both technical and financial – constitutes the first steps toward developing guidance materials for Canada's (often flat-roofed) IC&I sector.

While the focus of this project is on smart blue roofs, passive blue roofs should also be built into the conceptual and detailed designs to allow for performance comparisons between them.

An initial investigation of CVC's head office for a smart blue roof revealed some key facts and constraints:

- The rooftop can pond up to 180 mm of precipitation, which means it can capture the 100 year storm
- The roof area is 644 M^2, with 550 M^2 available for ponding. Coupled with CVC's current rainwater harvesting tank (5 M^3), yielding 175 M^3 of storage

- The current Ontario Building Code only allows for a maximum ponding depth of 150 mm and a maximum ponding period of 24 hours. In order to fully evaluate evaporative cooling and rainwater harvesting benefits, CVC may need to apply for exemptions
- Static orifice controls are only effective for their design storms, making them useful only for a limited frequency of events. A control system which can open and close CVC's roof drain(s) would allow for enhanced stormwater management

Recommendations for Phase Two

Blue roofs have the capability to provide many benefits directly related to stormwater. The conceptual design resulting from **Phase Two** should describe a smart blue roof system with monitoring capabilities for analyzing:

- Peak flow control potential
- Evaporative cooling potential
- Water reuse potential – flushing toilets, landscape irrigation, maintenance, and drinking water
- Volume reduction potential
- The relative merits of passive and active blue roofs
- How municipalities can leverage the above benefits for financial benefit to both themselves and the private sector, specifically for devising incentive programs for promoting blue roofs to the IC&I sector

1.0 INTRODUCTION

1.1 Stormwater challenges

Municipalities across Canada face several stormwater management challenges which require creative solutions. The Smart Blue Roof Project evaluates one such solution for improving stormwater management, namely, systems which attenuate stormwater at rooftop level – what this report terms "blue roofs".

While each municipality faces unique circumstances, the stormwater challenges confronting the typical Canadian municipality can be classed into five interconnected categories: climate change, the stormwater infrastructure deficit, a growing urban footprint, underserviced urban areas, and financial obstacles.

1.1.1. Climate Change

According to the Intergovernmental Panel on Climate Change, warming of the earth's climate system is unequivocal, having risen by approximately 0.85 degrees Celsius between 1880 and 2012[1]. In Canada, linear trend analyses, which average temperatures across the country, point to an increase of approximately 1.5 degrees Celsius during summer months over the past 70 years[2].

Projecting future climate change-caused temperature increases requires making assumptions. Under business-as-usual scenarios, where no effort to mitigate greenhouse gas emissions, temperatures will increase by 5.6 degrees Celsius worldwide and by 9.5 degrees Celsius in Canada. Under more favourable conditions, where global emissions are kept to a level which would likely result in slightly less than two degrees Celsius overall warming worldwide, Canadians can expect approximately four degrees of warming[3].

While many researchers claim that extreme weather – thunderstorms, intense rainfall, droughts, hurricanes, etc. – will become more frequent and intense because of climate change[4,5,], others are skeptical. For example, it does not seem that there has been any increase in overall or short duration, hight intensity precipitation in Ontario[6], despite the number, extent, and cost of recent flooding events across the province (see Table 1 below). Rather, these authors argue, increases in the urban footprint (i.e. more impervious area coupled with inadequate infrastructure) explain increases in flooding and the resulting insurance claims.

Table 1: Recent flood events in Ontario with total insured losses

Event location and date	Total Rainfall (in millimetres)	Damages (in Canadian Dollars)
Toronto, August 7, 2018	58.2	(Not yet available)
Windsor/Tecumseh/Essex, August 28-29, 2017	***285	*165,159
Windsor, September 29, 2016	****200	***153,000,000
Burlington, August 4, 2014	100-150	*80,761,000
Greater Toronto Area, July 8, 2013	126	*982,038,000
Hamilton/Stoney Creek, July 25-26, 2009	135.5	**200,000,000-300,000,000
Toronto, August 19, 2005	153.4	*762,170,000
Peterborough, July 14-15, 2004	250	*108,733,000
Hurricane Hazel, 15 October, 1954	285	1,000,000,000 (adjusted to current day funds)
100 year design storm	118	N/A

**http://assets.ibc.ca/Documents/Facts%20Book/Facts_Book/2018/IBC-Fact-Book-2018.pdf*
***https://ec.gc.ca/meteo-weather/default.asp?/ang=En&n=DDD5D4BA-1*
****https://www.canada.ca/en/environment-climate-change/services/top-ten-weather-stories/2017.html*
*****https://www.cmos.ca/site/top_ten?a=2016#Windsor*

However, while it does seem that Ontario has not seen increases in extreme precipitation given Environment and Climate Change Canada data sets, this a) does not mean that it won't see increases in the future as temperatures continue rising and historically stable global climate patterns change, as modelling results synthesized by Environment and Climate Change Canada predict[7], and b) regardless of cause, flooding events across the province are causing increasingly severe damage. Although researchers have found that extreme precipitation events are increasing in the northeastern portions of the United States adjoining Ontario[8], thorough analyses aimed at determining whether the frequency of extreme precipitation events in Canada have in fact increased with the rise in temperatures are lacking. Regardless of the reasons for the known increases in the cost of flood damages in Ontario[9], investigating novel methods for mitigating flood risk is a worthwhile exercise.

Climate change will also require Canadians to adapt to more extreme heat. Rising temperatures will exacerbate the urban heat-island effect, making it difficult to keep cool during long summer days. This will also increase demand, especially peak demand, for energy and water.

Finally, according to the Organization for Economic Co-Operation and Development, severe weather is likely to become one of the greatest reasons for higher costs in the future delivery of municipal services and infrastructure management, as municipalities are faced with the challenge of ensuring that the level of service requirements are met.

Figure 1: Flooding at the Meadowvale Conservation Area in Mississauga, Ontario, February 2018. Photo courtesy of Jon Clayton.

Figure 2: Results of flooding – Terra Cotta, Ontario, 2018. Photo courtesy of Jon Clayton.

Figure 3: In 2007 the Island Lake Reservoir Orangeville was nearly emptied by a drought.

1.1.2. The stormwater infrastructure deficit

According to the Federation of Canadian Municipalities' Canadian Infrastructure Report Card, Canada's current reinvestment rate in stormwater infrastructure – the percentage of total asset value invested yearly in order to maintain those assets in their current condition – is only 30 per cent of the minimum amount required to maintain linear stormwater assets, and 76 per cent of the minimum amount required to maintain non-linear assets[10]. In Ontario, the stormwater infrastructure deficit is estimated to be 6.8 billion dollars[11], and climate change is expected to increase this deficit by shortening asset-replacement cycles[12].

1.1.3. A growing urban footprint

According to Statistics Canada, Canada's population in 2016 was 35.2 million people, and its population had grown by 5 per cent between 2011 and 2016[13]. Statistics Canada also predicts that this growth trend will continue, especially in Ontario and British Columbia, and it estimates that Canada's population will be between 40.1 and 47.7 million by 2036, and could be as high as 63.8 million by 2061[14].

Urban centres across Canada will necessarily expand to accommodate these population increases. This entails replacing pervious surfaces with impervious ones, whether as part of Greenfield developments or through the intensification of existing developments. This will add burden to existing stormwater infrastructure and will make flooding events more likely, especially given that much of this development will take place upstream of existing developed areas (at least in the GTA).

1.1.4. Underserviced urban areas

Most urban areas in Canada built before 1980 lack adequate stormwater quantity and quality controls. 65 per cent of the urban area in Toronto and Region Conservation Authority's jurisdiction is considered by them to be underserviced regarding stormwater management. In the Region of Peel, only 25 per cent of the total urban area has water quality controls, and in the Lake Simcoe and Region Conservation

Authority's (LSRCA) jurisdiction only 38 per cent and 21 per cent have quantity and quality controls, respectively[15]. While these stats are particular to the Greater Toronto Area, municipalities across Canada also include extensive urban areas built without adequate stormwater controls.

These underserviced urban areas are susceptible to flooding and contribute high pollutant loads to receiving waterways. Improving their situation – mitigating flood risk and improving water quality controls – can be prohibitively expensive, especially when only public lands are considered by municipalities for stormwater management[16].

1.1.5. Financial obstacles

As discussed above, there are significant limitations to the amount of stormwater that can be cost-effectively managed, using traditional or low impact development (LID) practices, within existing urban areas, and exclusively on public lands. While several innovative LID stormwater projects have been implemented across Canadian municipalities, and specifically within the Region of Peel, they have failed to lead to wide-scale adoption by the private or public sectors.

Earlier this year (2018) the Sustainable Technologies Evaluation Program released a report investigating barriers to the implementation of LID stormwater management practices on private property[17]. It found that the top barriers are:

- High upfront costs
- Uncertain maintenance requirements
- Low or no return on investment with a long payback period
- Landowners bear the cost while the benefits accrue to downstream properties and the general public
- Relatively high transaction costs (i.e. expenses incurred in designing installing LID practices – these include costs associated with receiving planning approval)

The financial barriers are critical, and the report found that these barriers persist, even in jurisdictions (such as the City of Mississauga) where private landowners can receive a credit on their stormwater charge by improving stormwater management on their properties.

1.2 The Benefits of Blue Roofs

In blue roof systems, stormwater is temporarily held in roof storage areas or structures until it evaporates, enters a rainwater harvesting system, or flows downstream, at a controlled rate, through the use of flow control devices or structures.

Blue roofs have the potential to provide multiple benefits, directly and indirectly related to stormwater management:

- **Peak flow reduction:** retaining or detaining stormwater on rooftops during intense storms keeps water from municipal systems during intense rainfall events, mitigating flood risk. This also reduces combined sewer overflows and erosion in receiving streams.
- **Runoff volume reduction:** by reusing stormwater or allowing it to evaporate from a rooftop, less water reaches the municipal system than would from a traditional system, extending municipal infrastructure's life span and helping to restore the natural water balance.

- **Stormwater use:** by using stormwater for non-potable purposes – flushing toilets, irrigating lawns and gardens – municipally-supplied drinking water is conserved and the cost of filtering and pumping it avoided.
- **Evaporative cooling:** allowing water stored on a rooftop to evaporate mitigates the urban heat-island effect and reduces the need for air-conditioning use (and the energy it requires).
- **Potential cost savings:** compared to other stormwater management techniques, whether traditional or low impact development, CVC expects that blue roofs will have relatively low life-cycle costs.
- **Retrofit scenarios:** blue roofs can be used to utilize space in underserviced, crowded urban areas, especially legacy Industrial, Commercial and Institutional (IC&I) zones which lack adequate stormwater infrastructure.

The Smart Blue Roof Project will evaluate each of these potential benefits.

1.3 Meeting Canadian municipalities' stormwater challenges

Describing the above-described benefits in terms specific to climate change adaptation and mitigation:

Extreme rainfall:

- Reducing peak flows means mitigating flood risk and erosion potential and service disruption
- Reducing pressure on downstream infrastructure by decreasing peak flows and volumes of runoff, extending the life expectancy of downstream infrastructure
- Deferring or avoiding capital and O & M for municipalities and private landowners

Extreme drought:

- Tempering vulnerabilities of regional water supply **and sanitation systems** through reuse
- Reducing energy use (and GHG emissions) by private landowners and municipalities (through reducing potable water use avoiding water-pumping costs, respectively)

Extreme heat:

- Reducing the urban heat island effect and air-conditioning use (and associated GHG emissions) by both municipalities and private landowners through evaporative cooling

The stormwater volume and peak flow reductions resulting from retention, evaporative losses and rainwater re-use, as well as the benefit to time-to-peak, are particularly important in underserviced urban areas prone to flooding. With respect to the development necessary for accommodating Canada's projected population growth, municipalities could require blue roof implementation as part of the planning and permitting process for greenfield developments and intensification of existing developments. This would relieve existing infrastructure from taking on additional stormwater inflows and unburden municipalities from having to assume additional assets post construction. In addition, blue roof adoption would benefit municipalities with combined sewers, where storm events frequently result in the direct discharge of untreated stormwater and sewage directly into rivers and lakes.

Perhaps most importantly, blue roof adoption by the private sector would help municipalities realize the cost savings associated with having the private sector manage its own stormwater on-site[18]. The trick will be to develop incentive programs that would make implementing LID practices financially beneficial to businesses and institutions. Recall that one critical barrier to LID adoption by the private sector is high capital costs, and that CVC expects blue roofs will be relatively cheap compared to other LID and traditional practices. This will shorten pay-back periods. With the right incentive programs in place, municipalities will be able to make their investments in stormwater management infrastructure go further, decreasing their respective stormwater infrastructure deficits without even increasing reinvestment rates.

Figure 4: An example of a modular tray blue roof. Source: Massacheusetts Department of Environmental Protection

1.4 Types of blue roof systems and potential for application across Peel region: an overview

1.4.1. Passive vs. Active Systems

Generally, conventional stormwater management and LID practices are passive systems governed by fixed control structures to achieve target water quality and quantity objectives[19]. However, there is an increasing need to implement active systems, responsive to changing weather conditions, which would allow for control over the flow of water through a stormwater practice to optimize performance under diverse conditions. Active systems employ the use of control devices to regulate drainage of water from the roof[42].

1.4.2. Advantages of smart blue roofs

Passive systems rarely optimize system performance whereas active system use Continuous Monitoring and Adaptive Control (CMAC) to maximize stormwater management benefits. This approach relies on sensor and information technology to make existing stormwater management systems adaptive by embedding them with connectivity and decision-making capabilities[20].

Stormwater management systems enhanced with CMAC would automatically aggregate information from on-site sensors (e.g. water level measurements) and weather forecasts. A remote software program implements custom logic-based decisions using the data sources to manipulate when and how to store or to release water collected at the sites[21]. The logic and parameters of an active water management solution can be configured for different outcomes, such as maximizing retention time, modulating a valve to control release rate, and preparing systems for extreme rain events[66].

The Sustainable Technologies Evaluation Program (STEP) offers resources and details on blue roof practices on its website.

1.4.3. Potential application across the IC&I sector

Initial assessments show that IC&I lands generally comprise 23-30% of the typical urban area and can be described as buildings with large roof areas and large paved surfaces (parking lots, and service roads) with a relatively small percentage of open space. As a consequence, IC&I lands generate the largest runoff volumes per unit area of all urban land use categories. Depending on the capture volumes from rooftop surfaces, blue roofs could capture and retain large stormwater volumes, ultimately reducing the size requirements for downstream stormwater management controls and mitigating flood risk. Reducing the stormwater management system footprint is critical in dense, highly developed urban areas with little available land for traditional end-of-pipe controls (e.g. storm ponds).

The City of Mississauga recently implemented a stormwater charge and credit program. Businesses are able to apply for a credit on their stormwater charge based on the effectiveness of their on-site stormwater controls. A large portion of applicants for the credit program to date have applied on the basis of having roof top storage on flat-roofed buildings. This is a positive indicator that many existing IC&I buildings have the structural capacity for blue roof implementation.

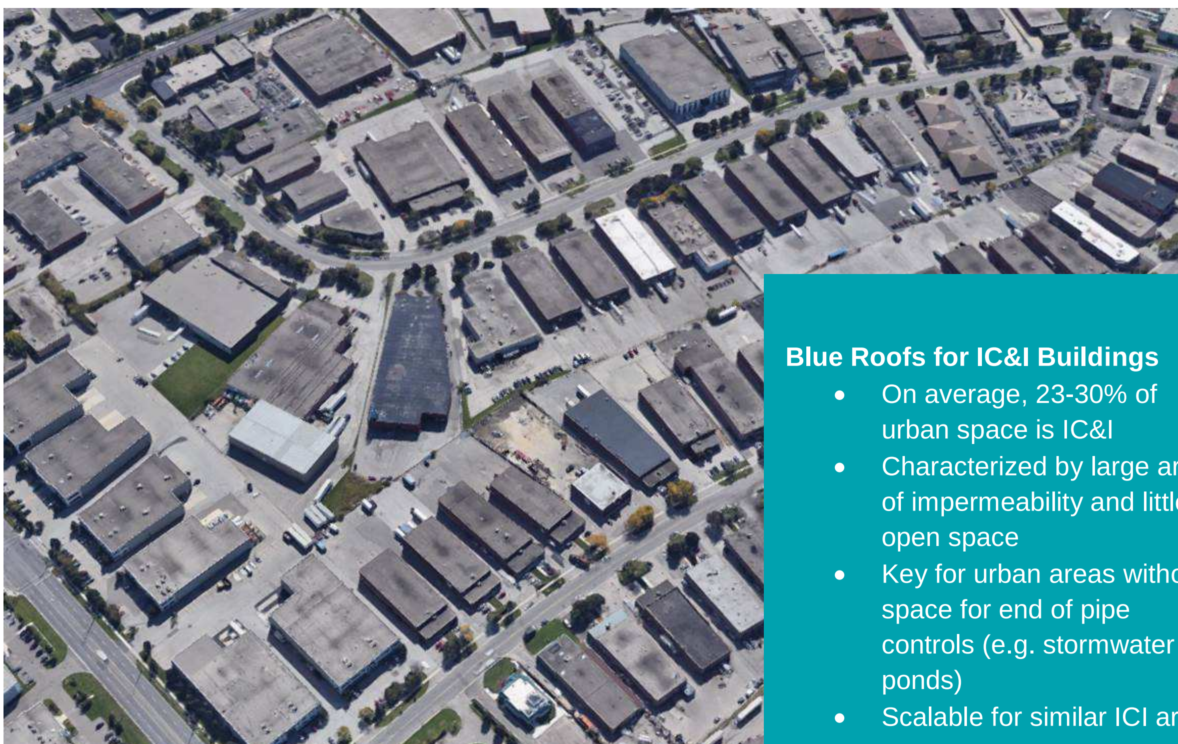


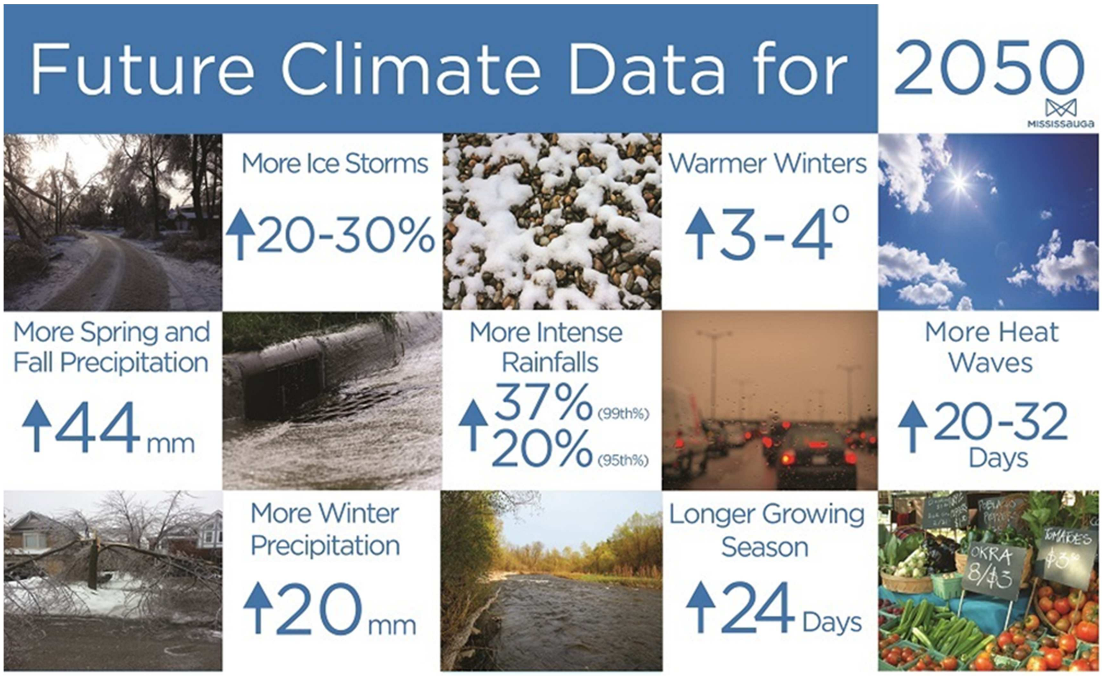
Figure 5: A typical ICI sector landscape

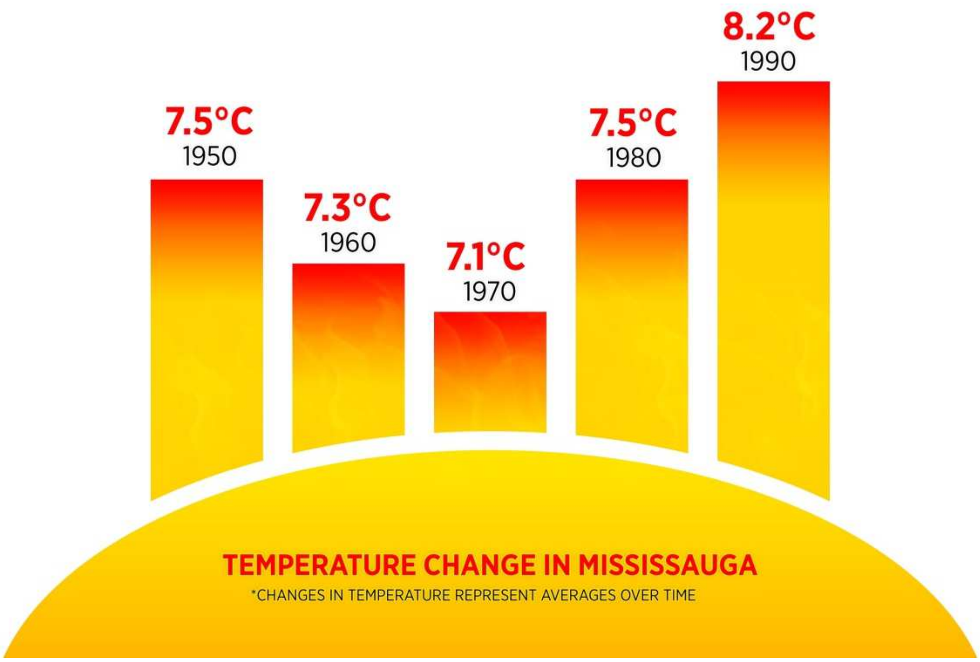
Blue Roofs for IC&I Buildings

- On average, 23-30% of urban space is IC&I
- Characterized by large areas of impermeability and little open space
- Key for urban areas without space for end of pipe controls (e.g. stormwater ponds)
- Scalable for similar ICI areas

1.4.4. Supporting Region of Peel's Municipal Priorities

The 2015-2035 Region of Peel Strategic Plan highlights that the Region is focusing on adapting to and mitigating the effects of climate change using various measures. In 2011, together with its municipal and conservation authority partners, the Region of Peel adopted the Peel Climate Change Strategy, which emphasizes that temperature increases (drought) and extreme storm events (flooding) will have significant impacts on the Region's built form and infrastructure. The Region's strategy commits to reducing community vulnerability to the effects of climate change, lowering greenhouse gas emissions and strengthening partnerships with conservation authorities and lower-tier municipalities. The Smart Blue Roof project supports each of these commitments.





Following adoption of its Climate Change Strategy, in 2013 the Region of Peel developed the Water Efficiency Strategy (WES) in response to growing demands on the water supply and wastewater treatment system. The primary objectives of WES are as follows:

- Reduce peak day water demands
- Meet legislation and requirements and goals for water efficiency
- Keep regional residential per capita water demands in line with other leading GTA municipalities
- Help business customers manage their water demands more effectively
- Manage system water loss

The Smart Blue Roof will support Peel's WES by evaluating the potential for blue roofs to decrease peak day water demands, use stormwater for non-potable needs (thereby avoiding using municipally supplied water for these purposes) and to help business customers better manage water demands.

1.5 Project structure and phases

STEP's CVC-led Smart Blue Roof Project has received funding through the Municipalities for Climate Innovation Program (MCIP) offered by the Federation of Canadian Municipalities. The project is a climate change adaptation feasibility study. It examines one stormwater management practice municipalities can use to adapt to climate change through building new infrastructure or retrofitting existing infrastructure.

The Smart Blue Roof project will endeavour to:

- Better understand how smart blue roofs can be adopted by and implemented in the private sector to reduce pressures on municipal infrastructure
- Show how smart blue roofs can support climate change adaptation strategies
- Quantify expected performance and costs of smart blue roof systems
- Increase Credit Valley Conservation's stormwater credit
- Demonstrate how innovative technologies can be used for designing and building effective integrated water management systems

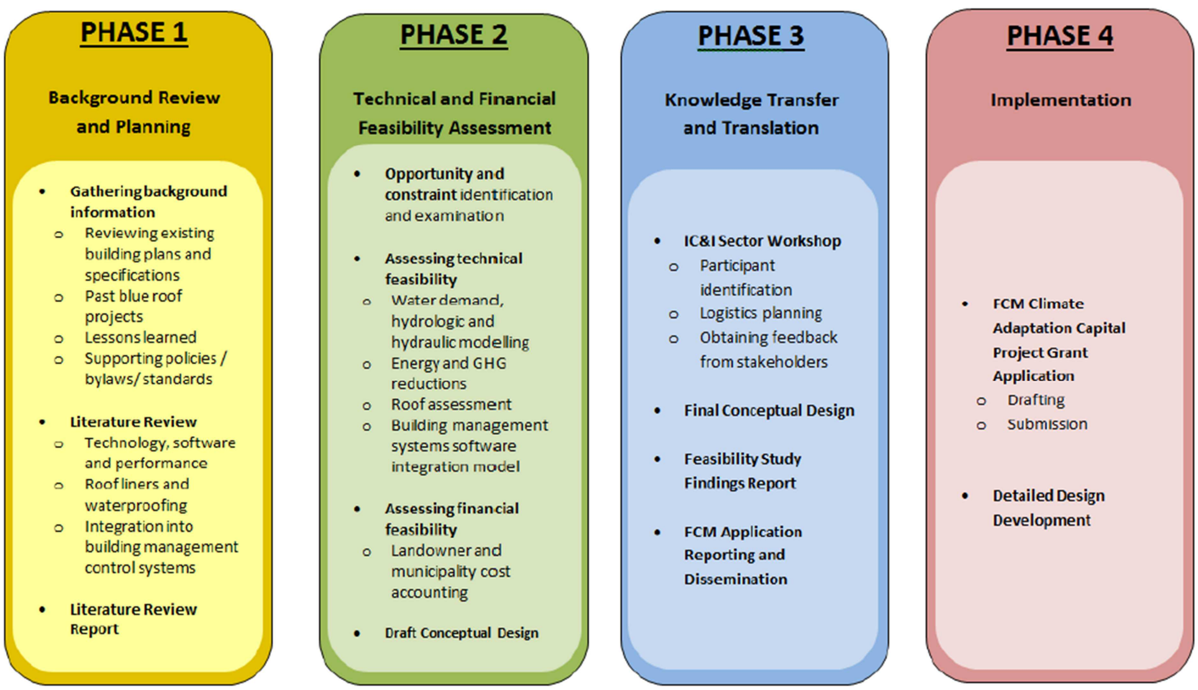
The ultimate objective of this project is to demonstrate how the IC&I sector can implement cost-effective stormwater and potable water efficiency technologies with shorter payback periods that meet their capital investment criteria while also increasing resiliency to climate change and its effects. Implementing blue roofs can also reduce the cost and footprint of other SWM systems (underground storage, ponds, etc.) and therefore increase the developable area of Greenfield developments.

To achieve this objective, the Smart Blue Roof project will investigate retrofitting CVC's head office building with a real-time controlled blue roof to build capacity and resiliency within local stormwater, wastewater and water supply systems. Going through this process will result in an in-depth technical and financial feasibility studies of the conditionalities, opportunities, barriers, costs and benefits associated with standardizing blue roof technology for the IC&I sector, both within the Region of Peel and across Canada. Gaining this experience will facilitate developing guidance materials which will help the IC&I sector achieve reliable, measurable and effective adaptation to climate-related flooding, drought and extreme heat.

Over four phases the project will deliver the following:

- Phase one:
    - A comprehensive literature review and evaluation of building codes, standards and technologies related to blue roof technology, including research about integrating blue roof automation into building management systems
    - An initial analysis of the suitability of CVC's head office for a smart blue roof retrofit and of the benefits this retrofit would provide

- Phase two:
  - A detailed evaluation of the existing state-of-the-art-technical elements associated with blue roofs and rainwater harvesting systems, including:
    - Roof storage liners, automated roof drainage valves and security, rainwater filtration, energy efficient pumping, level/depth sensors, predictive weather algorithms, automation data visualization, rain harvesting system cistern sizing and integrations
  - An economic, regulatory and insurance business risk analysis of blue roof technology in the context of stormwater management, potable water offsetting and continuing provision of municipal services
  - Thorough analyses of the potential benefits municipalities would realize given blue roof adaptation by the IC&I sector
- Phase three:
  - An IC&I building sector multi-stakeholder workshop to share project findings and obtain feedback from participants
  - A detailed business case assessment of the feasibility of, and recommendations pertaining to, a proposed CVC program to promote smart blue roofs for the IC&I sector
- Phase four
  - Install a smart blue roof at CVC head office - funding dependent



2.0 THE STUDY AREA AND POLICY CONTEXT: CREDIT VALLEY CONSERVATION ADMINISTRATIVE OFFICE, MISSISSAUGA

The CVC administration office was designed for expansion in 2008 with construction of the expanrion, referred to as 'Building A', completed in 2010. Located at 1255 Old Derry Road in Mississauga, Ontario, Building A will be the focus of this study.

Building A is situated in front of an older office structure ('Building B'), with a one-storey tunnel connecting the two (see Figure 7). This structure is a typical example of IC&I sector buildings in the GTA and across Canada, as it has a flat roof without rooftop flow controls, making it ideal for this feasibility study.

Figure 6: Building A

CVC Site Features:

- Certified LEED Gold building
- Registered with the Canada Green Building Council
- Existing stormwater features:
  - Rainwater harvesting system
  - Permeable pavement parking lot
  - Vegetated swale
  - Catchbasin
  - Storm Sewer

2.1 Current Conditions

The new office expansion is certified Leadership in Energy and Environmental Design (LEED) Gold, optimizing the use of land, energy and materials in a cost-efficient manner. In addition, many low impact development practices have been installed on the property.

2.1.1. Stormwater Management And Drainage

The original stormwater servicing reports and plans were prepared in accordance with design criteria and requirements of the City of Mississauga and CVC.

Figure 7: CVC Administration Office

Existing Drainage System

The drainage system for the site includes:

- storm sewers
- catchbasins
- gutters
- low gradient grass/vegetated swales
- roof leaders
- permeable pavement parking lots
- rainwater harvesting system

This system conveys frequent precipitation events away from the driveway surface, parking lots and landscaped areas. None of the features on this site have been designed to pond water for any period of time.

Existing Roof Drainage – Building A

Building A was not originally designed to include rooftop storage for larger storm events. It has a series of internal roof drains that then convey the water via pipes to a 5,000 L rainwater harvesting retention tank located in the basement. The roof does not contain scuppers so all runoff is conveyed through the internal roof drains.

A relief bypass pipe is used to convey excess rainwater from the tank when the tank is full. The bypass pipe drains to the municipal storm sewer system. The tank is also periodically filled with water from the building's sump pump. (Figure 8 and Figure 9).

Figure 8: Building A - 100mm Roof Drain Inlet

Figure 9: 450mm Perimeter roof lip sithout scupper

Table 2 summarizes the roof drain specifications for Building A. Storage is not effectively included within the design because the roof drains lack orifice controls. However, some ponding will occur around the drains during high-intensity rainfall events if the capacity of the drains is exceeded.

Table 2: Roof Drain Specifications

Building	Roof Area (m2)	#of Roof Drains	Diameter of Roof Drain (mm)	Actual storage above drain (m)	Actual Storage Volume Above Drain (m3)
Building A	1,051	8	100	0	0

Rainwater Harvesting System (RWH)

Rainwater harvesting is the process of intercepting, conveying and storing rainfall for future use, providing the combined benefits of conserving potable water and reducing stormwater runoff volumes. With minimal pre-treatment required, harvested rainwater from Building A is used to flush Building A toilets and to irrigate landscaped areas thereby helping to maintain predevelopment water balance.

By providing a reliable and renewable source of water, the rainwater harvesting system can also help reduce demand on drinking water supplies. This reduction in demand can result in significant cost savings due to:

- Delayed expansion of municipal water treatment and distribution systems
- lowered energy use for pumping and treating water
- lowered consumer water bills

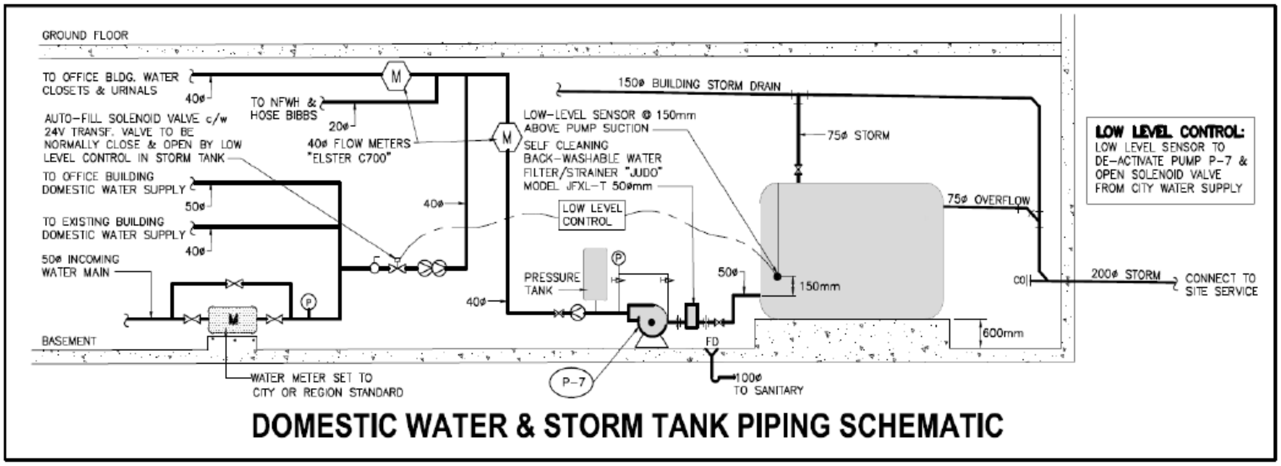


Figure 10: Schematic diagram of Building A Rainwater Harvesting System

Figure 11: Rainwater harvesting system located in the basement of Building A

2.1.2. CVC Building A: General Structural Details

Typcial IC&I sector building structure configuration tends to be similar across the country and presents many opportunities for retrofitting with smart blue roof stormwater controls. CVC's Building A represents a typical configuration of an IC&I building providing a key reason for using Building A to pilot the feasibility of smart blue roof technology. The information and data collected from CVC's Building A will be transferable to the larger IC&I community. The next phase of the feasibility study will cover other types of roof structures typically found in IC&I sector buildings.

Building A is a 4-storeys building with a partial basement level on the west side. It is 40m long by 18.8m wide and is located just south of an older office building (Building B), connected to it with a single storey tunnel.

On the east side of Building A, there is a 1-storey garage. All mechanical equipment is placed on the west side of the roof and is hidden behind a mechanical roof screen. The far west roof side was designed for additional load for the mechanical equipment and housing pads. Roof design assumes no flow control.

General Structural Systems

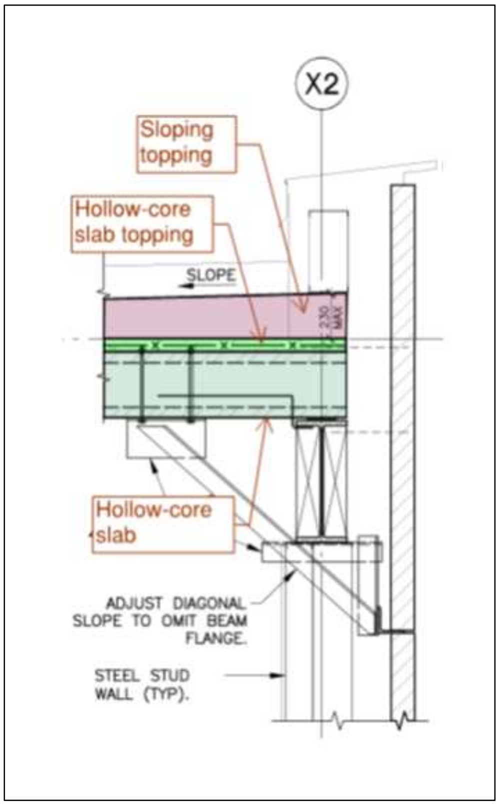


Figure 12: Typical roof structure

The building structure is a steel framing system. The floor steel beams and supporting floor slabs are connected to the steel columns that are supported on cast-in-place footings.

Floor plates are deep hollow-core slabs with concrete topping. At ground and basement levels, the floor consists of 115mm 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.

The lateral load resisting system is a conventional moment frame in one direction and a conventional braced frame in the other direction.

Roof Plate

The roof plate is a 254mm deep hollow-core slab with 50mm concrete topping, supported on the roof by steel beams. On the top of the roof plate, sloping topping was added to provide roof slope. The depth varies from 230mm at perimeter to 50mm.

Roof Structure Loads

The design loads for the roof plate are:

- 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 $SDL_{topping}$ = 4.7 kPa

The sloping topping load varies from 2.8 kPa to 6.6 kPa, as displayed in the diagram below.

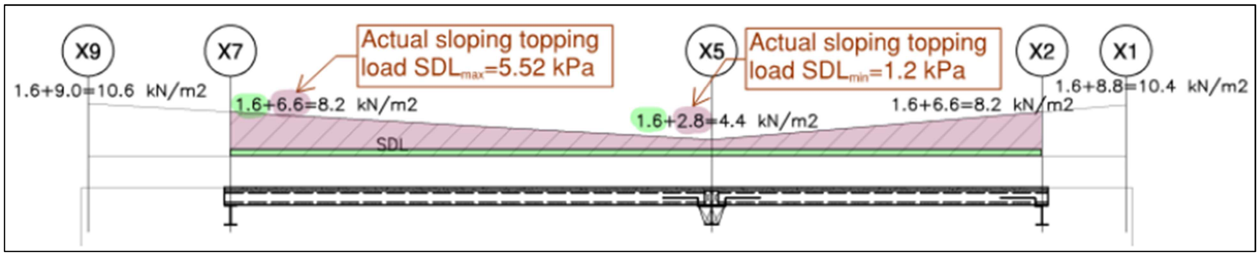


Figure 13: Superimposed Dead Load (SDL) Diagram for Precast Design

Actual Superimposed Dead Load (SDL)

The actual sloping layer was cast in two directions, as seen in Figure 9. The actual average load over one roof segment is 4.1 kPa leaving an average allowance of 0.6 kPa.

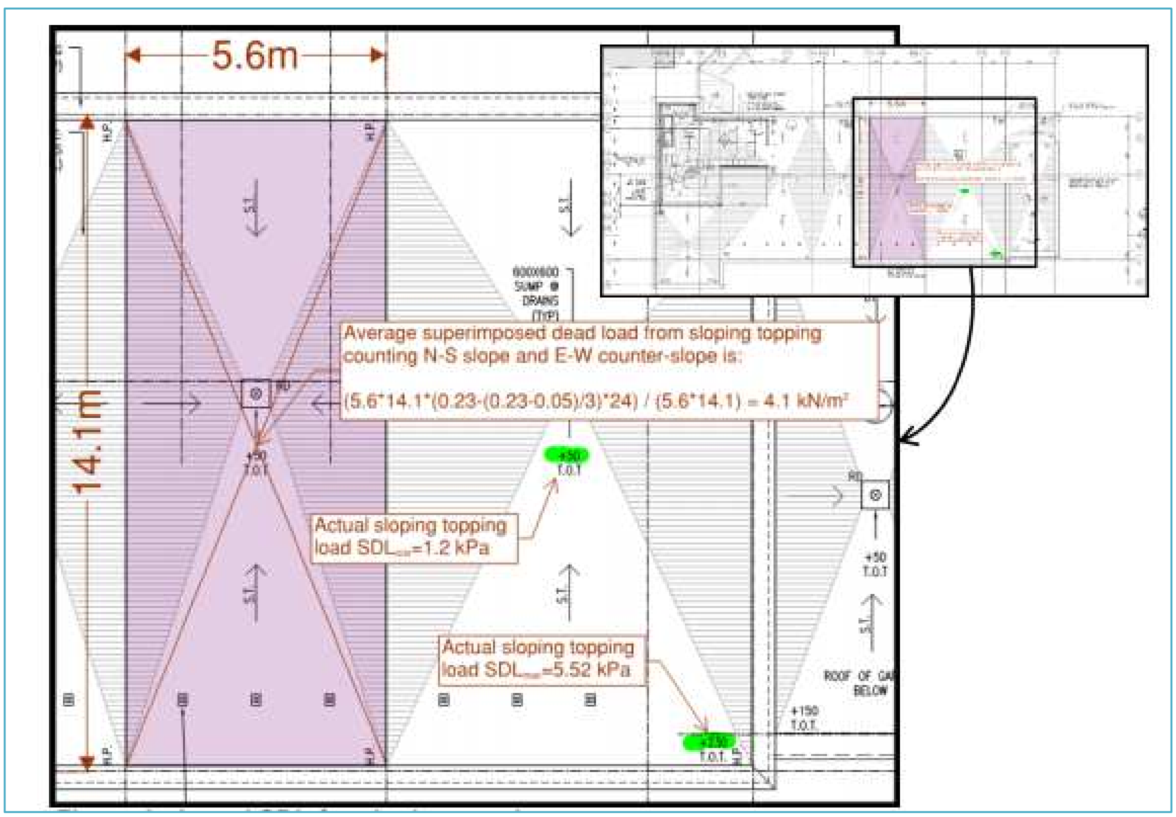


Figure 14: Actual SDL for sloping topping

Structural Materials and Strengths

Table 3: Typical materials and strengths used on the project

Structural Materials and Strengths	Strength/Grade (MPa)	Remarks
Concrete (general location)	25	Class N
Reinforcing Steel	400	N/A
*Structural Steel: Rolled	350	N/A
*Structural Steel: Hollow & Structural	350	N/A
*Structural Steel: Angles and Plates	300	N/A

*New carbon steel conforming to G40 series structural quality steel

2.1.3. Mississauga Stormwater Fee and Credit Programs

The Corporation of the City of Mississauga Storm Sewer Bylaw (By-law 259-05) prohibits (deliberate, point-source) discharge into any connections, municipal, or private storm sewer system. The legislation also delineates acceptable concentrations of various pollutants.

The City of Mississauga implemented a stormwater charge in 2016 through the Storm Sewer By-law that requires all property owners to pay a charge based on the amount of impervious area on their property. Owners with more impervious area discharge more stormwater runoff to the municipal system and therefore have a higher charge.

Concurrent with implementing stormwater charges, Mississauga adopted a Stormwater Credit Program. This incentive-type approach rewards multi-residential and non-residential properties for implementing stormwater management practices that provide relief to the City's Stormwater Management Program. Property owners must provide evidence of having taken measures or adopted practices with the express intention of supporting stormwater management resulting in a reduction in stormwater costs that would normally be incurred by the City.

The bylaw identifies four categories of stormwater management under which property owners may be eligible for a credit, including peak flow reduction, water quality treatment, runoff volume reduction, and pollution prevention (*Schedule B, By-law 135-15*).Table 4 summarizes them.

Table 4: Mississauga Stormwater Credit Apportionment (Stormwater Charge Credit Application Guidance Manual, 2015)

Category	Evaluation Criteria	Total Credit (50% Maximum)	
Peak Flow Reduction	Percent reduction of the 100-year post-development flow to pre-development conditions of the site.	Up to 40%	**To a total not exceeding 50%**
Water Quality Treatment	Consistent with Provincial criteria for enhanced treatment.	Up to 10%	
Runoff Volume Reduction	Percent capture of first 15 mm of rainfall during a single rainfall event.	Up to 15%	
Pollution Prevention	Develop and implement a pollution prevention plan.	Up to 5%	

Under the by-law, **peak flow reduction** describes the planning, design, construction, operation, maintenance and renewal of infrastructure to manage stormwater runoff rates and reduce the potential for and severity of flooding of downstream lands. This category includes roof top storage, stormwater detention basins, quantity control ponds and underground chamber systems.

Water quality treatment describes measures for actively or passively removing suspended solids and other contaminants from urban stormwater runoff. The category includes, for example, stormwater quality control ponds and low impact development works (e.g., green infrastructure).

Runoff volume reduction describes measures for reducing the volume of urban stormwater conveyed to the City's storm sewers. This includes low impact development works, and rainwater harvesting systems.

Pollution prevention describes responses to spills, both ongoing and incidental, occurring chiefly on roads and commercial and industrial lands.

Based on the characterizations of each category described above (and established in *Schedule B, By-law 135-15*), it is anticipated that operation of a blue roof system may qualify for credits under the categories of peak flow reduction, water quality treatment and runoff volume reduction. Consultation with City of Mississauga officials will be required to confirm eligibility.

In 2016, CVC submitted a stormwater credit application for the new building features and permeable pavement parking lots. The credit program evaluated how well the existing stormwater management system performed based on City of Mississauga credit criteria.

It is recognized that many BMPs could be eligible for more than one type of credit. Permeable pavement for example, can provide a combination of peak flow, water quality treatment and runoff volume reduction. For this illustration, credits could be applied to multiple categories. Further, credit eligibility will be contingent on proof of functionality and on-going maintenance through self-certification reports and periodic City inspections.

An objective of the Smart Blue Roof project is to demonstrate proof of concept and to encourage IC&I property owners to retrofit their buildings. The stormwater charge credit program provides additional financial retrofit incentive. Further, IC&I developers and builders will be encouraged to leverage passive orifice rooftop control technologies, which are commonly used in new buildings, to maximize runoff volume reduction and therefore increase the available stormwater credit.

Table 5: CVC Credit Award Evaluation Results

CVC STORMWATER CREDIT AWARD 2016	
Credit Type	**Percent Approved**
Peak Flow Reduction	7.3
Water Quality Treatment	3.6
Volume Reduction	9.3
Pollution Prevention	0.0
Total	**20.2**

2.1.4. Jurisdictional Scan of Policies, Bylaws and Standards Supporting Blue Roof Technologies and Rainwater Harvesting

Introduction

This section reviews the policies, bylaws and standards that could support blue roof and rainwater harvesting technologies.

In the context of this section, "incentives" refer to instruments like tax credits, rebates, or educational programs, while "disincentives" describe potential liabilities or fines that may arise from the adoption of blue roof technology.

Jurisdiction and Legal Underpinnings in Canada

A recent Ministry of the Environment review of the Framework for Municipal Stormwater Management proposes that stormwater be recognized as a resource and encourages reuse where possible (e.g., for flushing toilets, landscape watering etc.). When implemented, this recommendation will likely bode well for blue roof and other green stormwater infrastructure.

In addition, the province of Ontario has empowered municipalities to support green initiatives with changes to the *Municipal Act* and the *Building Code Act*. Municipalities now have power to pass by-laws to require green technologies along with plans to help the City manage their own energy costs and consumption. These changes specifically address green and alternative roof surfaces.

In Canada, the responsibility for stormwater management lies chiefly with municipalities, and there is a network of provincial legislation supporting municipal stormwater management efforts. Table 6 summarizes the stormwater management responsibilities of municipalities, conservation authorities, and provincial ministries in Ontario.

Table 6: Stormwater Management responsibilities of municipalities, conservation authorities, and provincial ministries in Ontario

Municipalities	Conservation Authorities	Provincial Ministries
• Design, permitting, and construction of new capital improvement projects • Operation and maintenance of stormwater management facilities • Asset management, valuation, and planning • Rehabilitation, renewal, retrofit, reconstruction or upgrade of existing facilities • Emergency response, recovery, and clean-up after flooding events, system failures	• Prohibit, restrict, regulate or permit certain activities, including stormwater management, in and adjacent to watercourses (including valley lands), wetlands, shorelines of inland lakes and the Great Lakes-St. Lawrence River System, and other high risk lands. Working together with the Ministry of Natural Resources and Forestry (MNRF), conservation authorities are also responsible for flood forecasting and warning and the operation of flood control structures.	*Ministry of the Environment and Climate Change:* • Approve sewage works, including those for stormwater, under the *Ontario Water Resources Act*. • Provide technical guidance via *Stormwater Management Planning and Design Manual* (2003) *Ministry of Municipal Affairs:* • Provide direction to municipalities on stormwater management requirements in land use planning, including the *Provincial Policy Statement, 2014* and the *Growth Plan for the Greater Golden Horseshoe*

Municipalities	Conservation Authorities	Provincial Ministries
• Engineering and support services for review and regulation of proposed land or building developments • Inspection, monitoring, environmental compliance programs, record maintenance • Support for public education and community involvement programs • Administration, staffing, computer resources, equipment, and enforcement of by-laws and detection of unlawful discharges		*Ministry of Transportation:* • Provide design standards for provincial culverts, bridges and highway drainage systems and approves some land development proposals if stormwater runoff is discharged to a roadside ditch that is part of a highway drainage system. *Ministry of Infrastructure:* • Provides funding for infrastructure projects, including stormwater management facilities • Provincial lead for water-related natural hazards.

Adapted from "Urban Stormwater Fees: How to Pay for What We Need" report[22].

Federal Oversight

Federal oversight of stormwater management is limited mainly to grant programs. Recently, Infrastructure Canada has been administering short-term funding to provinces and municipalities in support of water and wastewater infrastructure via the Clean Water and Wastewater Fund (CWWF). The $2 billion fund is allocated to provinces according to population, and is delivered via bilateral agreements between the federal government and individual provinces and territories. Provinces and municipalities identify and submit for approval, a list of infrastructure projects in need of funding. CWWF allocations may cover up to 50% of the cost of these projects in provinces, and up to 70% of project costs in territories. The CWWF program prioritizes projects that improve asset management, system optimization and planning for future upgrades to water and wastewater systems[23].

As mentioned above, the Federation of Canadian Municipalities (FCM)'s Municipalities for Climate Innovation Program is another federally-funded initiative that includes $75 million in funding over five years to help municipalities build climate change resiliency.

Provincial Oversight

Governance of stormwater management in the province of Ontario falls under the purview of several pieces of legislation. The Ontario Ministry of the Environment Framework for Municipal Stormwater Management summarizes the laws, policies, and programs addressing stormwater management in Ontario[24]. Appendix A describes relevant statutes relating to blue roof technology in detail.

Municipal Oversight

Other than Mississauga, several other municipalities have implemented stormwater charge and credit programs, including Markham, Guelph, Kitchener and Waterloo. Brampton also plans to introduce a charge and credit system in the near future. An overview of rebate programs that support blue roofs is provided in section 3.1.6.1.

2.1.5. Liability for Stormwater Management

This section will also discuss potential liability for private and public actors engaging in stormwater management, as it relates to blue roof technology. Legal obligations related to stormwater may arise from either legislation (i.e., laws created by government) or common law (i.e., legal precedents established by the judiciary). While in most cases, the judicial system views policymaking as a responsibility best left to governments, there are some cases in which a government department may be subject to judicial scrutiny. Generally, poor choice of policy, or policy design missteps are exempt from adjudication. However, government departments who fail to properly execute or implement a policy may be liable for resultant damages to private property[25]. Private actors whose actions adversely affect public sector stormwater management may similarly be found liable.

Municipalities

There have been a number of recent successful class action lawsuits in which courts have found evidence of neglect of stormwater management, at the expense of the municipalities involved. These cases are relevant because they represent a potential liability that municipalities need to be aware of surrounding blue roof technology, which, if poorly designed or mismanaged, could result in storm sewer overload and flooding.

Overburdened stormwater infrastructure is a common condition. Henstra and Thistlethwaite[26] observe that the incidence of extreme weather due to climate change has placed municipalities at greater risk for flooding and associated consequences.

Existing municipal infrastructure is hazard-based. The systems are “calibrated” according to standards, which in the past could reasonably be assumed to be static (e.g., “100-year storm”). These storms are following a trajectory that is increasingly difficult to predict. Henstra and Thistlethwaite suggest that perhaps the costs associated with climate change-induced weather events should be shared with provincial and federal governments in an evolving approach based on risk management, rather than historical precedents.

> Framing blue roof technology as a potential tool for mitigating or offsetting the burden of extreme weather events on municipal infrastructure may be the most effective means of increasing implementation and for garnering support from private sector owners/builders and government actors, ideally in the shape of incentive-type policies and laws.

Zizzo, Allan, and Kocherga[25] summarize the burden of responsibility of private sector actors involved in stormwater management system design, implementation, and maintenance as follows:

> “…consultants, engineers and other design professionals are all subject to legal liability for failure to take relevant information into account, or adapt to current, foreseeable conditions. Professionals who provide stormwater management services can potentially be sued by those who suffered harm and/or by governments that relied on their advice and actions. All parties involved in stormwater management have an interest in ensuring that sound, defensible decisions are being made and appropriate actions are being taken.”

They further remark that property owners also have responsibilities where stormwater management is concerned, and may be found liable if they are determined to have been negligent. The authors provide the example of a resident who altered site grading, which redirected stormwater flow toward basement foundations, causing flooding to adjacent properties. In cases where both a municipality and private actor are determined to have neglected stormwater management, both actors may potentially be found liable.

Conservation Authorities

The Supreme Court of Canada has ruled that government entities, including conservation authorities, can be found liable for the negligence of their employees and contractors, depending on the statutory provisions involved. In cases where government departments have outsourced installation or maintenance to private organizations, stormwater management ultimately falls under the umbrella of municipal or conservation authority statutory duties. Contractors hired by governmental ministries or departments may also face negligence claims. In assigning liability for negligence, courts may also consider reasons of fairness; for example, a ruling may take into consideration that governments are typically in a better financial position to compensate claimants than most contractors[25].

Insurance Companies

The unpredictability of future severe storms is challenging for insurance companies. The result of this is an increasing reluctance among insurance providers to insure flood prone areas. As extreme weather events become the norm, it has been recommended that governments absorb the costs of flood damage to high risk areas, to alleviate some of the growing burden of insurance companies[25].

Where applicable, consultation with insurance companies is recommended prior to the design and implementation of blue roof systems. In a subsequent phase of this study, insurance companies will be consulted for their perspectives on blue roof systems.

2.1.6. Exemplary Blue Roof Policies and Legislation in Other Jurisdictions

Ontario and its municipalities do not have policies encouraging adoption of blue roofs in particular.
However, the credit-type programs that have gained popularity in some southern Ontario municipalities and are potentially useful tools for encouraging blue roof adoption. A number have developed informal guidelines for on-site stormwater management, which has in some cases given way to entrenchment in by-law ammendments. The City of Toronto's Green Roof Bylaw is a good example and may be applicable to blue roofs. The recent amendments to the Municipal Act and Building Code Act, mentioned previously, provide municipalities with greater authority to enact bylaws relating to roof structures.

The goal of these guidelines is typically to ensure that on-site stormwater management is conducted in a safe and effective manner. The review of municipal policies and programs from international jurisdictions shows there is a growing general interest in local, on-site stormwater management.

Fee Credit or Rebate Programs

<u>Guelph and Waterloo, Canada</u>

Several municipalities in Southern Ontario have introduced fee credit or rebate programs similar to that which was recently enacted by the City of Mississauga. As of January 1st, 2018, the City of Guelph introduced a seasonal rainwater harvesting rebate available for residential property owners who purchase and install stormwater collection tanks on-site. Eligible property owners will receive a rebate of $0.50 per litre of stormwater collected, up to a maximum of $1000[27].

A second program exists for business and multi-residential property owners, which offers properties exercising stormwater and pollution management best practices a discounted monthly stormwater service fee charge, up to a maximum of 50% of the total fee[27].

The City of Waterloo's stormwater credit program offers property owners a credit of up to 45% towards their stormwater utility fee and specifically identifies rooftop storage systems[28]. It's interesting to note they also offer residential incentives for practices including rain barrels, trees, cisterns, infiltration measures, or rain gardens but the audience for blue roofs is directed at the IC&I sector. The City of Kitchener has established a similar program.

Victoria, Canada

The incentive-type stormwater management program is also gaining popularity in other jurisdictions. Victoria, British Columbia, has a program for on-site management of stormwater by private property owners[29].

Palo Alto, U.S.A.

The City of Palo Alto, California has a program, for which residents, businesses, and city departments are eligible. Rebates are offered in exchange for the installation of rain barrels, cisterns, permeable pavement, and green roofs.

Philadelphia, U.S.A.

Philadelphia has established a stormwater grant program, which offers non-residential property owners a sum of up to $100,000 towards the cost of design and construction of an on-site stormwater management system. Applications are assessed according to total volume of runoff managed, cost-competiveness, environmental and educational benefits[30]. Grant recipients are also eligible for credits towards their stormwater charge once the stormwater management system is operating.

New York City, U.S.A.

In 2010, the New York City Department of Environmental Protection amended Chapter 31 of Title 15 of the Rules of the City of New York (RCNY), which govern house and site connections to the municipality's sewer system ("existing rules"). The amendment alters the permissible flow rate of stormwater to the city's combined sewer system for new and existing developments to mitigate overloading of the sewer system and ensure that the sewers do not surcharge. Blue roofs in the city must comply with the stipulations outlined in the amended Chapter 31[31].

The New York City Guidelines for the Design and Construction of Stormwater Management Systems includes support for blue roof technology. It defines these as systems that "provide temporary ponding on a rooftop surface slowly releasing the ponded water through weirs at the roof drain inlets to restrict flow" (p.9). The guide recommends blue roofs as a stormwater management tool for rooftops with a slope of less than 2%". The white paper also offers guidance for calculating release rates from control flow weirs and available storage volume.

Melton, Australia

Melton, Australia has released a guide advising property owners about stormwater detention. The recommendations predominantly relate to ground-level systems, but the paper suggests maximum depths for rooftop stormwater attenuation systems be determined according to the structural integrity of the roof area[32].

Marion, Australia

Facing increasing urban density and the resulting increased burden on stormwater infrastructure, Marion City Council determined that the most effective option was to implement large and small scale stormwater detention and retention systems in new developments. As of January 1st, 2000, the municipality has mandated the implementation of these systems in residential zones where the roof area of all buildings expressed as a percentage of the allotment/site area exceeds 30% and the development proposed comprises one of the following: a new dwelling, an addition to a dwelling greater than 40m2, or a land division where existing buildings are to remain[33].

Michigan, U.S.A.

In 1992, Michigan published a brief document outlining rooftop stormwater detention as a solution to reduce peak discharge to sewer systems. The technical specifications outlined in the document appear to align with this feasibility study's definition of a blue roof[34].

3.0 BACKGROUND INFORMATION

3.1 Blue Roof Technology and Performance

3.1.1. Blue Roof Components

The main components of a blue roof system is the rain water storage structure and the waterproofing membrane. Some blue roof applications may include real-time controls to make automated decisions about when and how to store or release water collected on the rooftop. Each of these components is described in detail in the following sections.

Rainwater Storage Structure

In blue roof systems, stormwater is temporarily held in roof storage areas or structures until it can either evaporate, be released downstream at a controlled rate, or sent to a rainwater harvesting system. The size of the area on the roof dedicated to storage is dependent on the type of blue roof system chosen.

From the literature review, three different blue roof systems or configurations have been identified:

- controlled flow roof drains
- check dams installed around an existing roof drain
- modular tray systems

All three systems have been installed and tested in various pilot projects. The New York Department of Environmental Protection (NYDEP) pioneered blue roof systems and has worked closely with the New York City School Construction Authority to include 14 rooftop detention projects[35]. An overview of all three systems is provided below.

Controlled Flow Roof Drain System

A controlled flow roof drain system is generally recommended for flat or nearly flat roofs with less than 2% slope[36]. In this system, a roof drain restrictor is placed over an existing roof drain to restrict flow and allow for the temporary ponding of rainwater on the roof (see Figure 15).

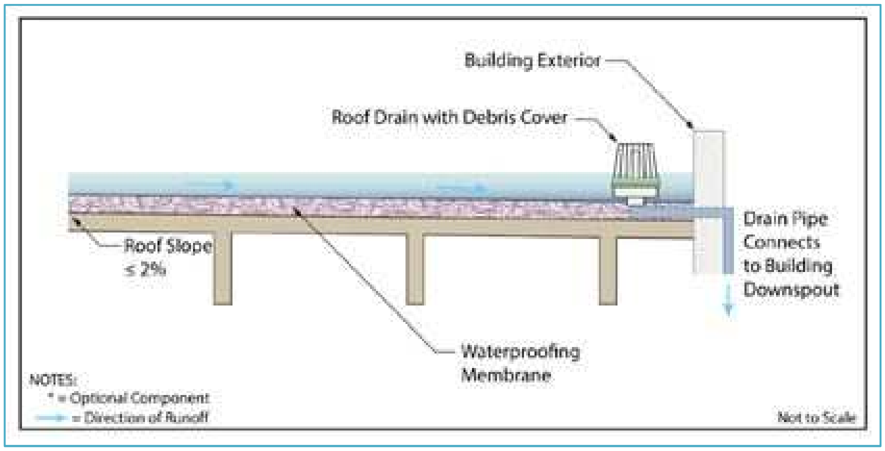


Figure 15: Profile section of a controlled flow roof drain system with a slope less than or equal to 2% (Source: NJDEP 2017)

These restrictors generally consist of a weir with an orifice, and are typically purchased commercially through a manufacturer.

Figure 16: Roof drain with flow control insert (Source American Hydrotech Inc.)

The design determines the number and the size of the weir and orifice flow control structures which is a function of the relationship between the water depth approaching the drain and the flow rate entering the drain. As well, the design will outline the overflow structure which will dictate the ponding depth[37].

During light rain events, the restrictor allows water to easily drain at the membrane level. In heavier rain events, the large amount of water will overwhelm the openings in the restrictor and the water will back up to a predetermined depth. The restrictor allows water to leave the roof at a prescribed flow rate. This restricted flow prevents the receiving sewer system from overflowing and causing common issues like flooded basements, streets, and other problems consistent with stormwater management issues (Hydrotech, Blue Roof Assemblies).

Storage in modified roof drain systems is determined by the roof slope and geometry relative to the height of both roof drain restrictors and parapets. The bulk volume occupied by all building mechanical systems, roof furniture, and appurtenances must also be factored into the storage volume calculations[37].

Controlled flow roof drain systems were installed and tested at a storage facility on Metropolitan Avenue, NY, as part of the series of pilot projects on blue roofs performed by the NYDEP. Monitoring results of this pilot project showed that "The controlled flow roof drain system provided some retention and detention, particularly for smaller storms, but was generally similar in performance to an uncontrolled reference" [38].

An important consideration for controlled flow roof drain systems is included in the Ontario Building Code (Reg. 332/12, Section 7.4.10.4). This Regulation specifies the maximum allowable draw down time (24 hours) and ponding depth (150mm), for rooftops where a flow control roof drain is installed. According to this Regulation:

"Flow control roof drains may be installed provided,

- (a) the maximum drain down time does not exceed 24 h
- (b) the roof structure is designed to carry the load of the stored water
- (c) one or more scuppers are installed not more than 30m apart along the perimeter of the building so that
- (d) the scuppers are designed to handle at least 200% of the 15-minute rainfall intensity
- (e) the maximum depth of controlled water is limited to 150 mm
- (f) they are located not more than 15m from the edge of the roof and not more than 30m from adjacent drains
- (g) there is at least one drain for each 900m^2"

In addition, municipalities usually have their own Flow Control Roof Drainage Declaration forms which typically mimic building code requirements, but still require submission[39]. These aspects should be carefully considered when designing a blue roof system.

Roof Check Dam Systems

Rooftop storage may be maximized by installing check dams or weirs at intermediate locations along the roof surface surrounding an existing drain. Check dams create temporary ponding areas during rain events before slowly discharging to the roof drain. This type of system is generally recommended for roofs with slopes greater than 2% to avoid excessive ponding depths[36]. Roof check dams should be used when the existing roof provides minimal containment opportunities or has no parapet[40]. In these situations, check dams configurations can support the creation of detention cells that slowly release stormwater toward the outlet drain[41].

The design of a roof check dam stirage systems is determined by the roof slope and associated area dedicated to ponding behind the dams[37]. The bulk volume occupied by all building mechanical systems, roof furniture, and appurtenances must also be factored into the storage volume calculations.

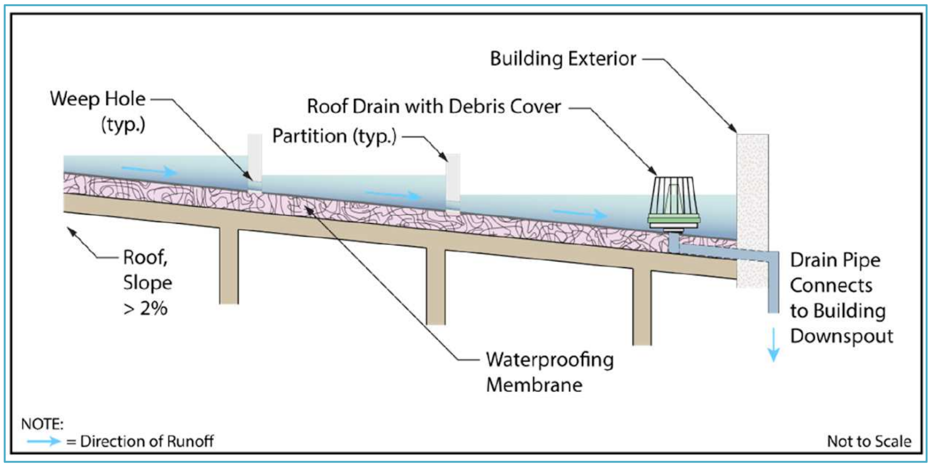


Figure 17: Profile section of a Check Dam System with a slope greater than two percent (Source: NJDEP 2017)[36] .

Check dams or weirs may be constructed of any material that can temporarily detain water and withstand environmental conditions on rooftops. Aluminum T-section dams, with drilled orifice holes and loose gravel have been used to retain and slow release rainwater[35]. If not commercially available, these dams can be easily fabricated[37].

These inverted T-sections are weather sealed and secured to the roof structure, creating ponding areas behind the dam. Holes, slots, or other perforations are typically evenly spaced along the dam to allow slow release of the ponded water.

Spacing of a series of check dams or weirs on sloped surfaces should ensure that one does not cause backwater against another at maximum water surface storage.

NYDEP installed and monitored this type of system at a storage facility on Metropolitan Avenue, NYC. Results indicated that “check dams provided a higher level of storm water control than a controlled flow roof drain system, likely due to more even distribution of detention storage across the roof, but did not achieve the same level of consistency as modular tray systems”[35].

The PWD recommends to “ensure that the dam possesses a watertight seal with the roof membrane and that any seams or connections between sections of the dam are also water-tight and do not create preferential flow pathways that undermine the designed slow release flow rate of the dam perforations”.

Modular Trays

Modular tray systems use plastic or aluminum trays to temporarily detain water during rainfall events. The trays can be physically attached to the roof or the underlying supporting grid and/or held in place with a ballast comprised of coarse stone or other weighed materials. It was one of the systems the NYDEP installed and tested in a pilot program[42].

Figure 18: Modular tray system

> *"These projects were the first to utilize a novel passive blue roof tray design developed by Geosyntec Consultants. Monitoring of these systems has demonstrated their performance as an effective means for peak flow mitigation and lagging the peak flow in combined sewer systems"*[42]

The use of modular trays as the primary water detention structure provides flexibility in both the size and configuration of the detention system and is well-suited for retrofit designs. Through selective placement and configuration of the trays, rooftop equipment and structures can be avoided and loading issues can be addressed[38].

As highlighted in a report, "a distinct advantage of a tray configuration over the modified inlet and check dam roof types is the ability to limit water retention and ponding to specific portions of a roof. As such, pathways and areas with lower structural loading capacity can be kept free of standing water after a storm event" [43]. The ability to limit the installation of modular trays to areas of the roof that are capable of withstanding the increased load is ideal for retrofitting current structures with blue roof systems. In the GTA we expect most blue roof installations will be retrofit versus new build.

Modular tray systems can be combined with green roof components to improve aesthetics and provide some additional green roof benefits. Consistent and reliable drainage of the trays with little maintenance is a key consideration. Some designs allow for trays to be interconnected to effectively act as a larger "tank"[38].

Waterproofing Membrane

A waterproofing membrane is a fundamental component of a blue roof system. While many types of waterproofing membranes are available and can work as part of a rooftop system, the intended use of the roof for storage of water should be confirmed with the manufacturer to ensure the warranty covers such use.

Common waterproofing membrane systems include:

- modified bitumen roofing (MBR)
- waterproof types of single-ply roofing
- metal roof panels
- spray polyurethane foam (SPF) roofing
- synthetic rubber membranes
- thermoplastic membranes
- liquid-applied (including polyurethane-based and polymer-modified bituminous products) roofing[38].

While high quality **MBR systems** (multiple MBR sheets tiled to reduce seam susceptibility) are suitable for blue roof usage, lower quality MBR systems are not recommended because they contain many layers of asphaltic sheets with fiber reinforcement that can wick moisture, and multiple seams where water can penetrate the system. Lower quality MBR systems are also fairly thin and less durable than other types of roof assemblies, requiring regular maintenance and more frequent replacement[38].

Single-ply systems designed specifically for green roof applications can hold water during a storm. Single-ply membranes have fewer seams, come in large sheets and variable thicknesses of thermoplastic, or thermoset (rubber). These are well-suited for blue roof applications[38].

SPF membranes are highly durable, incorporate insulation into the membrane and do not need a stand-alone insulating layer. These roofing systems are considered to be more stable than others and tend to be used in areas where hurricanes or high wind speeds are a concern or on roofs with atypical configurations. Because the system has no seams and is durable, this membrane is suitable for blue roof applications (NYDEP, 2012). The main drawback of SPF roof systems is the high cost.

Liquid-applied membranes consist of a hot or cold fluid coating that is applied onsite. The fluid is poured onto the roof and spread until the desired thickness is reached. The liquid-applied membrane is self-healing, very durable and does not have seams, making it a suitable option for use in blue roof systems[35]. Liquid-applied membranes tend to last the longest of any roof system with little maintenance required, but the initial cost of these membranes tends to be more expensive than other types. Additionally, this type of membrane requires a separate insulation layer.

In new construction that includes blue and green roof systems, The New York City School Construction Authority[44] recommends use of a "**hot fluid applied**, rubberized asphalt, fabric reinforced roofing system in a protected membrane configuration". An example of a hot fluid applied membrane of this type, is the Monolithic Membrane 6125® (MM6125®) from Hydrotech.

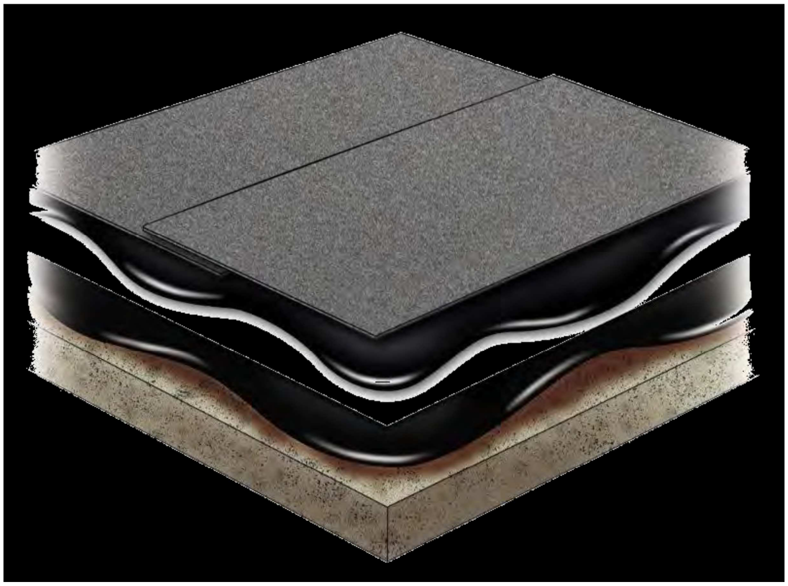


Figure 19: Monolithic Membrane 6125® (American Hydrotech Inc.)

Figure 20: Installation of liquid applied membrane (American Hydrotech Inc)

The blue roof material standards included in the Stormwater Management Guidance Manual published by Philadelphia Water[37] state the following:

Waterproof membrane:

a) PVC, EPDM (synthetic rubber), and thermal polyolefin (Thermoplastic olefin (TPO), an elastomer) are permitted.
b) All waterproof membranes must meet appropriate ASTM International specifications. PVC membranes must meet ASTM D4434 requirements, EPDM membranes must meet ASTM D4637 requirements, and TPO membranes must meet ASTM D6878 requirements.
c) Waterproofing membrane must be fully waterproof with properly sealed seams, corners, and protrusions to prevent any intrusion of standing water above the membrane.
d) Roofing membranes must meet all building code requirements and guidelines of the City of Philadelphia.

3.2 Blue Roof System Architecture and Real-Time Automation

A typical blue roof system consists of three different layers (Figure 21):

- the field level with all the sensors and actuators
- the automation level with the controllers
- the management level with applications and interfaces to visualize and analyze the data

The field level components communicate directly with the controller, and the management level handles the applications and data analysis. This method of operation is the safest and most reliable method as the system would still be operational in absence of connection to the management level (should internet connection be lost).

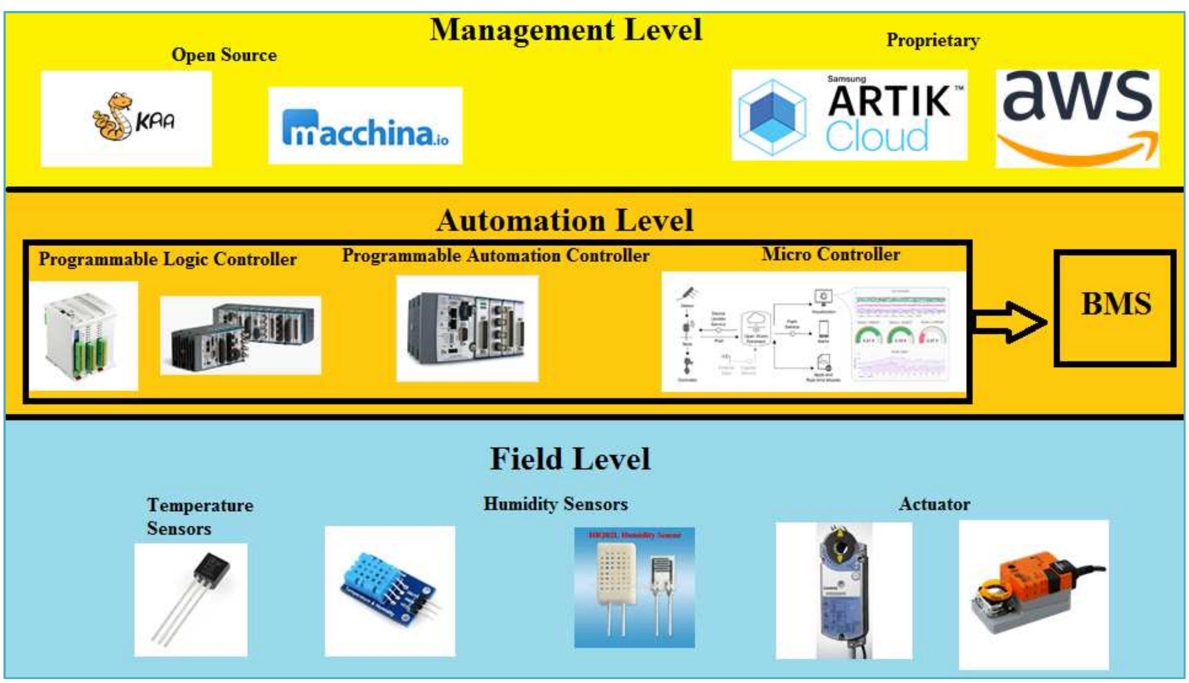


Figure 21: The three levels of a blue roof system

In case of a real-time operation of an automated blue roof (Figure 22), the (remote or local) weather station sends the weather forecast/information to the controller. If rain is forecasted, the system empties the roof and begins storing rainwater in the storage system (rainwater harvesting or other).

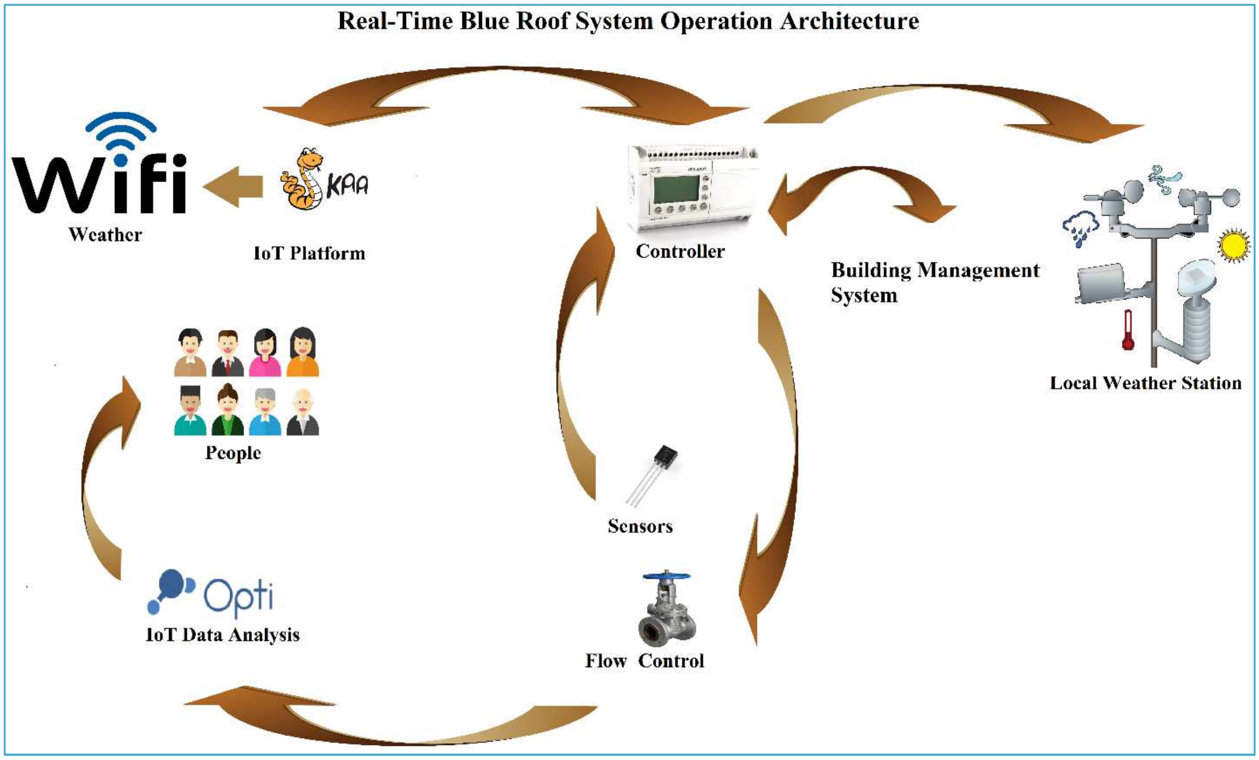


Figure 22: Operation Architecture of a Blue Roof System

Following is an introduction to water quantity monitoring, sensors, different types of actuators, and control valves. We'll then explain water quality monitoring and finally different networks through which these devices will communicate with the automation layer (i.e., the controller).

3.3 Water Quantity Monitoring

In blue roof application, monitoring is generally used to measure water quantity in commercial rooftops and cisterns (if a rainwater harvesting system (RWHS) is included). Water level monitoring is important for managing overflow potential and for mitigating storage structure stresses. RWHS can help reduce the use of municipal water, by collecting and storing rainwater for reuse for applications including toilet and urinal flushing, maintenance, and irrigation.

3.4 Water Level Measurement

Water level instrumentation uses water level sensors to automatically monitor and control the water level in a reservoir. There are four common types of water level sensors and instrumentation:

- float switch sensors
- probe level sensors
- ultrasonic sensors
- pressure transducers

Float Switch Sensor
Typically used in a cistern application, a float switch sensor uses magnetic switches for precise water control[45]. It's usually placed near the top of the cistern as a set point in an open connection (see **Figure 24**) and is electronically connected to a motor which turns on/off the water pump for a certain amount of time, based on the water level. When the water level rises above the set point, the magnetic switch closes and turns off the pump (see **Figure 23**). This system's only disadvantage is that it will turn on even when the water is completely out of the cistern.

Figure 23: Closed Connection

Figure 24: Open Connection[46]

Probe Level Sensor
The Probe Level sensor can be implemented on a commercial rooftop and/or in a cistern set-up. It introduces a hanging wired probe method for water level sensing in the reservoir. These probes can come in many different lengths and numbers, depending on the application. The probe colours vary depending on manufacturers[47].

There are two kinds:

- single point probe sensor (see Figure 25)
- multi-point probe sensor (see Figure 26)

In a cistern, when the water level contacts the shortest probe in the reservoir, it causes the valves and/or pump to automatically shut off. When the cistern starts draining and passes the longest probes, the motor pump turns on and begins filling the tank again. Typically, the long black probe is used as reference, and all other probe lengths in between the "high" and "low" level probes indicate a certain level of water in the tank.

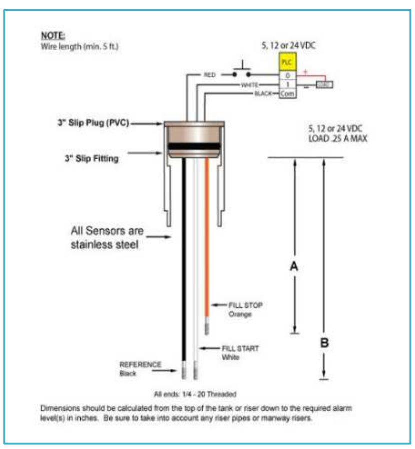


Figure 25: Single Point Probe [48]

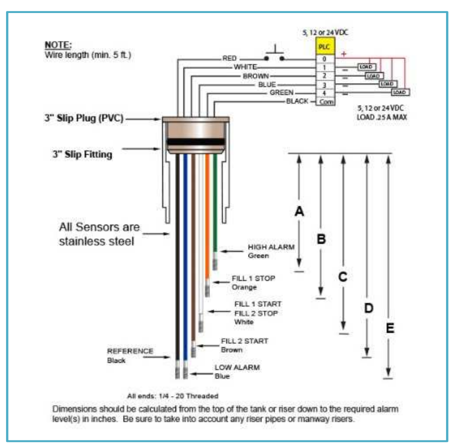


Figure 26: Multi-Point Probe [48]

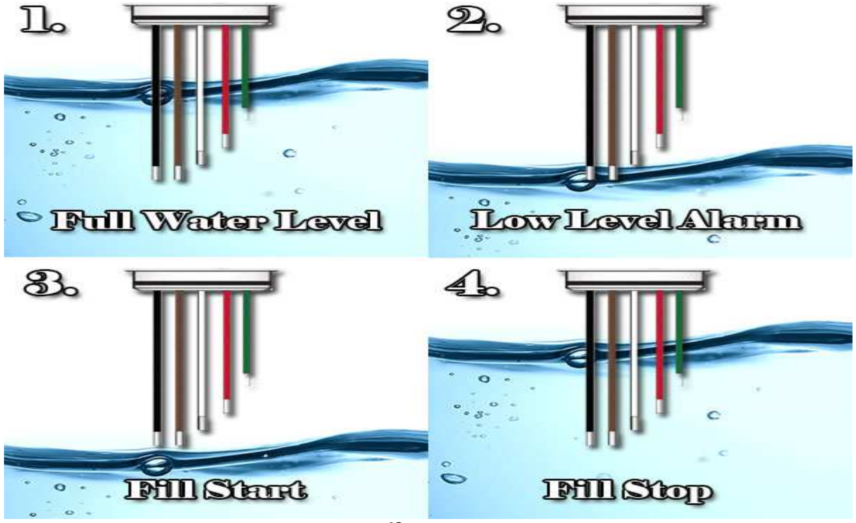


Figure 27: Probe Level Indication[48]

Ultrasonic Sensor

This is a contactless level sensor which uses high frequency wave pulses to measure the water level in the storage tank. It is mounted at the top of the tank pointing down and measures the water level by sending frequency signals from the sensor to the water surface and back. The signal travel time indicates of how much water is in the tank. This controller is the most complex to set-up because it uses a special program that requires the use of ultrasonic sensors and a relay board which consists of many capacitors, circuit boards, resistors, and semiconductors.

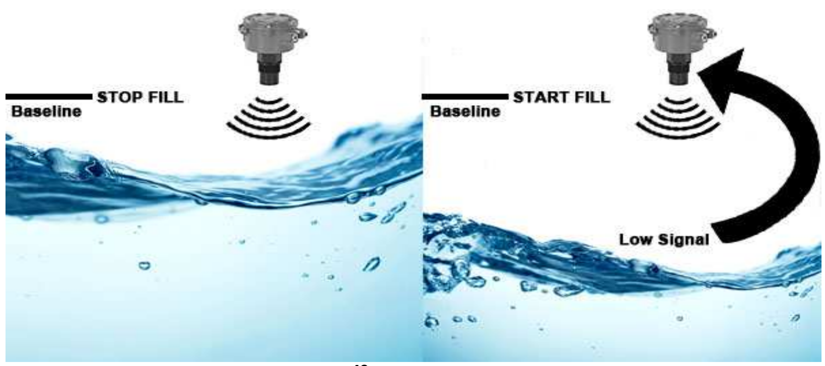


Figure 28: Ultrasonic Sensing [49]

Pressure Transmitter

A pressure transmitter (also called a pressure transducer), converts pressure into an analog electrical signal. Pressure transmitters generally work with 4-20 mA output but are also available with a 0-10mA output. This system measures the water level pressure with electrical signals using a 4-20mA scale and converting that signal into a readable measurement display. A 4mA signal would be equivalent to an empty water tank, and a 20mA signal would imply a fully submerged tranducer or a full tank. Similar to the probe level sensor, except it measures the pressure level in a water tank verses the water level.

The strain-gage is a pressure sensor in the transducer family that measures pressure using stress and strain. It converts force, weight, pressure, tension, etc., into resistance, which can then be measured[50] (See Figure 29) When the strain-gage is compressed by an external force, its electrical resistance decreases. When the resistance increases, the strain-gage stretches. There are thousands of types, each unique to its application.

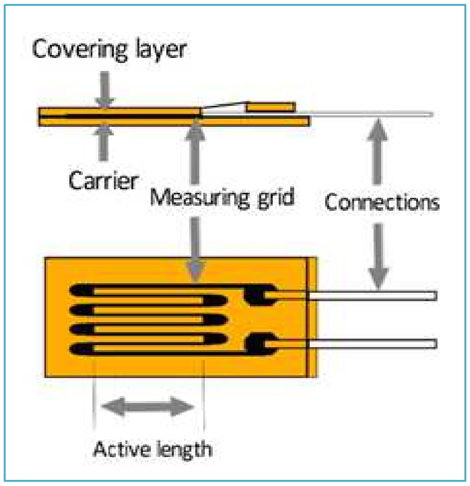


Figure 29: Strain Gauge structure [51]

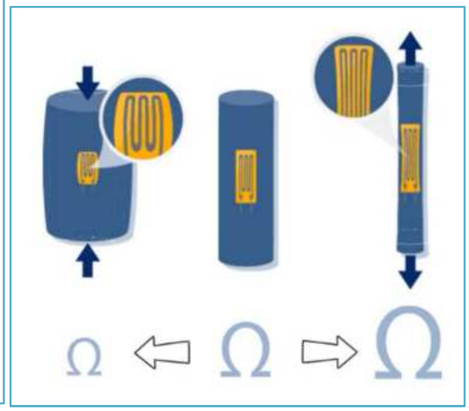


Figure 30: Properties of Strain Gauge [51]

3.5 Water Flow Measurement

Flow sensors are important in measuring and controlling the water discharge flow rate and detecting any clogs in the drainage system. Water flow meter systems typically measure the rate of flow of liquid passing through a point in a conduit or water passageway. It can also collect data to display municipal water usage offsets.

There are several types of flow sensors, each with its own unique design selected depending on the type of application. In this section, we will be covering 3 types:

- Turbine flow
- Electromagnetic flow
- Vortex flow

Turbine Flow Meter

The first type of flow instrument is the Turbine Flow meter, which measures the flow rate using a multiple blade rotor (located inside the tube) and a magnet pick ups connecting back to a controller. As water passes the turbine blades, it causes the blades to turn at a speed proportional to the water velocity. As each blade passes through the magnetic field, an AC voltage pulse is generated by magnetic pick ups which is converted into a reading (as seen in Figure 31). A turbine flow system has a digital flow meter, with an integral LCD display indicating the flow rate and total amount of fluid passing through the meter. Despite cost, this is one of the best types of flow meters.

Figure 31: Turbine Flow Meter [52]

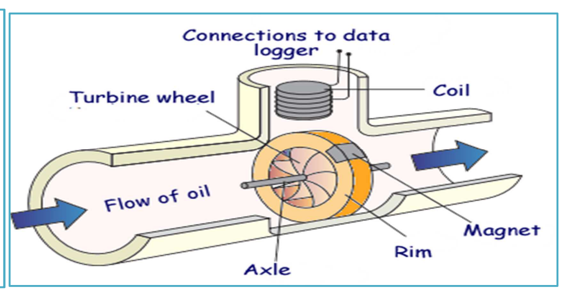


Figure 32: Turbine Flow principle [53]

Electromagnetic Flow Meter

Electromagnetic flow meters have no moving parts and typically measure water flow using electromagnetic fields. Its performance is independent of density, viscosity, temperature and pressure of the flowing water.

Figure 33: Electromagnetic flow meter [54]

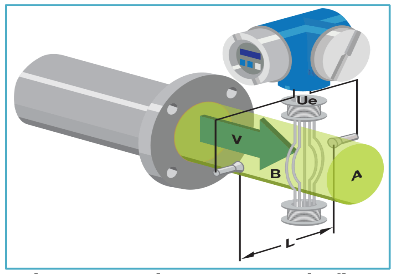


Figure 34: Electromagnetic flow principle[54]

Vortex Flow Meter

Vortex flow meters measure water velocity using a principle called the Von Karman effect, which was invented by a Hungarian Physicist, Theodore Von Karman. This type of flow measurement monitors water flow velocity in one of two ways; through an inductive transducer (as seen in Figure 35) or through a needle-like balancing sensor (as shown in Figure 37).

A vortex flow meter uses an obstruction in the flow of water to create what's called vortices (also called whirlpools or Eddies). The obstruction, called a bluff body, is placed in the middle of the pipe to cause water to separate and form alternating differential pressure. A precise measurement sensor takes these readings. This is called the Von Karman Effect.

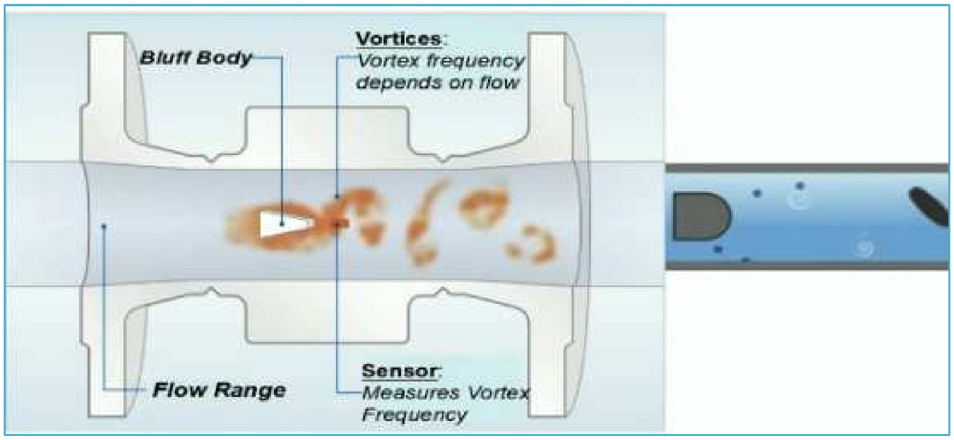


Figure 35: Inductive Transducer Vortex Flow [55]

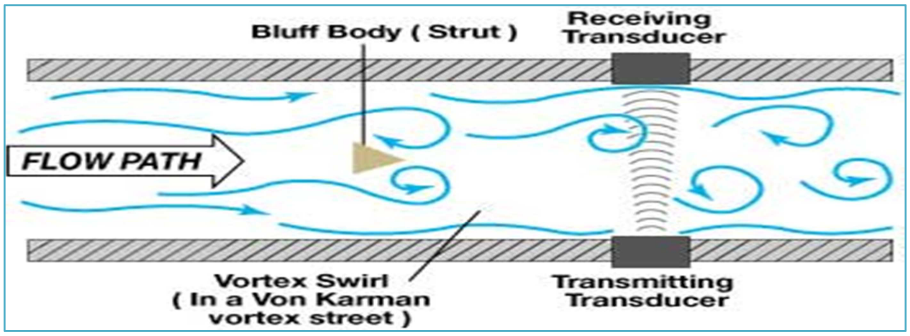


Figure 36: Inductive Transducer Magnetic Pick-up [56]

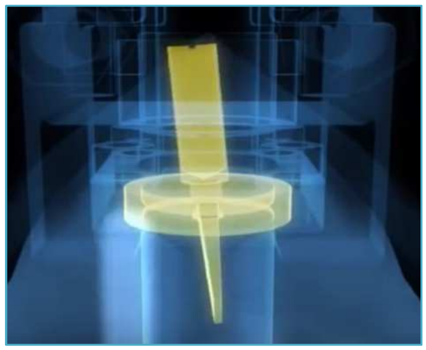


Figure 37: Inductive Transducer Needle Balancing Method [57]

3.5.1. Actuators

An actuator is a type of flow control that converts energy into motion and can also be used to apply force[58]. This means they can be used to control the gate of the storm drain for a blue roof system. There are three main types:

- hydraulic
- pneumatic
- electric

Each actuator is used in different situtations.

Hydraulic

A hydraulic actuator consists of a pump, piston, cylinders and fluid. The fluid is incompressible so when pressure is applied, the fluid moves the cylinder in the axis of the piston in linear, rotary or oscillatory motions. In a pneumatic actuator, it is the same but with pressurized air instead of fluid.

Hydraulic actuator advantages:

- they are durable and are well-suited for high-force applications
- they can hold the force applied without requiring additional pump pressure
- they lose less power than a pneumatic type when located at a distance[59].

Hydraulic actuator disadvantages:

- they can leak fluid, which leads to reduced efficiency and can potentially damage surrounding equipment
- they require extra components such as a fluid tank, noise reduction equipment, release valves, pumps and motors making it more costly [59].

This actuator can be used in a blue roof system where it can be easily accessed for regular maintenance.

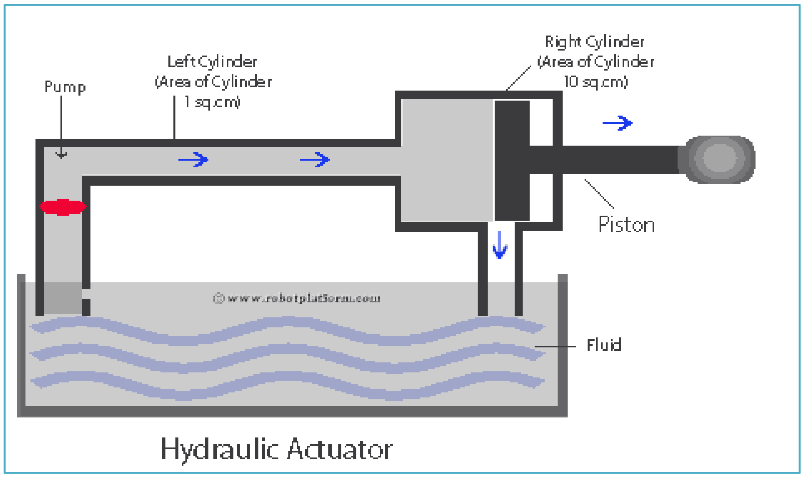


Figure 38: Diagram of a Hydraulic Actuator [59]

Pneumatic

Pneumatic actuator advantages:

- they are simple to use and can offer a high force application
- they are very accurate in linear motion
- they can be used in extreme conditions
- lower cost than other actuators[59]

Pneumatic actuators disadvantages:

- they can lose pressure and air compressibility decreasing performance
- compressed gas is a consumable, so it can add to operating costs and maintenance work[59]

This actuator can also be used in a blue roof system where it is easily accessible for maintenance.

Electric

Electric actuators function using a motor to convert electrical energy into mechanical torque. These actuators are usually used with other equipment such as glove and gate valves[60].

Electric actuator advantages:

- It is the cleanest form of actuator because no oil is involved (such as lubricating the piston)
- They also offer the greatest precision control positioning, are scalable and quiet[59]
- Little environmental impact

Electric actuator disadvantages:

- they are sensitive and not safe to operate in harsh, wet, cold or hot conditions
- the motor can overheat, causing failure
- they are expensive and not efficient to replace[59]

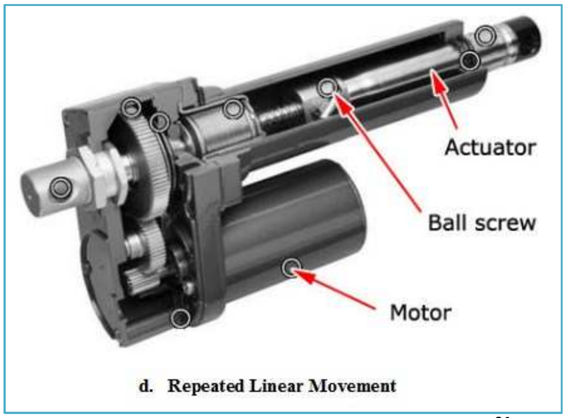


Figure 39: Diagram of an Electric Actuator [61]

This actuator could be used for a blue roof system, if it is located in a controlled environment.

Control Valves

A control valve regulates stormwater retention through communications with other sensors and controllers. They are essential in a self-regulated system. Water pressure and flow in a blue roof system are typically controlled by electro-mechanical devices called flow valves and pumps.

Values and pumps (see Figure 40) are managed by a controller and can only change their states (ON/OFF), when they receive electrical signals from it. In a passive blue roof system, only mechanical valves are needed, but in a self-regulating blue roof system, the mechanical valves are replaced by electrical control valves. If a RWHS has been incorporated, a pump may be necessary to distribute storage water back into the building for reuse.

The valves can either be hydraulic or pneumatic and can be used for inflow or outflow.

Figure 40: Electrical Control Flow Valve[62]

Figure 41: Electric Water Pump[63]

Figure 42: Pneumatic/Hydraulic Actuated Control Flow Valve[64]

There are many types of control valves, including the gate, vortex, ball, butterfly, angle, and globe valves, check valves, pressure reducing valves, and the air release valves (in an RWHS application). The most commonly used valve in a storm water management system is the Vortex Flow Control Valve (see Figure 43) which requires no moving parts or power to operate. During strong flow, water passes through the vortex, which creates back pressure upstream of its discharge. A great feature about the vortex flow control valve is that it allows debris to pass through due to its large opening, making it less prone to clogging.

Figure 43: Vortex Control Valve

3.6 Water Quality Monitoring

Water quality monitoring is important in a Rainwater Harvesting System (RWHS). Water quality systems monitor and control the cleanliness of the harvested water before it is resued in, toilets, irrigation water, etc. Typically these systems are designed to custom fit the application. So the focus of this section will be on the devices and filters incorporated into a system. Further research will be done in the next phase of this project.

An efficient water quality device can detect pH and oxygen levels, and turbidity (cloudiness of the water). In-Situ is a manufacturing company offering equipment to execute the needs for an efficient water quality monitoring system. Waspmote is another water quality monitoring device manufactured by Labellum (see in Figure 44) and it is used for potable water monitoring, pollution levels, corrosion and limescale detection.

Figure 44: In-Situ devices[65]

Figure 45: Waspmote[66]

3.6.1. Instrumentation Networking

It should be noted that any efficient stormwater management system requires a reliable network structure for communication between controllers, sensors, actuators and valves. Typically, all of these electronic devices connect through a local network structure, where communication is enabled through a cable or a wireless network, or a combination of both.

Continuous data is gathered and transmitted as electrical or radio frequency (RF) signals to a controller which is then stored on a local or a cloud server. The controller processes the data and sends commands to the corresponding actuators and valves to execute actions.

Networks may be wired or wireless. Wired networks that rely on power over ethernet (PoE) communications are becoming the preferred method for many applications. Since the introduction of Cloud Data Acquisition, wireless networks are becoming increasingly popular. Wireless methods may include Wi-Fi, satellite, infrared, broadcast, radio, and microwaves. The following tables compare these two methods.

Table 7: Comparison of Wired over Wireless Networks [67]

	Wired Network Structure - Pros	Wireless Network Structure - Cons
Security	• High security, less likely to be hacked	• Requires many combinations of protocols and security measures to achieve a similar level of security
Reliability	• Ethernet is unaffected by the environment and is least vulnerable to EMI (electro-magnetic interference). • Provides fast, constant upload/download speed regardless of the local network size	• Depending on the number of devices and wireless channels on the network, upload/download speed may be impacted • Susceptible to EMI interference (microwaves, cell phones, and high EMF electronics and cables) • Vulnerable to signal loss through walls and floors levels, or connection to ISP
Distance	• 330 ft. run without attenuation or loss of quality	• 250 ft. run at best but may be less through obstructions

Table 8: Comparison of Wireless over Wired Network [68]

	Wireless Network Structure - Pros	Wired Network Structure - Cons
Portability	• Highly portable	• Difficult to move around • May require additional cable and investment
Safety	• Compact use of space	• Potential physical and environmental exposure hazards for cables
Cost	• Can route and trace problems easily	• Troubleshooting may be costly depending on the size of the Ethernet network
Power	• Can function on batteries for a period of time. No power surge concerns	• Requires electricity to function • Does not function if using wired-technology products.
Set-up	• Easy, no cable connections	• Can be complex based on network size

Factors such as the type of application, the environment, and budget should be consider when determining whether a wired or a wireless network is preferred for your application. Wireless is made possible through a system called Wireless Sensor Network or known simply as WSN, which will be briefly explained in the next section.

3.7 CVC's Real-time Monitoring

CVC is familiar with system needs for real-time monitoring of environmental data; it currently operates a network of 58 real-time monitoring stations throughout the Credit River watershed. Parameters such as water level, precipitation, temperature and various water quality variables are collected using sensors and transmitted wirelessly to a server/database system that is used to organize and format the data for analysis. The sensors are programmed using Sutron dataloggers, which defines the sampling schedule and stores the data before it is transmitted using telemetry equipment.

Similar monitoring systems would be implemented for the blue roof, with additional real-time controls to adjust how the roof is operating based on the monitoring information received and expected weather.

4.0 WIRELESS SENSOR NETWORKS

Wireless networks refer to the interaction between two or more electronic devices using wireless methods such as Wi-Fi. A Wireless Sensor Network (WSN) is a wireless network of sensors working together and communicating with a centralized control system, where it monitors and records the environmental conditions for a specific purpose or task, then organizes the collected data. These sensors and instrumentation can work together to create either a simple network base or a highly complex network structure. WSN can measure sensitive environmental conditions like temperature, water quality, humidity, water levels and flow pressure.

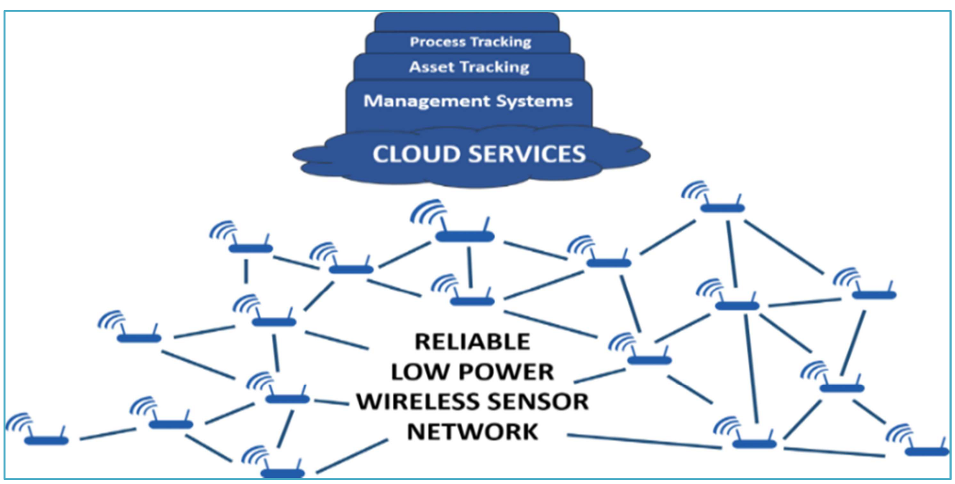


Figure 46: WSN structure [69]

4.1 Distributed Sensor Network

For a more stable network, most commercial/industrial networks use a Distributed Sensor Network (DSN). Imagine a network where all nodes are only connected to one centralized point. If that central node fails, all components and sensors connected to that network will fail. In cases where a strong network is needed (usually in industrial and commercial), a DSN would be recommended for 3 main reasons:

- sensor nodes are prone to failure
- better constant collection of data
- ability to provide nodes with backup in case of failure of the central node

The quality and compatibility of the network with the selected sensors and instrumentations is also important to consider.

5.0 SAFETY FEATURES FOR BLUE ROOF APPLICATIONS

An important element in the design and construction of a blue roof system is the consideration of safety features to reduce risk of system failure. Problems with a blue roof system generally fall into two categories:

- the system drains too slowly resulting in buildup of excess water on the roof for extended periods of time, bypasses of the controlled flow roof drains, or overflow via secondary drains/scuppers during small rainfall events
- the system drains too quickly, exceeding the design release rate [44].

The following safety features are recommended by the NYDEP and NJDEP to reduce the risk of a blue roof system failure.

1. **Leak/flood testing***:* Testing should be conducted during construction (after the installation of the waterproofing membrane and controlled flow drains), and on a regular basis as a maintenance action. The most common technique for leak detection is known as Electric Field Vector Mapping (EFVM), which is a low voltage test method to assist in locating and managing leaks. This testing should be conducted by a trained technician and it is recommended that some type of long-term leak detection system is employed and included in the blue roof maintenance plan[44].

Figure 47: EFVM testing on a roof membrane (American Hydrotech Inc)

2. **Overflow structure (scuppers):** Blue roofs must be designed with an overflow structure to safely convey excess precipitation to downstream drainage systems[36]. These overflow structures (e.g. secondary drains or scuppers) should be included in the blue roof system design to account for maximum ponding depths.

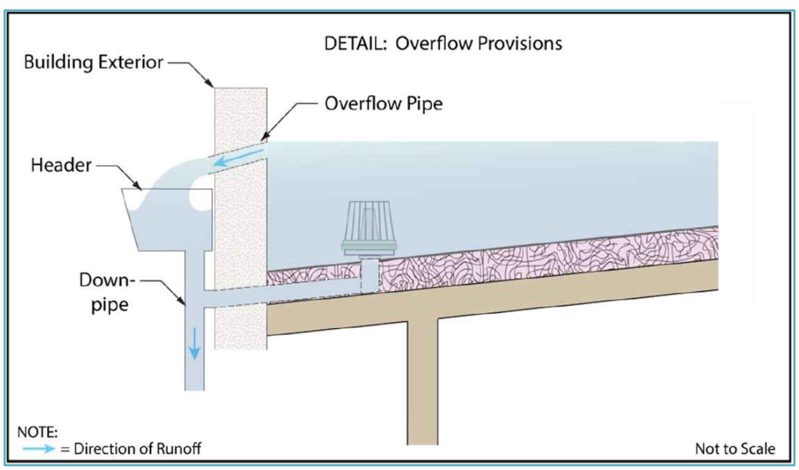


Figure 48: Potential configuration for an overflow structure used in blue roof applications[36]

3. **Screens or covers for roof drains**: To prevent leaves and other debris from entering and clogging roof drains, each drainage inlet should be equipped with a screen or cover that completely encloses the inlet. (Figure 51) Clogging can significantly alter the relationship between water depth and flow rate, diminishing system performance. It may also shorten system lifespan. Monitoring frequency may need to increase if clogging becomes chronic. These type of screens or covers are commercially available in various diameters to fit common drain sizes. Blue roof drains should be located away from overhead trees if possible.

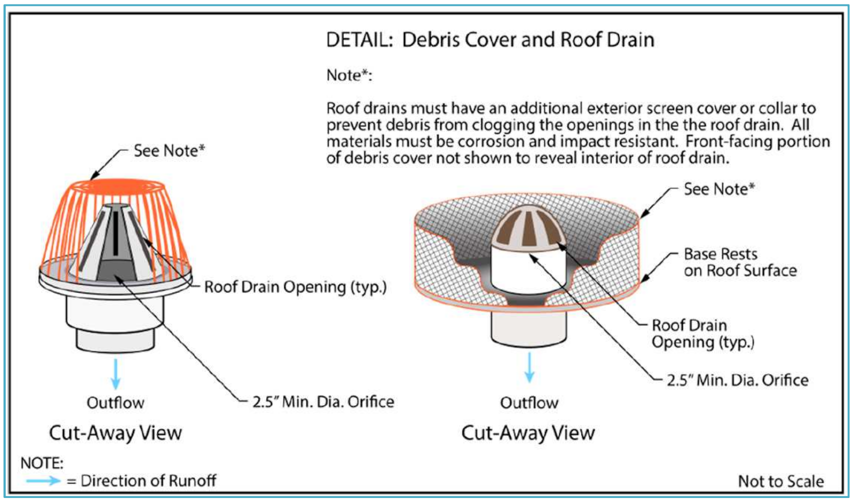


Figure 49: Detail of a exterior screen cover to prevent leaves and other debris from entering and clogging roof drains[36].

4. **Construction inspections:** The following inspections should be performed under the supervision of a licensed professional:
   - Building structural system and roof deck
   - Leak/flood testing of the roof membrane system and drains after installation
   - Verification that the controlled flow roof drains and screens have been properly installed
   - Testing of the roof drainage system's connection to the sewer

5. **Loads and structural capacity**: Blue roofs may add a significant amount of weight to a roof including the dead load of the blue roof components, as well as the added live loads as a result of rainfall, maintenance personnel, and equipment. An analysis of the structural load capacity of the roof is a crucial consideration and should be performed by a licensed professional. Analysis for deflection, which describes the degree to which a structural element is displaced under a load, is particularly important for roofs where ponding instability may occur near the drain[38].

6. **Waterproofing membrane:** Care must be taken during construction to ensure that the waterproofing membrane is not damaged. Seams, corners, penetrations, mounts or platforms for mechanical utilities, and any other areas of the roofing membrane where risk of leakage is highest, must be inspected for damage or failure and repaired in a manner consistent with the membrane material, including adhesives. Waterproofing and associated flashing should also be protected from damage due to abrasion, puncture, and ultraviolet light. Geotextile can be used to protect the field membrane from punctures associated with normal use, including maintenance. Access to the roof should be limited to maintenance needs only.

7. **Roof equipment:** Locating mechanical equipment on raised pads will reduce the extent of roof penetrations and flashing required. If structures and equipment are mounted directly on the roof within the area intended for ponding water, it may be necessary to provide additional waterproofing around the structure or equipment or to elevate the equipment above the anticipated maximum water depth to prevent damage and provide maintenance access. The loss of storage volume due to any objects on the roof must be considered during design to ensure that the blue roof functions optimally[36].

8. **Climate considerations***:* Drains clogged by snow and ice accumulation prior to a rain event should be removed to prevent possible overloading and damage to the roof. The same removal methods used for conventional roofs can be employed[38].

9. **Other considerations:** No standing water may remain on a blue roof 72 hours after a storm in order to allow for sufficient storage for the next rain event. Additionally, storage in excess of this period may render the blue roof ineffective and may result in anaerobic conditions, odor, water quality, algae, waterfowl and mosquito breeding issues[36]. An alternative to effectively and automatically control when and how to store or release water, is to enhance this infrastructure with CMAC.

6.0 BLUE ROOF OPERATION AND MAINTENANCE

Blue roofs must be inspected and maintained in order to function optimally[38]. Safe and easy access must be provided for trained building personnel to permit removal of debris under saturated conditions[37].

The operation of the blue roof system should be monitored at minimum, for the first year after installation to determine the effectiveness, appropriate maintenance activities and/or system modifications to ensure the system functions as intended.

6.1 Inspection and Maintenance Plan

Developing an inspection and maintenance plan is crucial to the success of a blue roof system and should be updated based on the results of the first-year post-construction monitoring. "The plan should include a maintenance schedule developed for the life of the rooftop system. The specific maintenance activities that are required to be completed, the frequency, timing and the person or entity responsible for completing the activity should be included" [38].

6.2 Recommended Inspection Activities

"Inspections are particularly important within 24 hours of significant rain events to ensure the specified ponding depths and drain times are being achieved, standing water does not persist for more than 24 hours, and there are no leaks as a result of roof conditions"[35]. Table 9 outlines regular inspection activities and their frequency.

Table 9: Recommended inspection activities for blue roofs [38].

Schedule	Activity
Semi-annually under dry conditions	• Inspect roof drain inlets to ensure in good condition. • Inspect drain inlet screens/covers and scuppers to ensure in good condition. • Inspect roof membrane to check for signs of deterioration.
Quarterly and after rain events	• Inspect roof to verify achievement of water depth and drain time requirements. • Inspect secondary drainage inlets for blockage or debris.
After snow/icing events	• Check roof drain inlets for blockage caused by buildup of snow or ice.

6.3 Recommended Maintenance Activities

"Maintenance activities for blue roofs should focus on preventing clogging of drainage inlets and deterioration of the roof membrane"[35]. In addition, adequate maintenance of the secondary drainage system is essential to ensure its performance in the event of a failure of the roofing system.

The rooftop system and membrane should be evaluated every 20 years to assess the need for replacement. Maintenance access points should be clearly identified in the plan for the system. In addition, any special training required to perform specific tasks should be included in the plan.

Table 10: Recommended Maintenance Activities for blue roofs[38].

Schedule	Activity	Equipment
During inspections or as needed to ensure performance	• Remove debris from drainage inlets and inlet screens to prevent clogging. • Remove debris from secondary drainage inlets/scuppers.	• Shovel
Winter considerations	• Break up ice formation around inlets	• Ice pick or equivalent tool

6.3.1. The Internet of Things and Stormwater Management-Real-time Controls for Blue Roofs

The Internet of Things (IoT) is a network of devices that performs real world actions. While the internet consists of data exchanges between a networked computers, tablets and phones, the IoT can include any electronic and mechanical device that can connect to the internet including coffee makers, door locks, fridges, rain gauges, and solenoid valves[70].

Once the network has been made and connected to the internet, IoT assembles the exchange of information to perform tasks. For example, IoT can support turning on lights when a door is opened. Applicable to this study, IoT can drain a blue roof or a rainwater harvesting tank to make space to retain an incoming storm event. According to Gartner in 2015, 33% of businesses planned to or were using IoT, while 25% of businesses considered doing so. To date (2018), 85% of global organizations are considering an IoT strategy for their business. IoT offers a number of benefits including:

- affordability;
- supports more powerful and smaller hardware;
- ubiquitous and cheap mobility;
- availability of supporting tools; and
- mass market awareness[70].

With IoT constantly evolving and businesses becoming more reliant on smart technology, businesses will be able to use IoT to advance and adapt more quickly to competitive changes[71]. According to a survey done by International Data Corporation, the leading reason companies are using IoT solutions is more efficient use of energy, money and time[72], because IoT platforms can manage mulitiple devices simultaneously.

The application for blue roof or storm water management systems, means IoT can manage operational services, prevent waterlogging, increase security, turn a passive system into a dynamic or active control system and make monitoring and management easier.

Internet of Things

The Internet of Things (IoT) is the technology that enables these improvements, the technological movement that promises to build the next generation of interconnected and smart buildings and cities.

An IoT system requires a solid infrastructure to function and the four major components are hardware, communication, software backend and applications. All of these components fall under security (IoT Analytics, 2015). According to AT&T "An IoT platform is a suite of software components that enables connection and information exchange between IoT devices and IoT applications" [73].

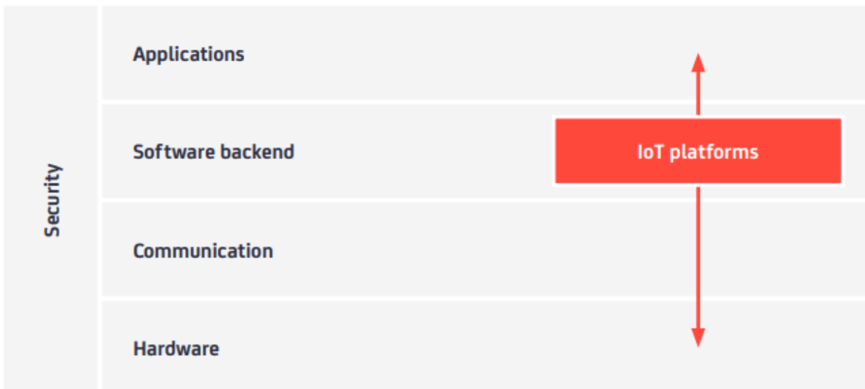


Figure 50: Infrastructure of an IoT system [73].

IoT Platform Building Blocks

An IoT platform in its most simple form is connectivity between objects, however, the true end-to-end IoT platform consists of the following eight architectural building blocks [73].

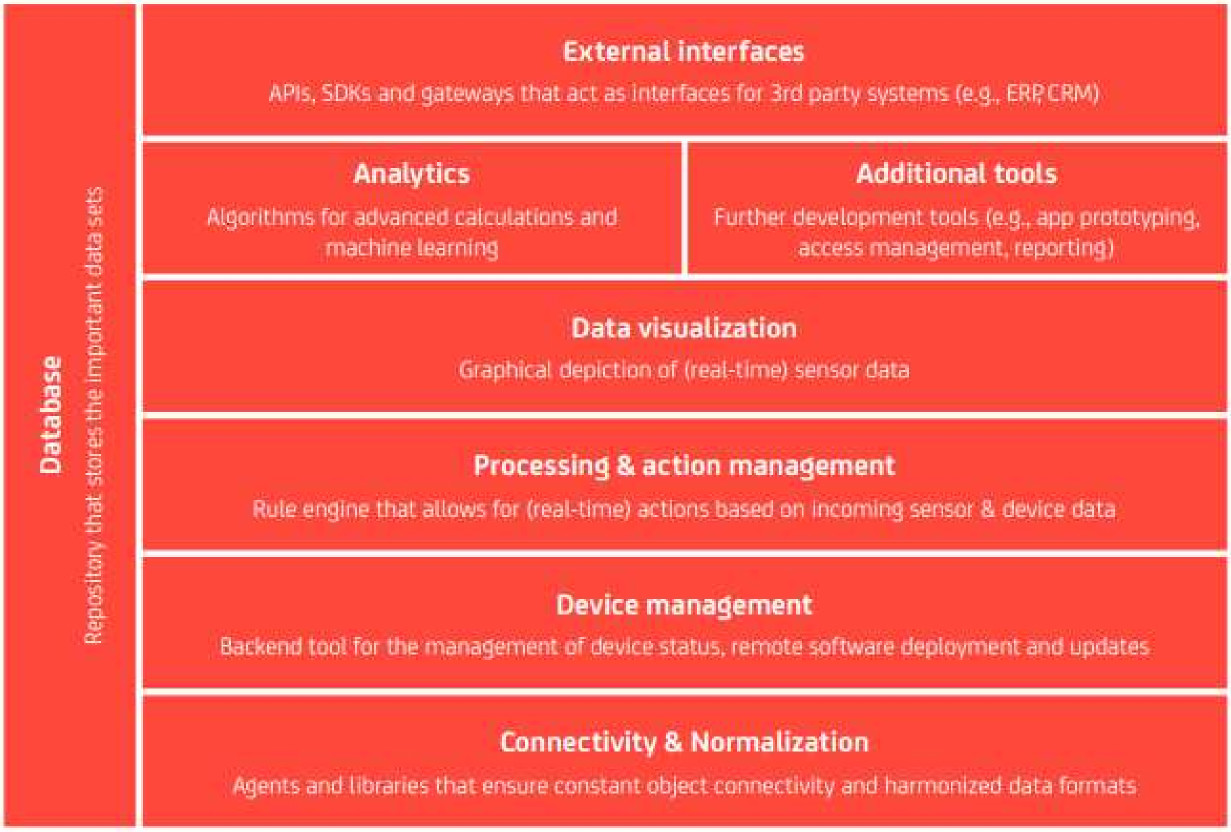


Figure 51: The eight components to a complete IoT platform[73]

- **Connectivity & Normalization**
  Every IoT platform requires this module. It brings different protocols and data formats into one software interface, allowing for easy monitoring, analyzing and management.

- **Device Management**
  The device management module ensures objects are connected properly and its software and applications are running/working and are current.

- **Processing & Action Management**
  The data from the database gets processed here and a rule-based event-action-trigger allows performance of "smart" actions based on the data.

- **Data Visualization**
  The data visualization module or visual analytics, puts data into a format that may include charts, graphs or 3D models for easier interpretation.

- **Analytics**
  Analytics performs dynamic calculations of sensor data from basic data clustering to more advanced machine learning.

- **Additional Tools**
  The IoT platform may offer additional tools for developers and managers. Developer tools allow for prototyping and testing the cases, while management tools support daily operations of the solution.

- **External Interfaces**
  Businesses are rarely built on a stand-alone IoT. They incorporate other systems, e.g. Building Management Systems.

- **Database**
  Databases all have three major requirements: volume (the amount of data that can be stored), variety (different forms of data), and velocity (how fast it streams data) [74]**.** Databases usually come in a cloud-based form for IoT Platforms and they can store Standard Query Language (SQL) and NoSQL data [73]

IoT Platforms Selection Criteria

When choosing an IoT platform for your project, constraints and needs must be factored in. There are many different types of platforms, each offering different benefits. Consider these factors when choosing an IoT platform[75].

Scalability: The network needs to grow as the load grows.

Customization: Consider if your IoT solution requires freedom in customization and tuning of products to your needs.

Reliability: For stormwater management, reliability is key. You must be able to check the systems health status, provide solutions for problems and in complete failure, disaster recovery capabilities.

Protocols: Some protocols are tailored for sensors and some are not. When considering your IoT solution, consider the type of devices you are using and run the correct protocol. See Appendix B.1 for a list of sensor-friendly IoT protocols.

Security: Security plays a big factor in any type of online network project. If the network is not secure, then hackers will have easy access to manipulate data. According to Ayla Networks[76], there are seven key functions to consider:

- **End-to-End Security Mechanisms**
  Mobile applications and connected devices need to be separately authenticated and must pass authorization. Device identity is best maintained in hardware by burning the credentials of the device into its connectivity module**.**

- **End-to-End Data Encryption**
  The best way to encrypt data end-to-end is to have it encrypt automatically before it is sent to the database.

- **Access and Authorization Control**
  This gives users different levels of data access**.**

- **Activity Auditing**
  IoT platforms should keep log records of who was authorized or attempted to be authorized so that any breaches can be traced to its source**.**

- **Hardened Cloud Infrastructure**
  Hosting data on cloud could be safer than having data elsewhere. ISO 27001 is a security certification that specifies security management best-practices and comprehensive security controls for datacenters and other environments**.**

- **Equal Protection Across Multiple Protocols**
  Devices may communicate over Wi-Fi, ZigBee or Bluetooth, and other wireless (and wired) protocols. Security should be equally strong between al of them**.**

- **Education**
  Human error is the greatest factor to cybersecurity vulnerability. Vendors should teach consumers through web pages or customer service desks about why security is important**.**

Cost: After considering the previous and knowing what you need, you must consider if your budget allows you to go proprietary or open source. Additionally, using IoT also reduces operating costs due to efficiency[75]**.**

Support: Keep in mind that proprietary platforms offer a dedicated customer support for consumers that are having trouble while open source only has the assistance of fellow users, although sometimes user inputs are better than customer support[75]**.**

7.0 OPEN SOURCE VS. PROPRIETARY VS. HYBRID PLATFORMS

There are three types of IoT platforms each with their own benefits: open source, proprietary (commercial) platforms and hybrid systems.

7.1 Open Source IoT Platforms

Open source (or free) software implies access to the source code for IoT platforms.This means anyone can change or upgrade it and it becomes theirs. This fosters innovation and allows more freedom.

Though open source platforms are free, payment is required to access extra features[77]. These platforms include but are not limited to ThingSpeak, Siemens Mindsphere, SiteWhere, DeviceHive, Zetta, DSA and Thingsboard io. A few platforms have potential application for storm water management systems. See Appendix B.2 for a sample list.

7.2 Proprietary IoT Platforms

Proprietary IoT Platforms are fee based, are typically billed monthly and are primarily for commercial use[78].

Proprietary platform service providers include Amazon IoT, Google Cloud IoT, Microsoft Azure IoT, Thingworx (PTC), IBM Watson, Cisco Cloud Connect, Artik Cloud by Samsung, Alya Network, Sap

Leonardo and many others. See Appendix B.3 for a sample list of platforms that have potential application for stormwater management systems.

7.3 Hybrid Platforms

Depending on project needs, a proprietary or open source platform may not be required. If vendor lock-in or frequent transfer of data from device to cloud is not needed, then a hybrid approach such as a serverless IoT solution is an option[75.]

A serverless IoT solution uses a combination of IoT platforms for different functions[75].For example, an open-source platform for data gathering and storage, a proprietary platform for control functions and a different proprietary platform for data analytics. In this way, businesses can transform all capital expenditure into operating expenditure**[75].** The custom serverless solution also reduces operating, development and deployment time and costs[75].

Table 11: Comparison between between open source, proprietary and hybrid platforms
X denotes has criteria; Y denotes capability to have criteria

Criteria	Open Source	Proprietary Source	Hybrid
Scalability	X	X	X
Customization	X		Y
Reliability	X	X	X
Protocols	X	X	X
Security		X	Y
Cost	X		X
Support		X	X

A hybrid platform is recommended for a blue roof system because of the complex systems and functions within a blue roof project. Open source can be used for data gathering because communication costs can add up for a proprietary platform, while anything that is private with a proprietary platform. Existing software for blue roof projects could be used (OptiRTC), if the project requires customization new software can be created.

7.3.1. Disadvantages of Continuous Monitoring and Adaptive Control (CMAC)

Some potential hurdles to advancing the adoption of CMAC exist including local integration with large urban systems and cyber security.

Local integration with large urban systems: One of the largest challenges relates to the design of stormwater management solutions as single entities, without considering the complex spatio-temporal dynamics that govern stormwater flow and quality across large urban areas [21].

This implies that benefits achieved at a local scale may often be masked or eliminated at the city scale if the performance of an individual element is not designed in a broader system context (Kerkez et al., 2016). Regional implementation of many distributed CMAC systems will require potentially complex and careful logic implementation to ensure that unintended consequences are minimized[21.]

Cyber Security: An important consideration for real-time stormwater control. Kerkez et al. (2016) mention that "failure to recognize, plan for, and manage the ongoing cyber security risks introduced by the distributed installation of sensors and actuators in stormwater infrastructure will result in new risks to public health and safety, which may undermine trust in broader efforts to deliver the potential benefits of these technologies". Also, as with many controlled systems, there may be an inherent risk to infrastructure, private property, or even human life due to poorly designed control algorithms [20].

7.3.2. Continuous Monitoring and Adaptive Control in Action

Villanova University implemented CMAC in existing green roof SWM infrastructure. A cistern that collects runoff from a non-green roof is dynamically connected to the green roof to enhance its evapotranspiration capacity. The cistern includes a water-level sensor, actuated valve and connection to the cloud-based decision software. Findings from this study demonstrate that CMAC maximizes runoff capture from the non-green roof and optimizes irrigation to the green roof.

New York City demonstrated that a CMAC approach can be applied to a conventional rainwater harvesting system[21]. Performance was improved by minimizing discharge to the combined sewer during rainfall events and reducing municipal water use for irrigation of local vegetation while optimizing vegetation health.

The advanced rainwater harvesting system proposed in this study was connected to a CMAC platform, powered by OptiRTC (Opti Boston, MA, USA), a technology company that specializes in cloud-based software that optimizes stormwater systems. Findings from this study demonstrate that "recent advances in technology through CMAC can provide significant performance improvements over conventional rainwater harvesting systems in both water conservation and runoff control"[21].

8.0 INTEGRATING SERVICES INTO BUILDING MANAGEMENT SYSTEMS

8.1 Introduction

A Building Management Systems (BMS), also known as a building automation system (BAS), is a computer-based control system that monitors and manages equipment such as lighting and cooling systems. It is a critical component to managing energy demand.

There is an opportunity to increase efficiencies by integrating blue roofs with existing BMS through the use of programmable controllers. Implementation can be done on several different levels that vary in complexity and functionality. These include:

- No integration
- Monitoring only
- Monitoring and configuration
- BAS plus-in using Cloud
- BAS with Algorythm

For additional detail on the features of each please see Appendix D Supporting information for the integration of building management services with controllers.

8.2 Introduction to Programmable Controllers

A programmable controller is an electronic and digital processing device that monitors and manages building functions. The controller does this for the sensors and actuators in the blue roof system. Data on conditions like temperature, wind speed, humidity or solar radiation, are relayed to the controller, which then initiates particular operations according to its programming. This could mean functions particular to the blue roof like operating values to manage flow from the roof to the drainage system or managing other functions associated with the BMS including building heating.

8.3 Benefits of Controllers Integrated with BMS

The external conditions data is already being processed by the controller, so integrating the controller with the BMS can create a more responsive and efficient building operation, including but not limited to heating, ventilation and air conditioning functions.

8.4 Communication Protocols

Protocols are the communication rules between different devices. Each device requires specific rules in order to work properly. The controller must support the protocol that the BMS requires.

The BMS software program can be proprietary, using such protocols as C-Bus or Profibus or it can integrate the use of Internet protocols and open standards such as DeviceNet, SOAP, XML, BACnet, LonWorks, and Modbus.

8.5 Controller Options

There are four types of controllers, all of which can operate a rainwater management system. Some are designed specifically for this purpose while others offer basic functionality:

- Programmable Logic Controller (PLC-based)
- Programmable Automation Controller (PAC-based)
- Micro Controller

8.5.1. Residential Controller PLC-based Controllers

The Programmable Logic Controller (PLC), has been widely used for basic industrial and general building control automation and water and wastewater treatment applications. The rugged hardware of PLC-based systems allows for use in extreme environments. Despite their broad acceptance, they are not designed to optimize automation systems with higher-quality measurements.

8.5.2. PAC-based Controllers

This is where a programmable automation controller (PAC) can help. A PAC combines the functionality of a PLC and a PC. It natively supports advanced functionality like vision, high-performance analog measurements, human machine interfaces (HMI's), or (field programmable gate array (FPGA) technology[79]. There are a number of PAC configurations. See Appendix C for more details.

8.5.3. Microcontrollers

Open-storm system[80] is an open-source system developed by the University of Michigan. It is an industrially rated platform that allows analog and digital sensors to transmit data wirelessly over a cellular network. It is able to withstand harsh environments better than other open-source hardware platforms like Arduino or Raspberry Pi. Open-storm provides the design of their open-source system for a microprocessor-based controller, including hardware and firmware.

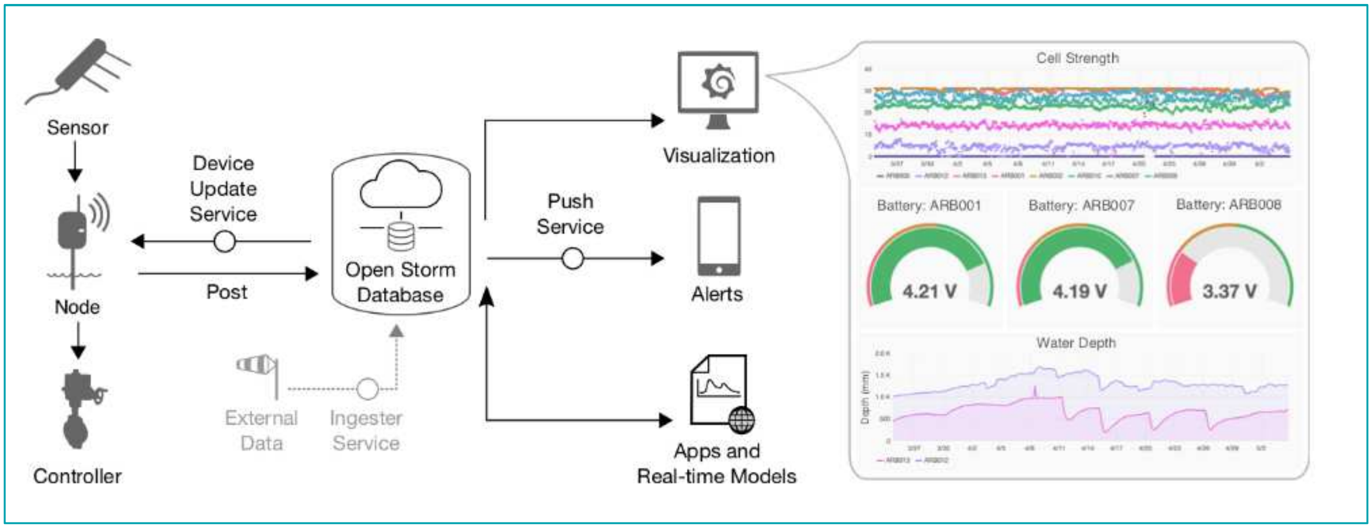


Figure 52: Open-source system: Open-Storm cloud4.

8.5.4. Controllers and Rainwater Harvesting Systems

While this study focusses on the IC&I sector, controllers for residential rainwater collection systems have been piloted and can inform application to an ICI market. Studies completed in the residential sector focus on the automation of rainwater collected through rainwater harvesting tanks (as opposed to blue roofs). An example of a controller that has been used is the RWA-Automation Controller package. The RWA-Automation Controller[81] supports a rainwater collection system through use of a controller, remote display, rain sensor and power supply. Figure 53 illustrates a typical controller system. For retrofitting buildings with blue roofs, there is opportunity to develop software that can integrate the automation of the system with existing building control infrastructure.

Further information on a recent residential pilot study that used IoT in concert with rainwater harvesting can be found in Appendix E.

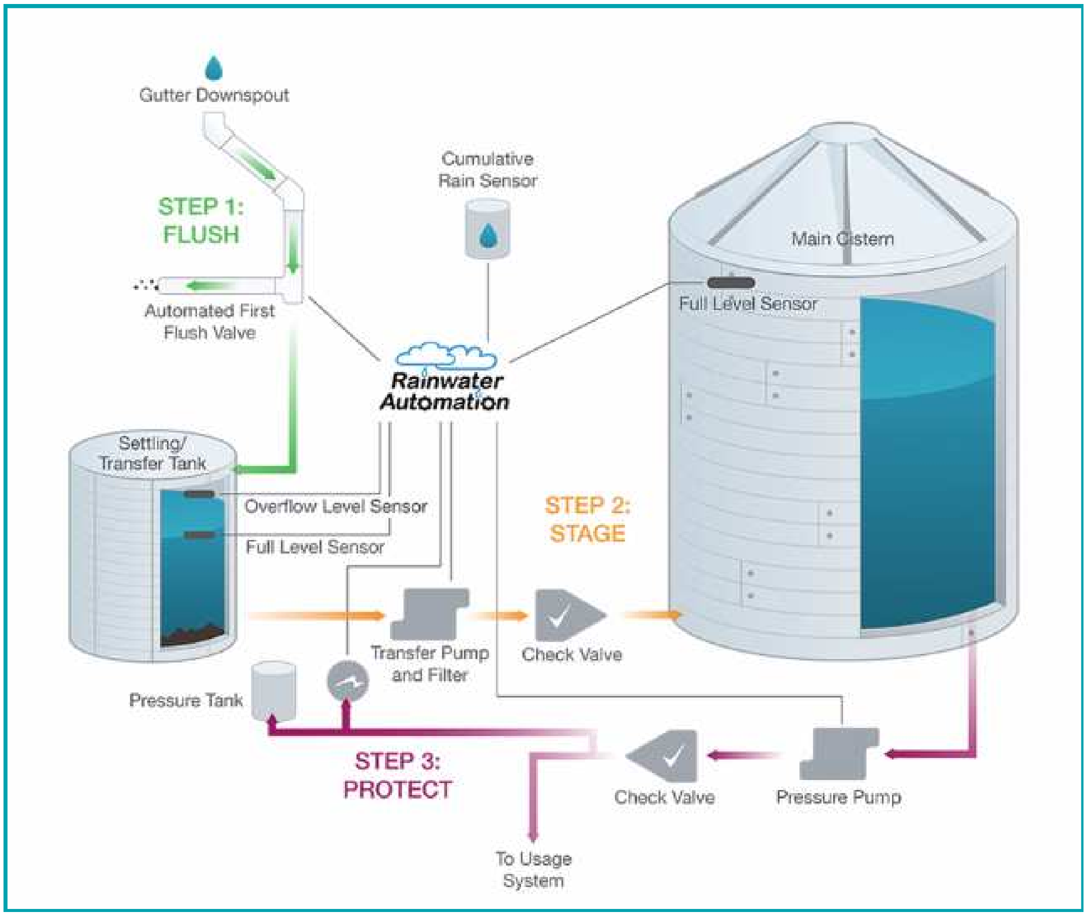


Figure 53: RWA-Automation Controller; Typical blue roof / rain harvesting system structure
Source: Rain Harvesting Supplies Inc.

9.0 COUPLING RAINWATER HARVESTING SYSTEMS WITH AUTOMATED BLUE ROOFS

9.1 Design Goals

Typically rainwater harvesting systems for non-potable use consist of the following main functions:

- Collection
- Primary and/or First Flush Filtration
- Storage
- Secondary Filtration
- Bypass Overflow
- Reuse/Discharge

9.2 Active Rainwater Harvesting

In the instance of active rainwater harvesting, the functions performed by a passive blue roof are complimented by the addition of a level sensor (pressure transducer, ultrasonic, capacitive), an electrically actuated valve, as well as weather forecasts and an algorithm to manage the water storage in real time.

10.0 COMPONENT DESCRIPTION

The following is an overview of the components required for real-time control of a blue roof rain harvesting system (see Figure 53)

- Level sensors measure volume of water stored on the roof and in the tank, and the flow to/from the container can be calculated by measuring changes of volume over time
- Filters on the intake from the roof keep leaves, dirt, pollen, and other particles out of the system
- Calming inlet avoids disturbing the sediment at the bottom of the tank with new water rushing in
- Automated roof drain valves control flow of water from the roof into the storage tank
- Sump pump is an additional water source, status signal from it allows controller to differentiate between sump water and rain water filling the tank and calculate reclaimed volumes separately
- Both roof and tank have a passive overflow intake to prevent overfilling even in cases of system failure
- Backflow preventer stops sewer water from going into the system
- Flow meter is used on the reclaimed water output of the tank to directly measure reclaimed volume
- Total volume change over time measured by level sensors, direct measurement of outflow, and status information from sump pump allows calculation of all the flows in the system: outflow, inflow from rain, inflow from sump pump
- Controlled overflow valve can be included to be able to drain roof directly into the overflow storm sewer for additional benefits
- First flush during rainstorm washes dirt and contaminants off the roof, this can directed to the overflow instead of clogging the main filter and going into the storage tank
- When both the roof and storage tank are still full from the last rainfall, the roof can be drained slowly to create more storage volume in the tank for the next storm. If the water is released quickly, it introduces a high peak flow.

11.0 COMPONENT DIAGRAM

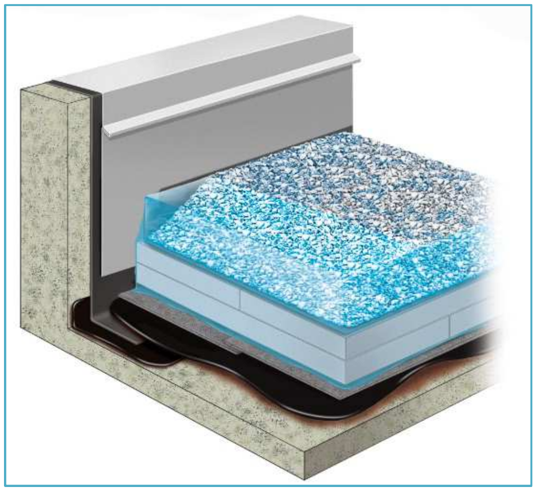


Figure 54: Blue Roof Cross Section
Courtesy American Hydrotech Inc.

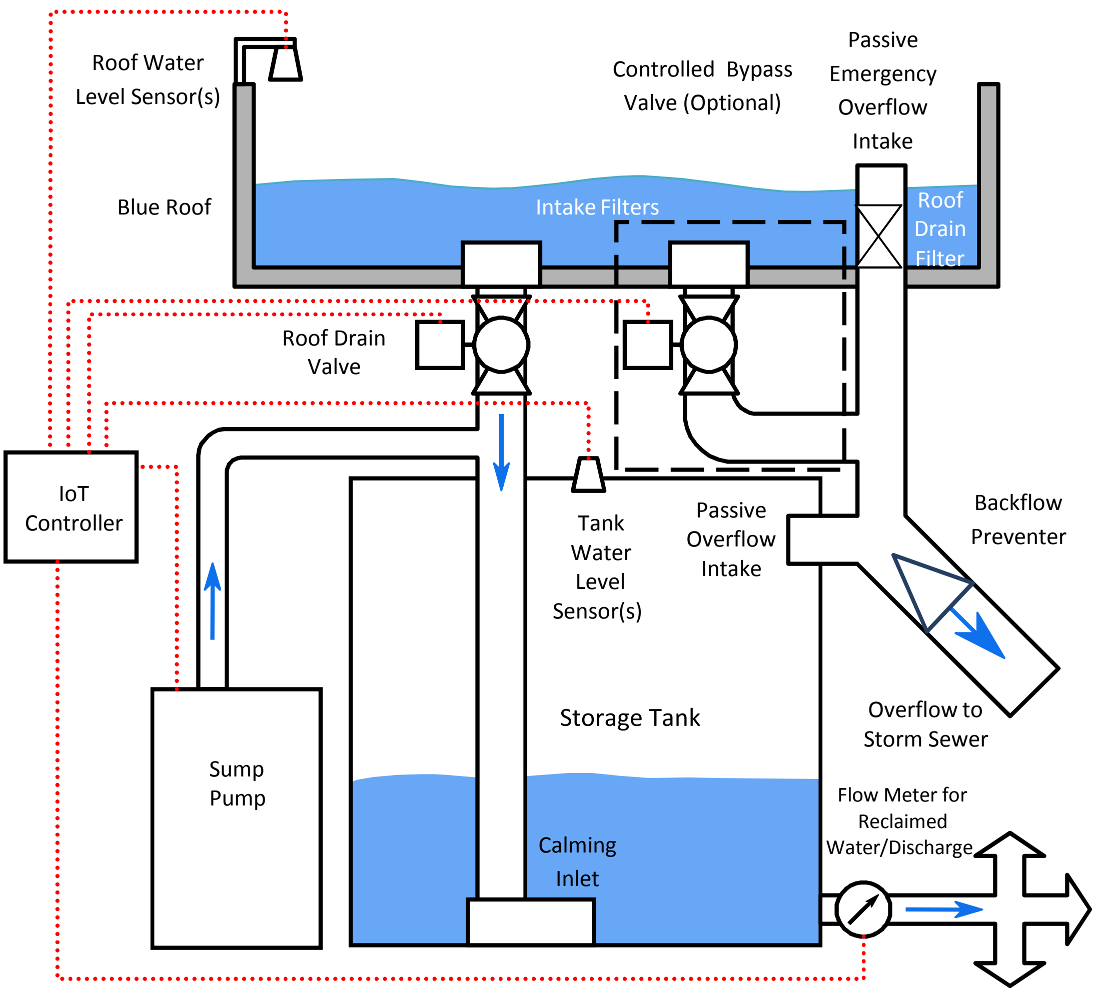


Figure 55: Schematic of System Integration. Source: RainGrid 2018

11.1 Requirements for Integrating the Two Systems

Integration of a blue roof with a rain harvesting system begins with the sizing of the cistern for the required uses. The typical purpose of a cistern is to feed either interior building envelope non-potable demand (toilet flushing, cleaning, cooling tower make up), or exterior demand management requirements (irrigation, fountains, ponds, water features). A tertiary demand may be environmental flows in the form of groundwater recharge, or the reduction of stormwater discharges from the property. These calculations are correlated to the volumetric source of supply, typically the roof area draining to the cistern, which may provide either a greater or lesser volume than necessary to meet the demand requirements depending on the seasonal rainfall patterns.

Integrating a blue roof into a rain harvesting system is predicated on the necessity to store greater volumes of water to accommodate these operational demands than a cistern can be sized large enough to manage, or where space considerations limit the size and location of the cistern.

This section will highlight the opportunities of sensors and instrumentations, controllers and the integration with BMS and IoT platforms.

11.1.1. Sensors and Instrumentation Opportunities

Securing Building Integrity

Blue roof water level and flow monitoring/controlling capabilities work in harmony with the BMS to provide the status on the amount of water stored on the blue roof. This information is key to preventing undue stress on the overall structure. The system's controller knows exactly how much water is stored on the rooftop and will take appropriate actions.

During rainstorms when the blue roof reservoir is nearing maximum water capacity, water level monitoring sensors will begin sending electrical signals to the main controller. The controller signals the main rooftop drain valve to open accordingly, preventing the structure from overflowing. If this system fails or is overwhemed, scuppers will ensure the ponding depth does not exceed design specifications.

Controlling and Monitoring Water Reuse

It is then the job of the water flow monitoring system to regulate the rainwater that has entered the system, the flow pressure within the system, and how much water enters and exits in certain points of the system by using valves and flow pressure sensors.

If the intent is to re-use the collected stormwater, the integrated RWHS would require a water quality monitoring system. Water quality monitoring allows the blue roof system to provide non-potable water for the entire building.

11.2 Controllers and Integration with BMS Opportunities

Simplifying

Integrating the BMS with the controller as the interface means the controller becomes the central device that processes all received data from remote sensors and BMS. Remote control and monitoring make it easier for the operators or maintenance workers to manage the system. If a programmable automation control (PAC) is used, it can analyze the data but also learn patterns. For example, the system will learn from the previous weather data and predict the next operation before the next rain event.

Efficiencies

Integration saves money and maintenance time as the controller fulfills duties normally done by humans. The system can be designed to be scalable, especially if using open protocols and a scalable platform. An automated system can also be operated 24 hours per day, so that important operations are not missed during a rainfall event. It is more difficult to control for 24 hours per day using humans for all operations.

11.3 Real-Time IoT Opportunities

The Internet of Things offers three significant benefits the operation and maintenance of blue roofs, including:

- Remote real-time access
- User friendly platforms
- Improved efficiency

Remote Real-Time Access

As seen in Figure 56, all devices are connected within an IoT network allowing for efficient management of them. IoT platforms come with additional tools for management and development, this can help customize interfaces that manage these systems and devices. This interface allows real-time viewing of the status of your system and remote control on/off of devices which increases energy efficiency.

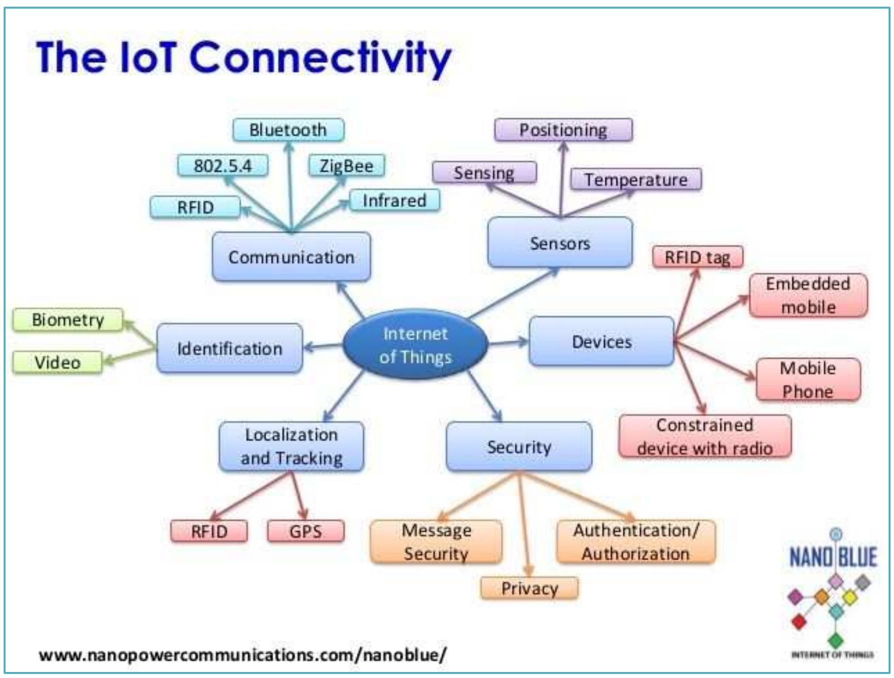


Figure 56: IoT Connections. Source: Nano Power Communications

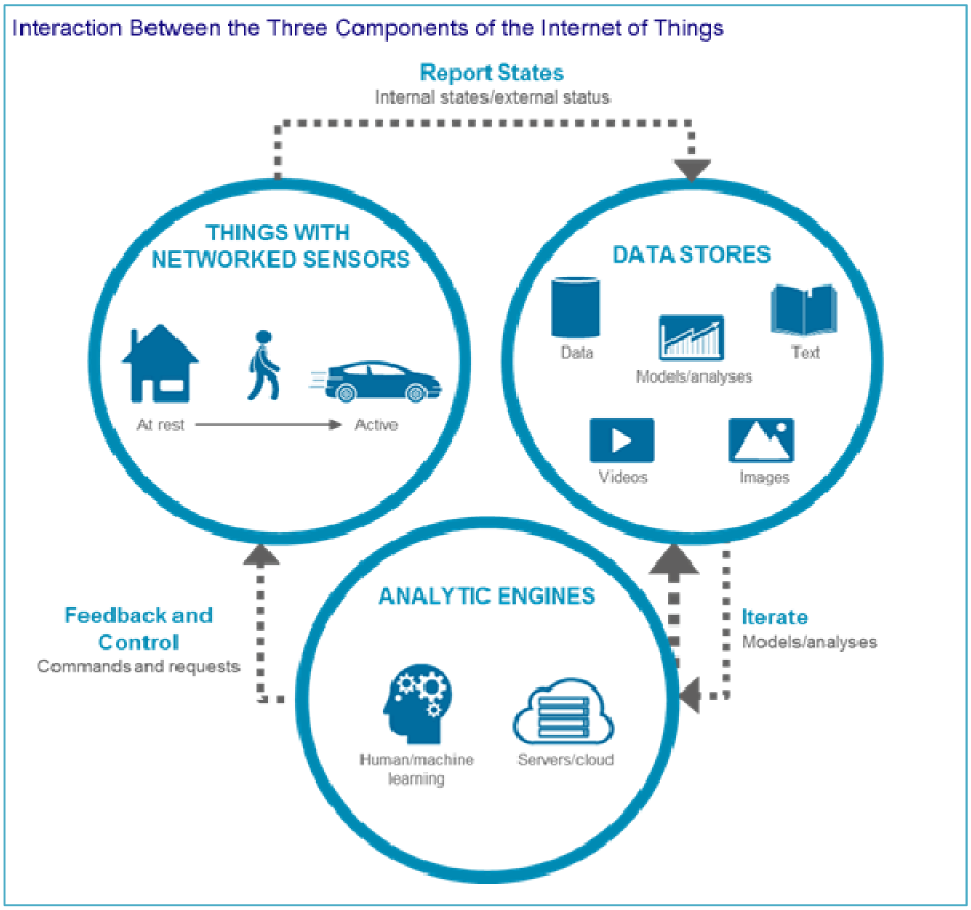


Figure 57: Interactions of IoT. Source: Celent

Metrics and Analytics

IoT platforms usually come with their own cloud storage database for easy access and analysis. The data can be depicted visually, allowing easier interpretation and learning.

SMART Systems

IoT platforms offer a machine learning function, which will help in the evolution towards a smart system. A smart system facilitates pattern learning and adaptation to weather patterns.

11.4 Constraints of Blue Roofs and the Integration with BMS and IoT Platforms

This section will highlight the constraints of sensors and instrumentations, controllers and their integration with BMS and IoT platforms in particular.

11.4.1. Sensors and Instrumentations

There are several possible constraints including device compatibility, protocol restrictions, and durability within harsh climate conditions. It is advisable to look for these sorts of specifications when choosing a blue roof system to minimize high cost maintenance and/or parts replacement.

Compatibility
The advancement of technology will provide operating systems with greater, more effective outcomes but only if parts are compatible. Compatibility may depend on the manufacturer, the level of advancement in the technology (the device may be too accurate for the system) or even the method of connectivity of the device. Attempting to integrate incompatible devices may result in:

- the system may not work optimally
- parts of the system may not respond
- the entire system will cease to function
- the system will eventually fail due to a malfunction or premature wear and tear

Ensure compatibility between all parts by carefully testing and paying attention to product specifications.

Environmental Factors
When choosing the type of sensor for a blue roof system, take note of the sensor's environmental ratings, the environment it will be installed in (e.g. whether it's indoors or outdoors) the possible weather conditions (rain, heat, snow, hail, etc.), and obstructions it may be exposed to. If the device is not rated for the type of environment, it may lead to degradation in its physical properties and performance.

Protocols
If the system involves IoT platform(s), your sensor(s) and/or instrumentation will need to meet security protocols to enable digital communication with the rest of the system.

11.4.2. Controllers and Integration with BMS Constraints
Similar constraints exist for the controller in the Smart Blue Roof system.

Protocols
The controller must meet the existing BMS communication protocols. Otherwise the controller will not work.

Security
Security is a concern, particularly with an open system protocol. Hackers can gain access via the BMS computer.

Harsh Environments
Environment rating should also be consulted for the controller. Otherwise system failure is a risk.

Investment vs. Performance
There is a range of controller pricing options. The balance between cost and performance should be considered.

11.4.3. Real-Time IoT Constraints
The opportunity to view a system status at the touch of a button is a highly welcome evolution. Within a blue roof system, there are countless devices and sensors. However the integration with IoT also has its challenges.

Security
IoT is something that is being more ingrained into our society with each passing day. This means hacker attacks will become more catastrophic as we develop more into IoT.

Security for devices is also a problem. Some devices run on lower power which means that encrypting data is not an option because they can't power the encryption function. This makes the device more vulnerable to attacks.

There is much competition to develop the new technology standard. This creates compatibility issues between devices. Current technology may become obsolete in a few years due to the competitive climate of IoT.

Complexity
IoT is complex and requires certain skills to understand, implement and deploy an end to end IoT solution [64]. Not just implementing but, developing hardware, software and middleware may have many issues and problems which needs expertise to fix and handle.

12.0 EXAMPLES OF BLUE ROOF SYSTEMS

This section highlights some real-life installations and pilot projects of blue roof systems, emphasizing design components, construction goals, success and failures where available. The term 'blue roof' post-dates the development of this technology so the online search for case studies included expanded descriptions to capture other relevant examples.

12.1 New York City, U.S.A.

New York City Department of Environmental Protection Pilot projects.

Since 2010, The New York City Department of Environmental Protection (NYDEP) has led the advancement of blue roofs through a concerted and widespread implementation of the technology, as part of the Green Infrastructure Plan and Pilot Program[43].

Rooftops represent approximately 28% of impervious surfaces in New York City, affording great potential to reduce stormwater runoff to the sewer system at source. In addition to cost effectiveness, ease of operation and maintenance, NYDEP views blue roof technology as a significant opportunity for green infrastructure implementation.

To better understand the functionality of blue and green roofs alike, NYDEP developed three green infrastructure rooftop pilots outlined below.

Project Name: **Public School 118 Queens**
Site Location: Queens, New York

Overview:
NYDEP segmented one roof into 3 sections, a blue roof, a green roof and a control section, left unchanged. Each measured approximately 3,500 square feet. The green roof was designed to detain precipitation in the four inch deep soil layer and to promote evapotranspiration through plant uptake and sun exposure. The blue roof design included check dams made from perforated aluminum T-sections,

designed to slow the flow of runoff to existing drains. The control area served as a baseline, against which comparisons were made.

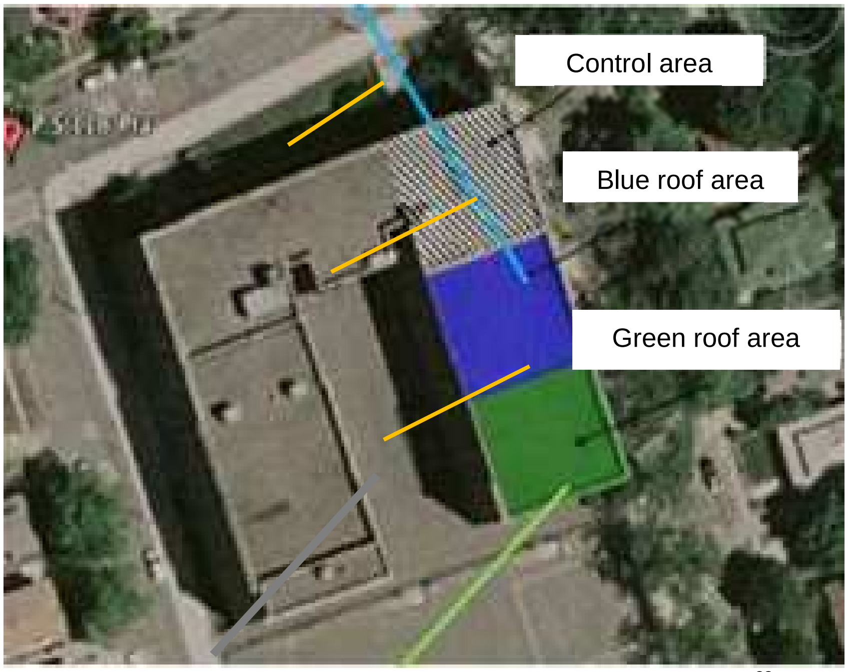


Figure 58: Rendering of PS118 blue, green and control segments[33]

A full weather station, water level loggers and drain inserts supported monitoring evaluations for both the green and blue roof systems, with a v-notch weir and water level logger used to quantify flow from the control section.

They used ISCO 4230 Bubbler Level Sensor (Bubbler Flow Meter) and three Arlyn 320D- CR Scale Series. The Bubble Flow Meter from RSHydro is now discontinued, it was replaced with the Signature Flow Meter. Unlike the old design this new one is meant for open channel flow monitoring applications [53]. The 320D-CR Scales are for measuring the change in weight of the trays.

It is unlikely this water management system incorporates a controller as there is no mention of one in the 2012 Green Infrastructure Pilot Monitoring Report [10], plus there are no electrical valves and actuators. The sensors recording the weight changes on the roof are Arlyn Series 320D-CR industrial scales and a Data Logger, which do have the ability to communicate through Wi-Fi or RS232 connection.

Figure 59: Arlyn Series 320D-CR Scales and Data Logger
Source: Arlyn.com

A proprietary IoT platform called OptiRTC was used in this pilot. This platform focuses on efficiency and effectiveness on addressing storm water runoff. The OptiRTC improves water quality, prevents localized flooding, reduces sewer overflow, and monitors and adapts the storm water management system. OptiRTC features OptiNimbus, OptiCumulus, and OptiPlatform.

OptiNimbus is the continuous monitoring and adaptive control system of the OptiRTC platform. It integrates cloud-based technology, sensors and flow control and weather forecasts to improve water quality, prevent flooding and reduce sewer overflows.

OptiCumulus collects data and allows user access. It augments the performance of OptiNimbus by integrating additional on-site sensors and devices.

OptiPlatform is a public API with a single platform with secure cloud management. It contains web dashboards, real time alerts and data exports.

The monitoring campaign results are summarized in representative hydrographs comparing outflow rates between the green and blue roof pilots for an 1.1" rain event. The image shows less overall outflow from the green roof than from the blue roof system.

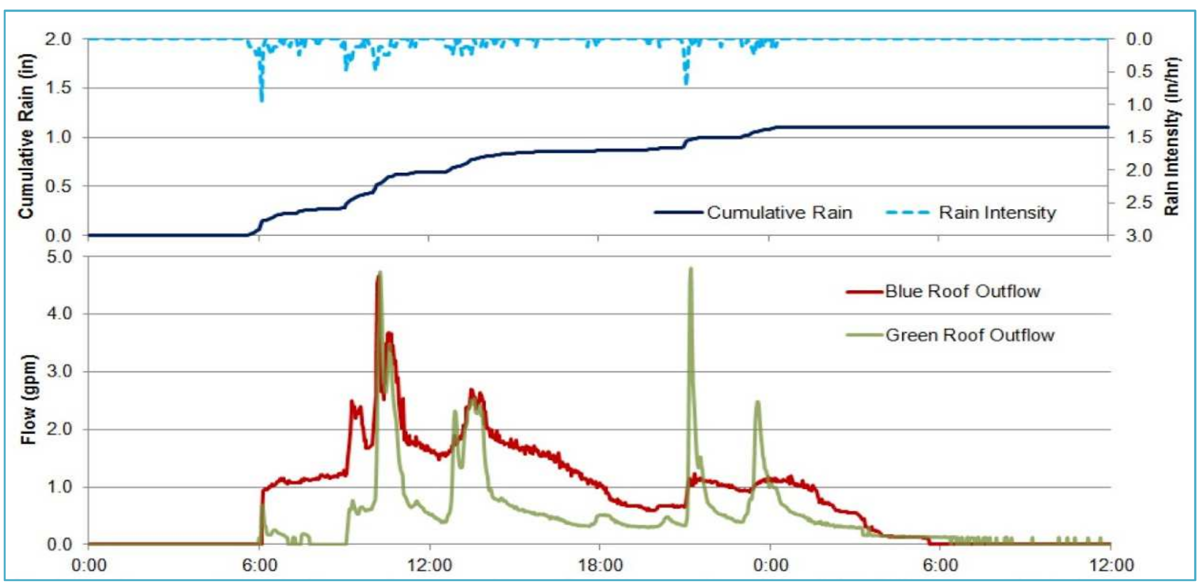


Figure 60: Representative Hydrographs of outflow rates green vs blue roofs PS 118 pilot[33]

For smaller storms with 1-inch of rainfall or less, the green roof pilot performed best, typically retaining 30% to 100% of rainfall volume in 2012. In 2012, the blue roof system of check dams had a measured volume retention falling between 20% and 80%.

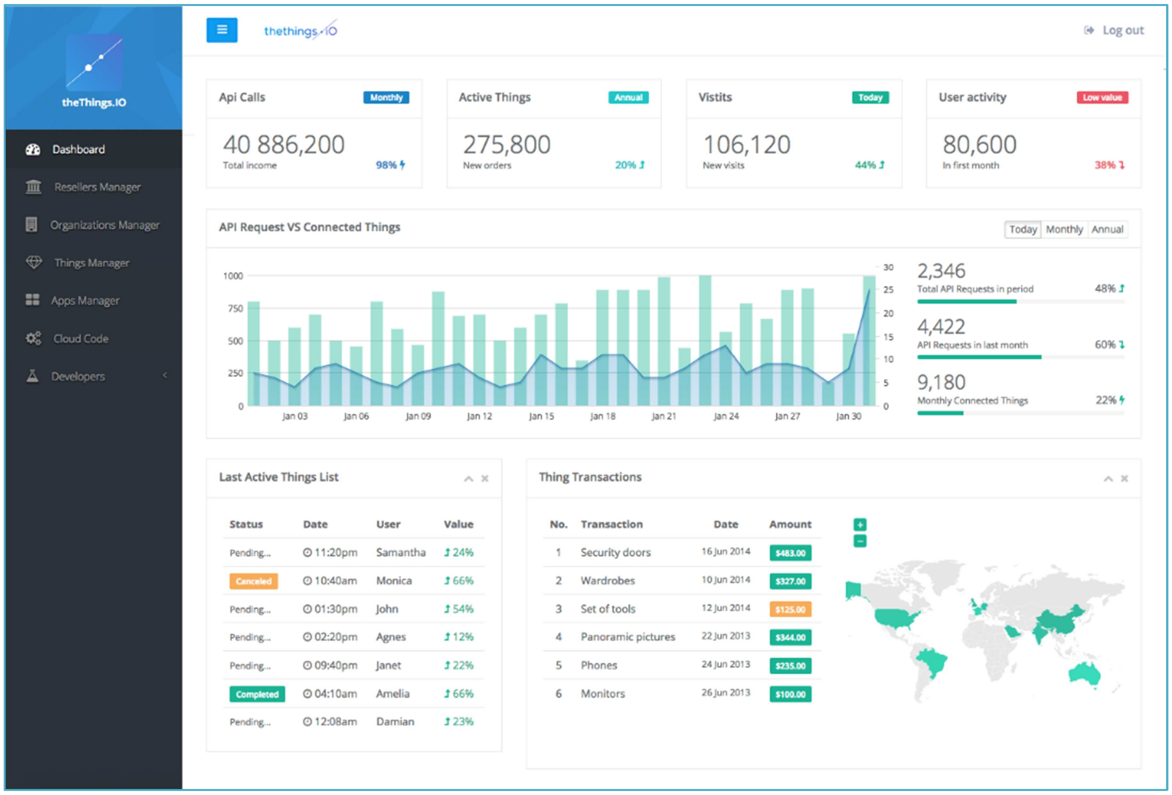


Figure 61: A typical dashboard for an IoT Platform
Source: NYC Department of Environmental Protection 2012

Project Name: **Metropolitan Avenue**
Site Location: Brooklyn, New York

Overview:
NYDEP installed three blue roof pilots at a storage facility on Metropolitan Avenue and monitored them throughout 2011 and 2012. The roof was segmented into four different areas:

- a modified inlet (an existing roof drain weir with an orifice limit flow)
- check dams installed around an existing inlet
- a modular tray system
- a control area

Each section allows for temporary storage capacity during and immediately after rain events, as well as opportunity for volume reduction through depression storage and evaporation. Specially designed drain inserts measured outflow rates and a rooftop weather station measured site-specific rainfall, wind, evaporation and solar radiation.

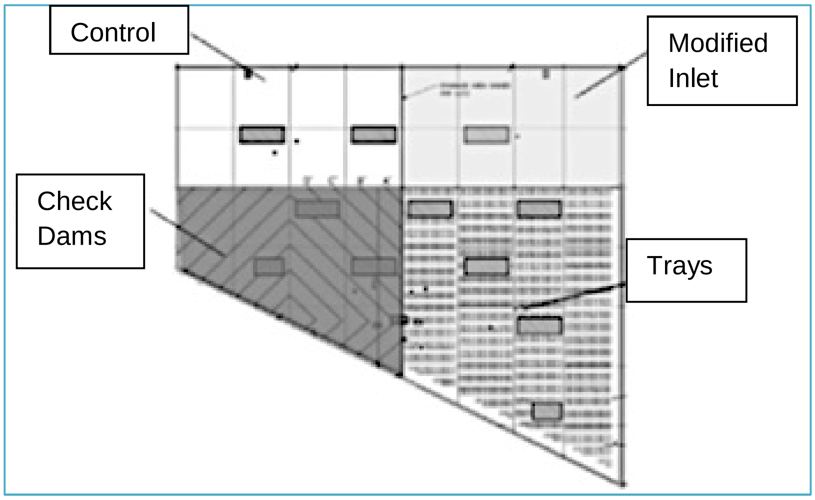


Figure 62: Schematic of roof segments at Metropolitan Avenue pilot Source: NYC Green Infrastructure Plan: 2012 Green Infrastructure Pilot Monitoring Report

Although designed for detention, each roof type also provided some degree of runoff retention. The modified inlet section provided both, particularly for smaller storms, but was generally similar in performance to the control area.

The check dams, constructed from 1" deep aluminum, with orifice holes and loose gravel to limit flow to the roof drain, provided a higher level of stormwater control than the modified inlet and control sections. This is likely due to more even distribution of detention storage across the roof, but it did not achieve the same level of consistency as the tray system.

The modular tray system (2"W x 2"H x 3/4" D), is designed to reduce flow as the water passes through a filter and small weep holes, then collects in the bottom of the trays. Stone ballast is used to prevent shifting by wind. The trays consistently provided the highest degree of detention and retention control, likely attributed to their distributed nature and the limited impact of roof slope on tray function.

The unmodified surface with existing drains provided some runoff retention due to the formation of small puddles and subsequent evaporation.

Drawing a comparison between the roof's four distinct quarters, Stein et al. (2012) observe: "a distinct advantage of a tray configuration over the modified inlet and check dam roof types is the ability to limit water retention and ponding to specific portions of a roof. As such, pathways and areas with lower structural loading capacity can be kept free of standing water after a storm event".

Project Name: **Bronx River Houses**
Site Location: Bronx, New York

Overview:
The Bronx River Houses is a public housing project, built in 1951, consisting of nine, fourteen-story buildings. This test, executed on the Community Center roof, was designed to compare the performance of four different tray configurations using a weighing scale system. Outflow rates were calculated based on scale readings of stored water and measured rainfall rates.

Monitoring results for the blue roof trays indicate that rainwater detention was consistent in all trays and showed some retention. Different drainage layer configurations were tested, but indicated no noteable differences in detention or retention performance between them. The trays typically emptied in less than 24 hours after the end of a rainfall event, avoiding nuisance ponding and providing the capacity needed for the next storm.

Project Name: **Osborne Association**
Site Location: South Bronx, New York City

Overview:
The mixed green-blue roof was designed to manage over 100,000 gallons of stormwater and is estimated to reduce the runoff from a typical New York City storm event by 32%. The roof is divided into several different segments, which alternate between 'green' and 'blue' trays. The green trays contain soil and vegetation to absorb rainwater and improve air quality and the blue trays detain and slow the flow of stormwater to the sewer system.

Figure 63: Osborne Association blue and green roof
Source: Osborne Association

Rooftop monitoring equipment was installed to measure precipitation levels and the rate of flow to the sewer system. Given the age of the building, its ability to withstand the increased load of a green roof was in question. The strategic use of alternating blue (lighter) and green (heavier) trays, resolved the concern. Additionally, the blue trays cost significantly less than the green trays, making a combined roof project more fiscally accessible.

Source: New York City Department of Environmental Protection 2013

Other Projects:

The New York City School Construction Authority (NYCSCA), has installed rooftop detention systems in fourteen new build schools and reports successful functioning to date.

12.2 Europe

Project Name: **Project Smartroof 2.0**
Site Location: Amsterdam

Overview:
This project involved the installation of a blue-green system on the roof of Building 002 at the former Navy Yard in Amsterdam. A new installation completed in September 2017, the evaporation and cooling effects of the technology are being carefully monitored as is the ability to sustain large numbers of native plant species.

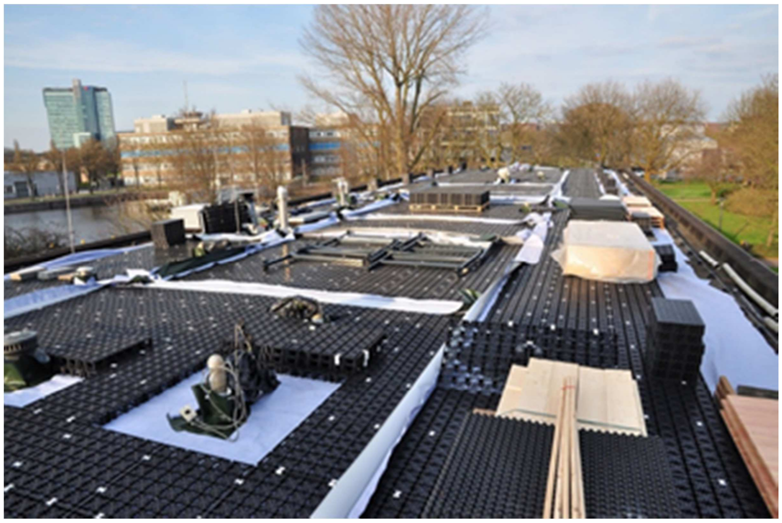


Figure 64: Amsterdam's Smartroof 2.0 blue/green roof project
Source: Amsterdam Smart City, 2018

Rainwater is collected in a drainage layer underneath the soil using an innovative system which enables capillary transport from storage-to-soil, naturally irrigating surface vegetation. The majority of rainwater evaporates, positively impacting water quality and control.

The Amsterdam project includes two types of water level management control systems[77]. One is the Cloud Water Control by SEL Environmental, a combination of water level and soil moisture content sensors to enable tracking of municipal water irrigation for the blue/green roof system[82]. The other is Smart Flow Control by Optigruen, a system that uses real-time weather forecast data to determine when to reduce the amount of water stored in the system to maximize water storage capacity during the rain event.

The SEL Environmental Cloud Water Control management system was custom designed for this project. SEL Environmental offers many options of standard types of automation controllers on their website, including real-time and programmable automation controllers.

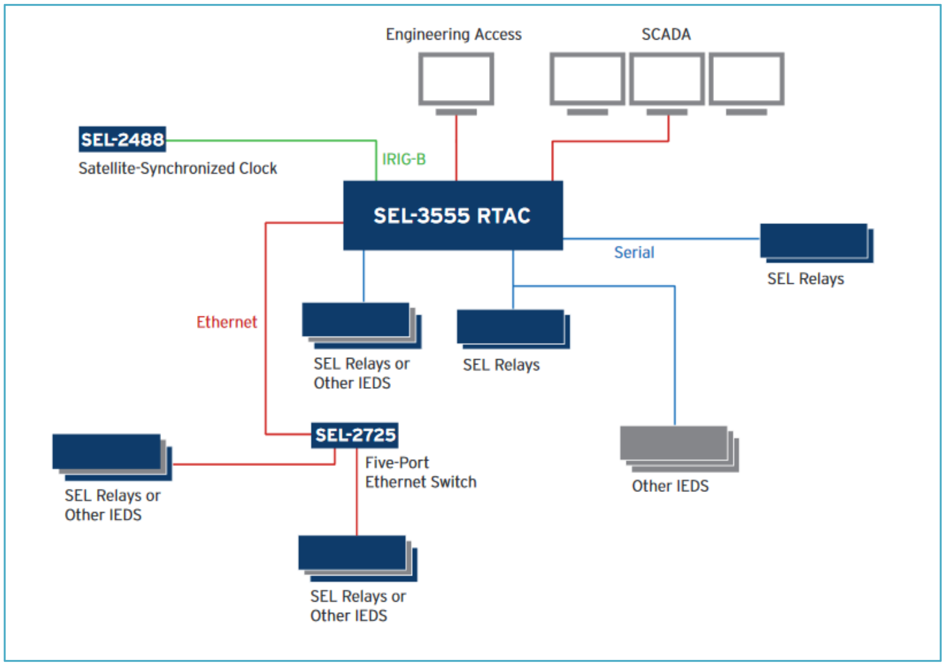


Figure 65: Application of SEL-3555 RTAC
Source: Selinc.com

The SEL-3555 Real-time Automation Controller (RTAC) is an automation platform that combines the features of the high-performance x86-64 architecture, embedded microcomputer and real-time operating system, plus a secure communications framework with IEC 61131-3 PLC programmability.

This RTAC eliminates the need for a PC in the substation due to an integrated video port and human-machine interface (HMI). It can be deployed as a data concentrator using different protocols, such as IEC 61850 MMS, Modbus, DNP3, IEC 61850 GOOSE, LG 8979, IEC 60870-5-101/104, the Parallel Redundancy Protocol (PRP), the IEEE 1588 Precision Time Protocol (PTP) version 2, or MIRRORED BITS communications, and integrates both serial and Ethernet intelligent electronic devices(IEDs). It enables logging on any system or IED data tag to view and archive station-wide event records.

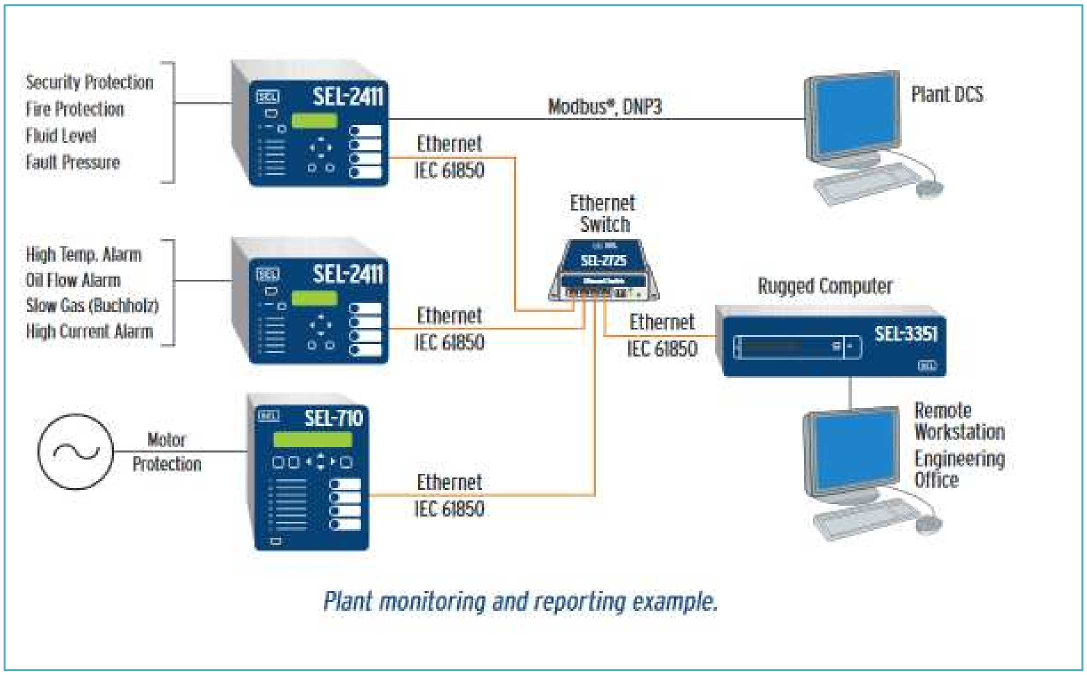


Figure 66: Plant monitoring and reporting example using SEL
Source: Selinc.com

The SEL-2411 is a programmable automation controller, that can be used in harsh environments. It can integrate with SCADA, provide sequential events reporting, station integration, remote monitoring, AC metering, and plant control system needs. The protocol used for communications are IEC 61850, Modbus, or DNP3.

Project Name: **Project Resilio**
Site Location: Amsterdam

Overview:
Rain Grid and Waternet are partnering on this project to investigate Smart & Dynamic Micro-Water Buffers - a network of blue roofs controlled through a central server. This study is underway and information is not yet available.

Other Information:
Several private firms have installed blue roof systems in Amsterdam but detailed information is not readily available. There are two firms primarily involved with these projects:

- Permavoid (UK)
- Polderdak (NL)

Permavoid's website highlights six different blue-green roof projects completed.

Project Name: **The Rathbone Market Project**
Site Location: London, England
Technology Provider: ABG Geosynthetics

Overview:
A real estate development undertaken by the English Cities Fund (ECF) in partnership with a local government arm, the Newham London Borough Council, the project aims to establish a sustainable mixed-use community.

Due to local site restrictions around space and infrastructure services ingfringement, below grade stormwater attenuation tanks were not an option. The roof presented the best alternative to implement SWM. The blue roof system was constructed on top of a hot melt waterproofing system.

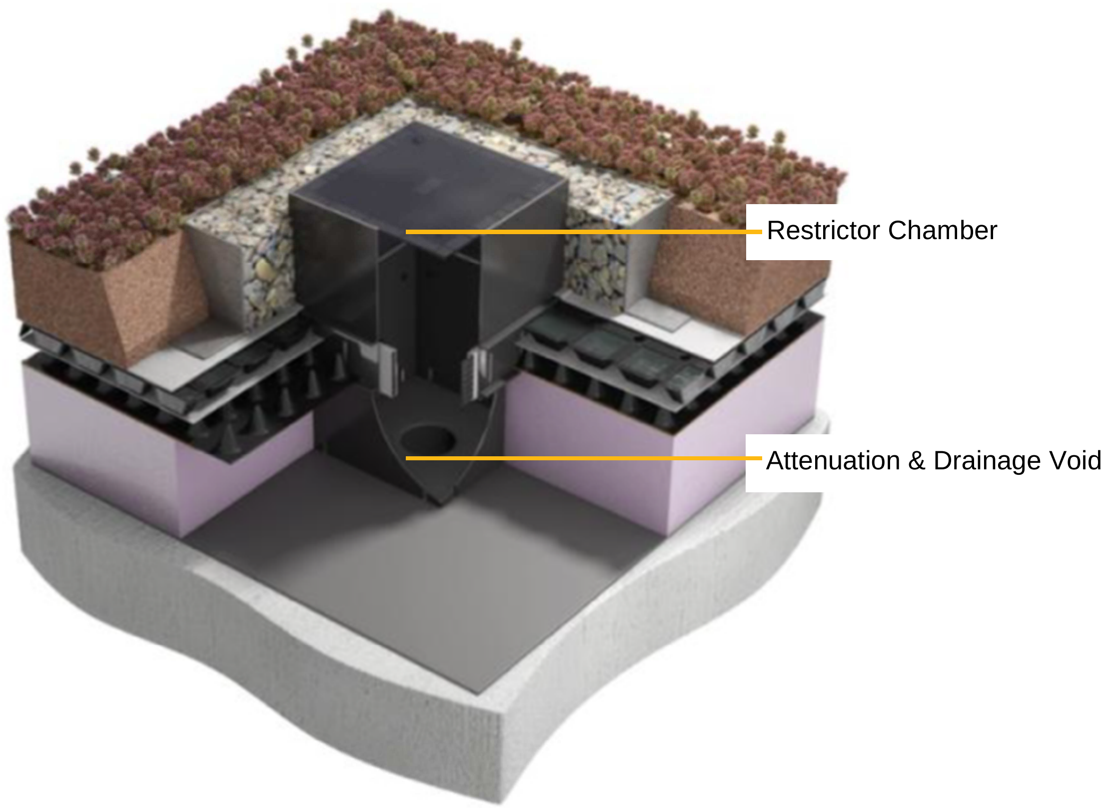


Figure 67: Cross-section of ABG Geosynthetics Blue Roof system: Source: ABG Geosynthetics

The restrictor chamber, visible at roof level, controls flow at predertmined discharge rates. The stormwater is fed to large capacity underground tree rooting cells, which further attenuate the water, also serving to irrigate surface plant material. The attenuation and drainage void functions when rainfall is above pre-determined rates. It serves to slow water release and is controlled by the restrictor chamber.

However, these blue roof systems are not “smart”. There is no sensor or electrical valve to monitor and manage the drain water remotely and as a result, controllers are not used in these systems.

Source: ABG Geosynthetics, 2018; The Buillding Centre, n.d.

Project Name: **Zenith House**
Site Location: London, England
Technology Provider: Alumasc

Overview:
The Zenith House Project is a new residential development. Traditional buried stormwater attenuation tanks were not feasible in this particular project due to limitations imposed on excavation depth. A roof system became the solution. Local planning policies dictate the maximum rate of stormwater discharge to sewers of 9 litres per second. Based on a maximum hydraulic head of 150mm, the system was designed to slow stormwater discharge to a rate of 4 liters per second.

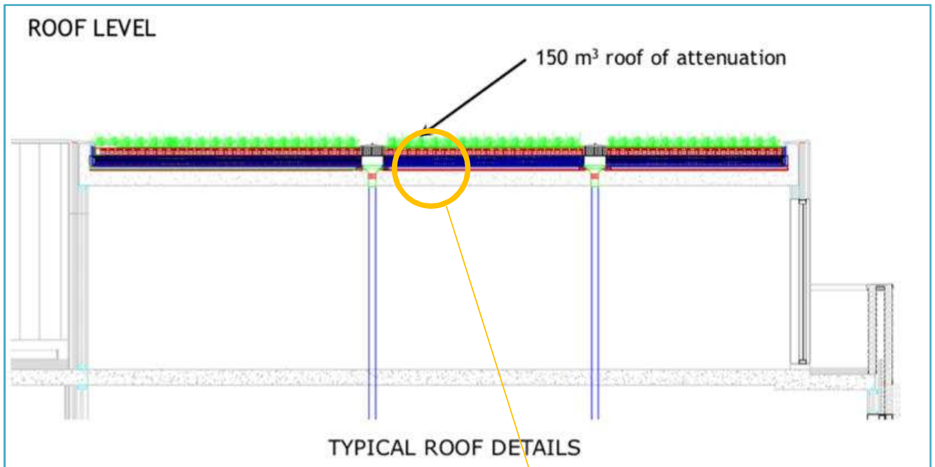


Figure 68: Zenith House Project roof detail. Source: Zenith House

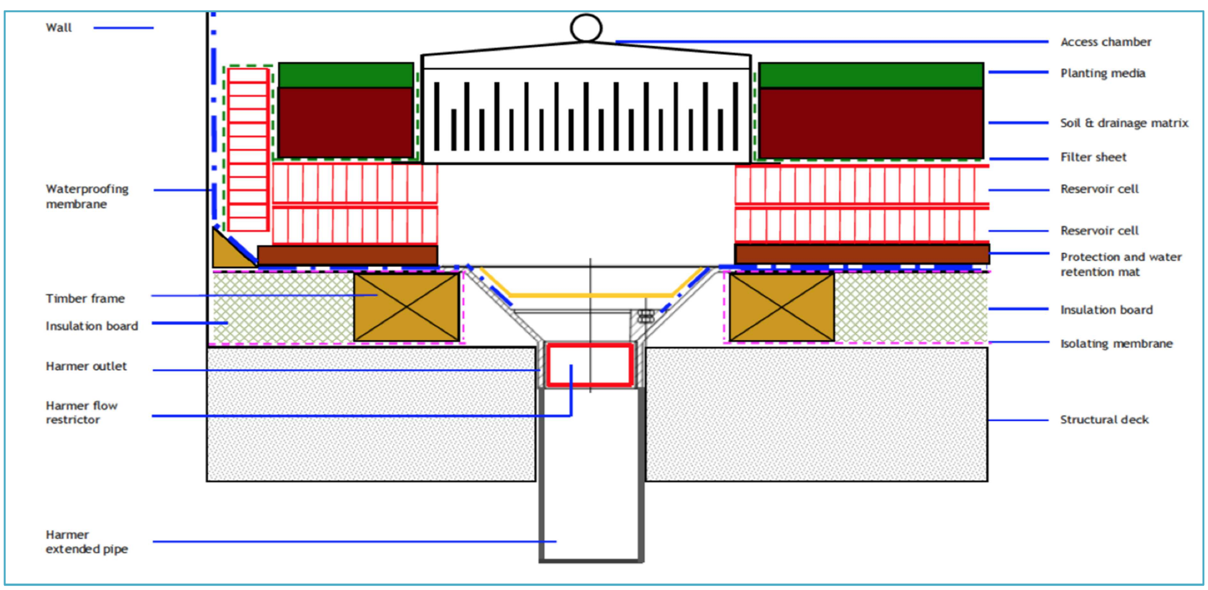


Figure 69: Alumasc typical roof schematic and detail of rainwater outlet. Source: Alumasc

The roof system design includes 16 rainwater outlets with integral flow restrictors, connected to pipes flowing to the sewage system. The roof is designed to be leak-proof up to a depth of 150mm. Roof waterproofing construction includes a hot melt membrane applied directly to the roof deck, followed by a layer of insulation and a bituminous membrane cap sheet.

Source: Alumasc Exterior Building Products Ltd & Ramboll Consulting Engineers, n.d

Project Name: **Huddersfield University Blue/Green Roof**
Site Location: Huttersfield, England
Technology Provider: AGB Geosynthetics

Overview:
The Huddersfield University Student Learning and Leisure Centre (SLLC) is a new four-structure development. The original plans called for green roofs, with overflow directed into buried sustainable drainage system attenuation (SuDS) tanks. Due to cost savings associated with a blue roof, this roof system solution was devised instead. Constructed on top of a hot melt waterproofing design, utilizing a restrictor chamber and attenuation and drainage void configuration, water flow is restricted, attenuated (in excess capacity rainfall events), and discharged at predetermined rates.

Similar to the Rathbone Market Project, this blue roof systems is not “smart”. There is no sensor or electrical valve to monitor and manage the drain water remotely and as a consequence, no controllers are used in these systems.

Source: ABG Geosynthetics, Huddersfield University

Project Name: ***University of Bristol Priory Road Lecture Hall***
Site Location: Bristol, England
Technology Provider: Alumasc

Overview:
During the build of the new Lecture Hall at the University of Bristol, blue roof technology was selected to address the sustainability agenda of the University and model effective urban SWM practices.

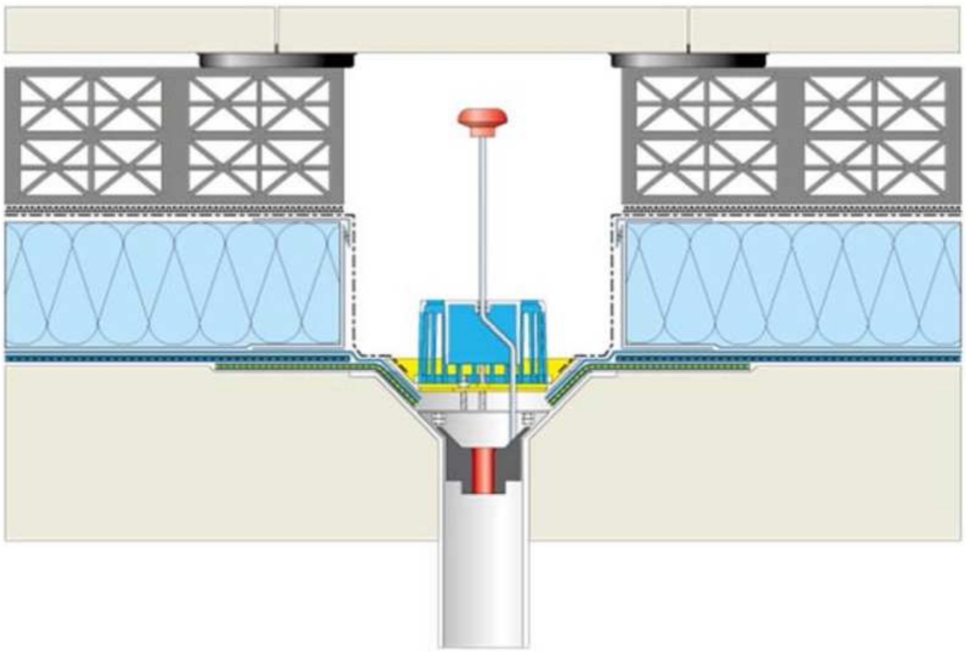


Figure 70: Detail of Alumasc drainage system. Source: Alumasc

The roof design, capable of holding 75mm of rainfall, combines green and blue roof technologies, providing thermal mass, rainwater absorption and visual appeal of the green with a managed rainwater attenuation system that discharges into the local sewage system on a predetermined basis.

Source: University of Bristol, 2014

12.3 Canada

Green infrastructure and adaptable stormwater management techniques have been adopted across Canada. Specifically, in Ontario the adoption of the Toronto Green Roof bylaw exhibits one of many innovative actions Canadian municipalities have taken to improve stormwater management. Smart blue roof technology has not been adopted to date.

12.4 Lessons Learned

The blue roof projects described in the preceding pages accomplished water attenuation using a variety of designs.

Generally, there was limited detail available beyond the basic design and effectiveness of the systems. In many cases it was not clear if smart technology was used. The Osborne Association Project in New York City is the only blue roof system confirmed to combine smart technology with stormwater management.

This project used monitoring equipment to measure precipitation and the rate at which water enters the sewage system Although not stated in publicly available sources, we can assume the system collects data in real-time. We also don't know if real-time was a part of Huddersfield University and Rathbone Market projects, or whether the system is simply engineered to restrict water discharge.

The overall results of this review suggest that the pairing of rooftop water attenuation with smart technology appears to be relatively unchartered territory and merits further research.

The NYDEP blue roof projects were the most well documented of all those reviewed. These may prove useful in the exploration of system configurations. NYDEP project monitoring results suggest systems of modular trays or check dams installed around an existing inlet show promise for potential blue roof applications.

13.0 MOVING FORWARD: IDENTIFYING OPPORTUNITIES AND CONSTRAINTS WITH SMART BLUE ROOF SYSTEMS

Smart Blue Roof System Opportunities

Based on the background information provided by CVC and the literature review completed by Ryerson University and George Brown College, opportunities associated with the installation of a smart blue roof system were identified. These include water and energy savings, enhanced stormwater management, increased stormwater credits and potential funding.

The literature review identified three different types of blue roof systems:

- controlled flow roof drain
- roof check dam
- modular trays

Water Savings

Modular tray systems appear to provide the highest degree of detention and retention control compared to the other two and lend themselves well to retrofit designs. Further research would be needed to determine if this is the best solution for this application based on the structural components of the roof; care would need to be taken to ensure the additional load of the trays is considered in the design, and that the sides of the trays are high enough to hold the desired volume of water. Note that supply of the trays would add significant capital cost.

Alternatively, Enviro-Stewards suggests that all but one of the roof drains be surrounded by a "donut"-type barrier as high as necessary to allow for the desired storage volume, and that just one roof drain be tied into a control system (likely the drain that is connected to the existing rainwater harvesting tank). This would keep the system as simple and inexpensive as possible, reducing risk associated with system failure.

The roof area is 644 m^2 and for the purposes of this design, Enviro-Stewards assumed the mechanical area would not collect rainwater, leaving an area of 550 m^2 for storage on the roof. Based on background information about the roof, the sloping topping is 230 mm deep at the perimeter of the roof and 50 mm at the roof drains. A picture in the stormwater report showed an available depth of 450 mm at the perimeter of the roof. Maximum storage volume was thus calculated using a depth of 225 mm above the sloping topping at the perimeter of the roof and 405 mm in the centre. This yielded a total storage potential of 170 m^3. However, this assumes a maximum ponding depth greater than 150 mm, which exceeds Ontario Building Code requirements. An appeal or approval would be required to exceed this ponding depth.

When combined with the existing storage tank, this gives a total potential storage volume of about 175 m^3. A preliminary analysis of this storage volume using the Connect the Drops rainwater harvesting design program, resulted in potential water savings that are presented in the table below. The software recommended storage of 19 m^3, so further analysis was performed using incrementally more storage, as illustrated in the table below. Note that a storage volume of 45 m^3 results in water savings equal to 175 m^3 storage, so it is unlikely that the roof will have to hold more than around 40-45 m^3.

Table 12: Rainwater Harvesting System Performance for Building A using Connect the Drops Design Program

Type of Year	Annual Rainfall (mm)	Rainwater Use by Storage Volume (m^3/y)				
		19 m^3	30 m^3	40 m^3	45 m^3	175 m^3
Dry	467.7	236.5	236.5	236.5	236.5	236.5
Moderately Dry	604.9	287.8	287.8	287.8	287.8	287.8
Typical	673.2	318.5	330.0	330.0	330.0	330.0
Moderately Wet	765.4	374.6	390.7	394.3	394.3	394.3
Wet	937.7	427.5	446.5	456.5	457.9	457.9

Notes:

1. *Example calculation - If a 19 m^3 rainwater harvesting tank is installed, 47% (318/673 mm) of all runoff volume during a typical year will be retained on site for re-use.*
2. *The calculations above do not assume a blue roof is installed, so the performance of the rainwater harvesting system is not optimized. No storage on the rooftop is available, so a significant volume of annual rainfall bypasses the rainwater harvesting system and discharges to the municipal system.*

It should be noted that for the purposes of the analysis, daily usage was assumed to be 5,422 L/d (based on CVC's rainwater harvesting presentation given in February 2018). Some of this water may not be suitable for all uses as it is not potable, but since the analysis of the two largest storage volumes resulted in zero overflow events, it is assumed that this volume of water is what the smart blue roof would be working with on an annual basis (the program assumes some losses based a few different factors such as rainfall intensity, among others).

Enhanced Stormwater Management

The combination of roof storage with a control system will offer additional benefits associated with stormwater management, such as the ability to drain the roof as needed to prepare for a storm event. This would mean that the system could predict events based on weather data and if there is not enough storage on the roof it could be drained in advance of a storm. This would allow the system to more effectively mitigate stormwater effects, since it would ensure sufficient storage for the stormwater, freeing up capacity in the storm sewer during a rainfall event.

According to the literature, integrating a control system can allow optimization of performance to meet specific site objectives (e.g. minimization of stormwater runoff, water conservation/efficiency, water quality enhancement) and recent advances in technology can provide significant improvements over conventional RWH systems in both water conservation and runoff control.

Peak Flow Control

Passive, static controls limit a blue roof to controlling a specific design storm or events. With active controls, the system can operate in a more dynamic fashion. A smart blue roof could adjust outflow 'real time' to mimic pre-development hydrology within a sensitive or vulnerable watershed.

Table 13 compares the difference in performance between passive and actively controlled best management practices.

Table 13: Comparison of performance between passive and actively controlled best management practices

Practice/Technology	Volume Control	Peak Flow Control						Evaporative Cooling
		2yr	5yr	10yr	25yr	50yr	100yr	
Conventional Roof Top Orifice Control (Passive) - Can only control one storm	N	-	-	-	-	-	x	N
Blue Roof with Real Time Orifice Control (Active)	Y	x	x	x	x	x	x	Y
Green Roof with Orifice Control (Passive)	Y	x	-	-	-	-	-	Y

Yellow	Erosion/Channel Forming Flow Rates
Light green	Minor System Design
Purple	Major System Design

Rainwater Harvesting & Peak Flow Control

Based on the City of Mississauga intensity-duration frequency curves and based on an estimated Time of Concentration (Tc) of 10mins (this is the minimum Tc per City of Mississauga design guidelines), the maximum rainfall intensity for the 100yr storm is approximately 176.3mm/hr with a maximum ponding depth of 72mm.

Based on a roof area of 645m^2 and assuming the maximum allowable ponding depth on the roof is 150mm, there is the potential to retain and detain the 100yr storm, provided the roof has adequate structural capacity.

Table 14: Roof Storage Coupled with Rain Water Harvesting

Available Ponding Depth for 645m2 flat roof	Depth of 100 yr Storm	Deficit	Number of 5,000L RWH Tanks needed to alleviate deficit *
100mm	72mm	--	--
50mm	72mm	22mm	3
25mm	72mm	47mm	6
15mm	72mm	62mm	8

* One (1) 5,000L (5m^3) tank is equivalent to 7.7mm of ponded water on the roof.

Table 14 illustrates how RWH tanks could be coupled with buildings with shallower parapets to provide peak flow control for the 100 yr storm. Buildings with shallow parapets could still achieve peak flow control with the help of other storage practices such as rainwater harvesting tanks. For example, if the maximum available ponding depth is 50mm, three (3) RWH tanks could be installed to achieve 100% control of the 100yr storm.

Table 15 below provides a summary of the different storage volumes with increasing rainfall volumes for Building A. For example, 50mm of water ponded on the roof would be equivalent to 65 – 5,000L tanks.

Table 15: Storage Volumes associated with different roof ponding depths for Building A

Storage Depth (mm)	cm	m	Storage Volume (m3)	Equivalent # of RWH Tanks	Average Daily Water Demand (m3/day)	Average Daily Evaporative Loss (m3/day)	Water Supply (Days)
5	0.5	0.005	3.225	6	0.2	--	16.1
10	1	0.01	6.45	13	0.2	--	32.3
15	1.5	0.015	9.675	19	0.2	--	48.4
20	2	0.02	12.9	26	0.2	--	64.5
25	2.5	0.025	16.125	32	0.2	--	80.6
50	5	0.05	32.25	65	0.2	--	161.3
100	10	0.1	64.5	129	0.2	--	322.5
150	15	0.15	96.75	194	0.2	--	483.8

The average daily water demand is based on re-use of the rainwater for flushing toilets at the CVC office, but there is potential to increase the demand. Based on a daily demand of 0.2m^3/day for toilet flushing it would take considerable time to use the water for this use alone. To increase potable and non-potable water demand we could consider:

- Storing water on the roof for evaporative cooling during the spring/summer/fall
- Storing water on roof and topping-up the RWH tank as it gets drawn down for
    - Landscape irrigation, maintenance
    - Drinking water
- Adding additional storage tanks
- Sharing with surrounding neighbours
- Water for cooling towers

Depending on the landowner (i.e. commercial/industrial/institutional) the water demand will vary.

Scaling it Up - Neighbourhood Scale

Figure 71 illustrates a typical business park. Retrofitting this neighbourhood with automated blue roof technologies and RWH systems could equate to significant stormwater storage, which is critical in areas with high flood vulnerability and no available space for end-of-pipe controls. These numbers could be used to scale-up benefits for other business parks with similar characteristics.

Figure 71: Typical IC&I business park within the Greater Toronto Area (photo taken from Google Earth)

Energy Savings

Another potential benefit associated with using the roof as storage for rainwater includes energy savings associated with cooling the building in the summer months. Evaporation is an efficient method of cooling and having water on the roof to remove heat from the building through evaporation may reduce energy costs associated with air conditioning. This merits further research in terms of quantifying these savings (perhaps by logging temperature thermocouples post construction).

Rebate and Funding Increases

Expansion of the existing rainwater harvesting system may increase the value of stormwater credits available to CVC from the City of Mississauga, which would be of benefit. In addition, there may be funding available through various levels of governments if and when this project gets to the detailed design and implementation stage.

Performance Indicators & Targets

Appendix F provides a detailed and comprehensive description of the various performance indicators and targets for measuring reduced vulnerability to extreme drought, heat and extreme rainfall. The table further summarizes baseline conditions, metrics, methods of quantification, and the impact of the project. Similarly, these could be used to scale up benefits for other IC&I business parks with similar characteristics.

14.0 SMART BLUE ROOF SYSTEM CONSTRAINTS

Constraints associated with the design and implementation of smart blue roofs appear to be numerous but surmountable. Care needs to be taken in the proper design and management of such a system to mitigate the risks.

Being a relatively new type of stormwater management system, there are a number of things that need to be taken into account when designing and implementing a smart blue roof system. These relate to both the design and the management of such a system.

Structural Capacity

With respect to storing water controllers, monitoring equipment, modular systems, etc., on the roof, the capacity of the existing building to physically support this storage must be taken into account. This includes the structural capacity of the roof itself (to be determined in the next stage of the feasibility analysis), as well as the condition of the roof in terms of waterproofing. For example, if storing the volume of water discussed in the previous section, the roof will need to be able to support an additional estimated 45 tonnes and will need to be waterproof. Safe access must also be provided for maintenance and monitoring purposes (e.g. pathways for people to walk safely on the roof).

Drainage Frequency

Drainage frequency is something that will have to be investigated further. The Ontario Building Code stipulates that flow control roof drain systems must be drained in 24 hours 24 hours and that the maximum depth of ponding is 150 mm. This limits the storage volumes on a blue roof; however, the Building Code does have an Appeals and Approvals process, so an argument can be made for increased retention time and depth of ponding. Some sources say the water needs to be drained in 30 hours to mitigate issues such as anaerobic conditions, odour, water quality and mosquito breeding, while other sources recommend drainage within 72 hours to allow for future storage and to avoid the aforementioned issues. Mosquitos will multiply in standing water after four to seven days, so further research is recommended as it relates to storage time.

Stormwater Discharge Rates

In addition, the stormwater discharge rate needs to be taken into consideration during the design, especially if the cities of Mississauga and Brampton have a maximum discharge rate requirement. The Ontario Water Resource Act requires a certificate of approval be obtained for the establishment, alteration, extension and replacement of stormwater infrastructure as well.

According to the literature review, problems with blue roofs generally fall into two categories: the system drains too slowly (resulting in buildup of excess water on roof for extended periods of time, bypassing of controlled flow roof drains, or overflow via secondary drains/scuppers during small rain events), or it drains too quickly (exceeds design release rate so full benefit not achieved).

Safety Measures for Components and Systems

Therefore, there is a need to ensure safety features are properly implemented. Some of these measures include leak/flood testing, overflow structures (e.g. scuppers), a vortex preventer and a fail-open control valve in the primary roof drain, screens/covers for roof drains and a maintenance schedule for clearing debris, construction inspections, loadings and structural capacity analysis, maintaining waterproofing membrane integrity during and after construction, raising any roof equipment (if using those areas to store rainwater, which Enviro-Stewards does not recommend), and clearing of ice/snow in winter. These types of measures will help to ensure long-term success.

Expanding this list of safety and maintenance measures to include tasks related to the “smart” aspect of the system will also need to be considered so that system control is maintained. For example, hardware components must be robust and able to function in severe environments to provide uninterrupted service. Ideally, monitoring performance for the life of the roof is recommended – this will help ensure things continue to work as intended and that any issues can be identified and remedied in a timely fashion.

There may be inherent risk to infrastructure, private property, or even human life due to poorly designed control algorithms, so consultation with insurance companies is recommended prior to design and implementation of a blue roof. In addition, there is a need to recognize, plan for, and manage the ongoing cyber security risks introduced by the distributed installation of sensors and actuators in stormwater infrastructure to minimize risks to public health and safety.

Integration with Large Urban Stormwater Dynamics

One of the largest challenges according to the literature review relates to the design of stormwater management solutions as single entities, without considering the complex spatiotemporal dynamics that govern stormwater flow and quality across large urban area. For example, regional implementation of many distributed continuous monitoring and control systems will require potentially complex and careful logic implementation to ensure that unintended consequences are minimized. Since this system will be localized this may not fully apply, but should expansion be a future consideration, this may be something to keep in mind.

The Right Site

Another thing to take into consideration is the potential limited benefit associated with this system. According to the literature review, this occurs on sites where roof area makes up only a small fraction of the total impervious area, which in this case is 8% (645 m^2 of 8,195 m^2).

Pairing of rooftop water attenuation with smart technology appears to be relatively uncharted territory, especially in this area, and merits further research.

Weather Predictions

Severe weather events are difficult to forecast, especially multiple days in advance; this is an inherent constraint on blue roof systems. Rooftop control algorithms will need to be continuously monitored and adjusted to optimize system performance while acknowledging that errors will occur. For example, some severe storms will not be forecasted enough in advance to properly drain the blue roof and provide more available rooftop storage. Other forecasted storms will not actually occur, so the blue roof might be emptied in advance and the opportunity for evapotranspiration and re-use will be lost.

15.0 CONCLUSIONS & RECOMMENDATIONS

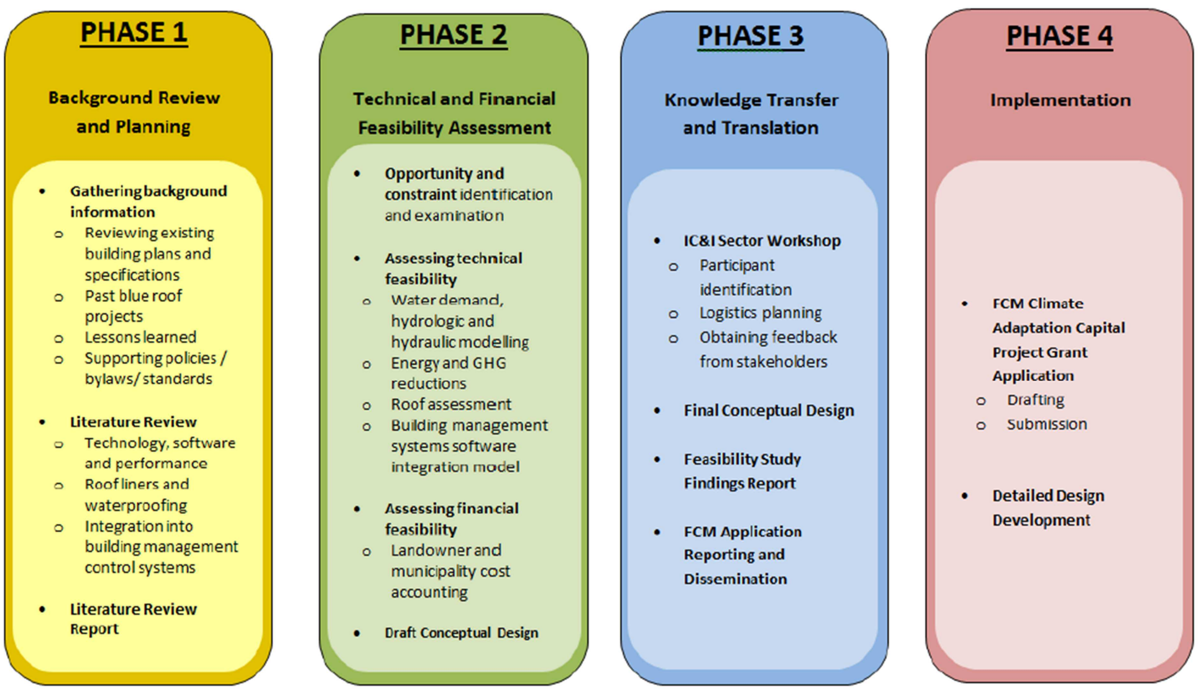
There are many opportunities associated with installing a smart blue roof, including water and energy savings, enhanced stormwater management, increased stormwater credits, and potential funding.

In the context of this project in particular, there is also the potential for knowledge transfer to future projects of this nature, since this type of project is relatively new, especially in Canada. Care must be taken to ensure the retrofit design will function as intended and not cause any harm, as there are inherent risks associated with storing water on a roof and pairing that storage with a control and monitoring system.

Consideration around sensor, valve and flow meter types in addition to programmable or passive controllers and hybrid IoT or open source platforms need to be considered.

This feasibility study is a great first step in understanding and designing a successful system, and further research is recommended.

The next phase of this project will examine the technical and financial feasibility of a smart blue roof system and development of draft conceptual design.



APPENDIX A: SUPPORTING MATERIAL FOR JURISDICTIONAL SCAN OF STORMWATER MANAGEMENT

Ontario Water Resources Act 1990
Under Section 53 of the *Ontario Water Resources Act*, stormwater infrastructure requires a Certificate of Approval (C of A) for its establishment, alteration, extension and replacement. Businesses with less complex operations may register themselves online on the Environmental Activity and Sector Registry (EASR). Applications for C of A are considered on a case by case basis by the MOECC. According *to Reg. 525/98* (under *Ontario Water Resources Act, R.S.O. 1990, c. O.40*)**,** which lists stormwater system alterations exempt from Subsections 53 (1) and (3) of the Act, the use, operation, establishment, alteration, extension or replacement of or change in smaller-scale storm water management facilities designed to service one lot or parcel of land are included. It may be the case that this exemption applies to blue roof infrastructure; however, confirmation of this is recommended.

Environmental Protection Act 1990
The Ontario *Environmental Protection Act* establishes a broad legal framework for environmental protection in the Province of Ontario. Under the Act, the following water-related regulations have been enacted:

- Deep Well Disposal (Regulation 341),
- Discharge of Sewage from Pleasure Boats (Regulation 343),
- Marina Facilities (Regulation 351),
- Sewage Systems (Regulations 358 and 359).

Environmental Assessment Act 1990
The *Environmental Assessment Act* is the province's chief planning statute, and predominantly governs public sector endeavours, including municipalities. The Act is administered by the Ministry of Environment and Climate Change and is generally relevant to stormwater management.

Building Code Act 1992
The Ontario Building Code is administered by the Ministry of Municipal Affairs – Housing, the Building and Development Branch. Section 7.4.10.4. of the *Ontario Building Code* addresses hydraulic loads from roofs or paved surfaces. The Code permits flow control roof drains, but stipulates that the maximum depth of retained water must not exceed 150mm, and roofs must be drained of standing water within 24 hours. This maximum depth is estimated to be sufficient to accommodate a 100-year storm, even taking into account the effects of climate change (Hill, 2018). Other requirements delineated in the *Act* include a roof structure design with the ability to bear the load of water, and the use of scuppers installed at a maximum distance of 30m apart lining the perimeter of the building. The scuppers must have the capacity to accommodate a minimum 200% of the 15 minute rainfall intensity.

APPENDIX B: SUPPORTING MATERIAL FOR THE INTERNET OF THINGS (IOT) PROTOCOLS

B.1 Types of Sensor–Friendly IoT Protocols

IoT Platforms use different protocols. The regular structure of an IoT platform is complicated, so it has been broken down into the following sections. Each section runs different protocols, here are some that are important for running sensors (Postscapes, n.d.)**.**

- Infrastructure
- Identification
- Communications/Transport
- Discovery
- Data Protocols
- Device Management
- Muti-layered Framework
- Semantics/Machine Learning
- Security

Communications/Transport:
These protocols are used for communicating with other devices and transporting of instruction data:

- ANT is a proprietary wireless sensor network technology, operates at 2.4 GHz.
- Ethernet is the wired version for connecting to the internet.
- WiFi is the wireless version to connect to the internet.
- Bluetooth is wireless and runs on 2.4 GHz ISM band. It has data rates of up to 3Mbps and maximum of 100 m range
- ZigBee 802.15.4 standard and operates at 2.4 GHz range of 250kps. The maximum sensors that can be incorporated are 1024 with range of up to 200 m. This can use 128-bit AES encryption.

When selecting this protocol for a blue roof system, we must first consider the area that the project is located in to determine the range of communication. Determining what communication protocols can be used with the sensor is a must, and if transmission of instructions/information to sensors and devices, will be done on a wireless or wired network.

Data Protocols: These protocols are used for transporting sensor data to database.

- Message Queueing Telemetry Transport (MQTT) allows publishing and subscribing to a messaging model.
- MQTT-SN is MQTT for sensor networks.
- Constrained Application Protocol (CoAP) allows integration with the web.
- Data-Distribution for Real-Time Systems (DDS) allows publish-subscribe for real time and embedded systems.
- Lightweight Local Automation Protocol (LLAP) sends simple short messages between smart objects using normal text, can communicate over any medium. 3 strengths are that it can run on anything now and in the future and it is easily understandable by humans.
- Simple Sensor Interface (SSI) is a simple communications protocol for data transfer between computers or user terminals and smart sensors.

- Websocket simplifies the complexity around bi-directional web communications and connection management.

These protocols are the most important when considering an IoT platform. The most important thing to remember to do is read the manual of the sensors before buying/choosing them. Sensors must run on the protocols that you are working with, if they don't they won't work.

Semantics/Machine Learning:

These protocols are used when you are trying to build Artificial Intelligence that works with sensors.

- SensorML provides standard models and XML encoding for describing sensors and measurement processes.
- Semantic Sensor Net ontology W3C describes sensors, observations and related concepts.
- Media types for Sensor Markup Language (SEML) can be used by any sensor and this can be used in HTTP or CoAP to transport data.
- These protocols are used when data is received by a device. This data is in the form of bits and these protocols determine whether there is a pattern to the bits, and what actions to take from there. For example, does the data received identify the route to be taken or the final destination of the transmission?
- For this blue roof project, the IoT platform should be scalable, reliable, has support, low-medium cost and everything is secure in the network whether its data control, communications or controller instructions. The IoT platforms must also support the sensor protocols required for the blue roof project.
- ANT is a proprietary wireless sensor network technology, operates at 2.4 GHz.
- ZigBee 802.15.4 standard and operates at 2.4 GHz range of 250kps. Maximum nodes that can be incorporated are 1024 with range up to 200 meters. This can use 128-bit AES encryption.

Data Protocols:

- MQTT: Message Queueing Telemetry Transport it allows publishing and subscribing to a messaging model.
- MQTT-SN: MQTT for Sensor networks.
- CoAP: Constrained Application Protocol it allows integration with the web.
- DDS: Data-Distribution for Real-Time Systems allows publish-subscribe for real time and embedded systems.
- LLAP: Lightweight Local Automation Protocol sends simple short messages between intelligent objects using normal text, can communicate over any medium. 3 strengths are that it can run on anything now and in the future and it is easily understandable by humans.
- SSI: Simple Sensor interface is a simple communications protocol for data transfer between computers or user terminals and smart sensors.
- Websocket: Simplifies the complexity around bi-directional web communications and connection management.

Machine Learning

- SensorML provides standard models and XML encoding for describing sensors and measurement processes.
- Semantic Sensor Net ontology W3C describes sensors, observations and related concepts.
- SENML: Media types for Sensor Markup Language can be used by any sensor and it can use this in HTTP or CoAP to transport data.

B.2 Supporting Material for Types of Open Source IoT Platforms

Kaa

Kaa is currently the most popular open source platform in the community. It is a middleware that has great scalability, 3rd party integration and high reliability. Kaa is licensed under Apache Software License 2.0 which means that everything from the platform is free. It has no single point of failure meaning there is always a backup server if one fails. Kaa supports HTTP, TCP and MQTT. Some of the solutions that has been done with this platform are Industrial, Smart City and Smart Energy.

Macchina io

Macchina runs on embedded Linux devices with as little as 32 MB of RAM. It implements web-enabled, modular and extensible C++ and JavaScript runtime environment. The platform supports HTTP, MQTT, REST, JSON-RPC, SOAP, UPnP, Modbus, OPC-UA and CANopen. This platform has an embedded database and supports 3rd party integration. Some solutions done with Macchina are Smart Connected Sensors and Industrial IoT. The Commercial version includes more protocols and remoting framework.

IBM Cloud

IBM Cloud previously known as IBM Bluemix and IBM SoftLayer (Rouse, 2017) is an open source IoT platform that gives you 256 MB of cloud memory. IBM cloud consists of cloud computing services and offers both platform as a service and infrastructure as a service. It allows you to integrate and manage your cloud, and it offers a private and public cloud. Most used cases for IBM Cloud is disaster recovery, backup and restore, high-performance computing, GPU computing, hybrid IT management and websites and web apps. For more memory, services and programming languages you need to pay as you go or pay a subscription fee.

B.3 Supporting Material for Types of Proprietary IoT Platforms

Amazon (AWS) IoT

The main services of Amazon's platform include AWS IoT Core, Device management, Analytics, FreeRTOS. The Core is a cloud platform that allows easy and secure access between connected devices, cloud applications and other devices. It can support billions of devices and trillions of messages and is therefore very scalable. The Device Management allows easy and secure to organize, monitor, and manage remote devices. Analytics is a service that analyzes massive volumes of data without having to worry about cost and complexity. FreeRTOS is an operating system for microcontrollers that allows for low-power edge devices easy to program, deploy, connect and manage. AWS is also certified with ISO 27001.

Verizon IoT

Verizon has a 4G LTE network that supports category M1 technology and 4G LTE devices and it includes services especially for IoT. Verizon IoT offers a web-based, open development environment called ThingSpace that helps speed up the IoT deployment process. It gives tools to manage, develop and deploy IoT solutions.

Artik Cloud by Samsung

Artik cloud has an end-to-end ecosystem strategy, so you don't need to develop your own modules or network stack or cloud on-boarding. It supports protocols such as REST/HTTP, Websockets, MQTT, and COaP. It includes Java/Android, ObjC, Python, Ruby, and more software development kits. It has built in security and you can monetize your data.

APPENDIX C: SUPPORTING MATERIAL FOR TYPES OF PAC CONTROLLER CONFIGURATIONS

Supporting Material for Types of PAC Controller Configurations

National Instrument PAC Controllers:
NI's (National Instrument) platform-based approach combines modular hardware and software to control the process. Depending on the application area in data acquisition and control, there are two different types of controllers in NI, packaged controllers, and board-level controllers.

Packaged Controllers are stand-alone systems that combine software with processing and I/O for measurements, controls, or monitoring applications. The platform modules and controllers include three hardware platforms, CompactDAQ, CompactRIO, and PXI.

CompactDAQ [2]: It is a multi-core processor with inputs and outputs modular. In addition, it could communicate through Ethernet, RS232 serial.

CompactRIO [3]: It is a PAC (Programmable Automation Controller) combining a processor, which is used for Industrial Internet of Things (IIoT), monitoring, and control applications. It supports communication by Ethernet network.

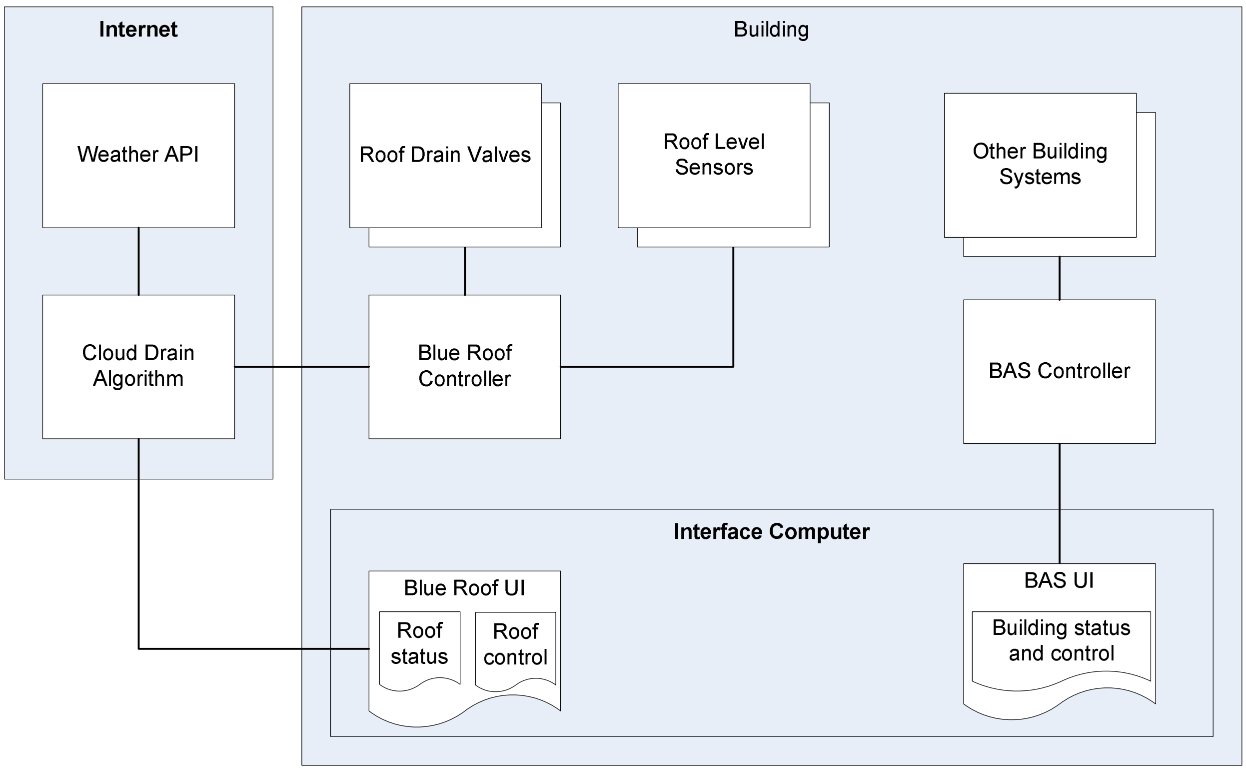
PXI [4]: It is a PC-based controller for measurement and automation systems. The controllers are either embedded or remote and communicate through Ethernet.

Board-level Controllers are small and embedded computers, which could be programmed for control and monitoring purposes. The I/O modular could be added to the controller for specific requirements.

APPENDIX D: SUPPORTING MATERIAL FOR THE INTEGRATION OF CONTROLLERS WITH BUILDING MANAGEMENT SERVICES

A blue roof system can be integrated into a Building Automation System (BAS) on several different levels that vary in complexity and functionality. The following section describes some possible configurations and their attributes.

No Integration



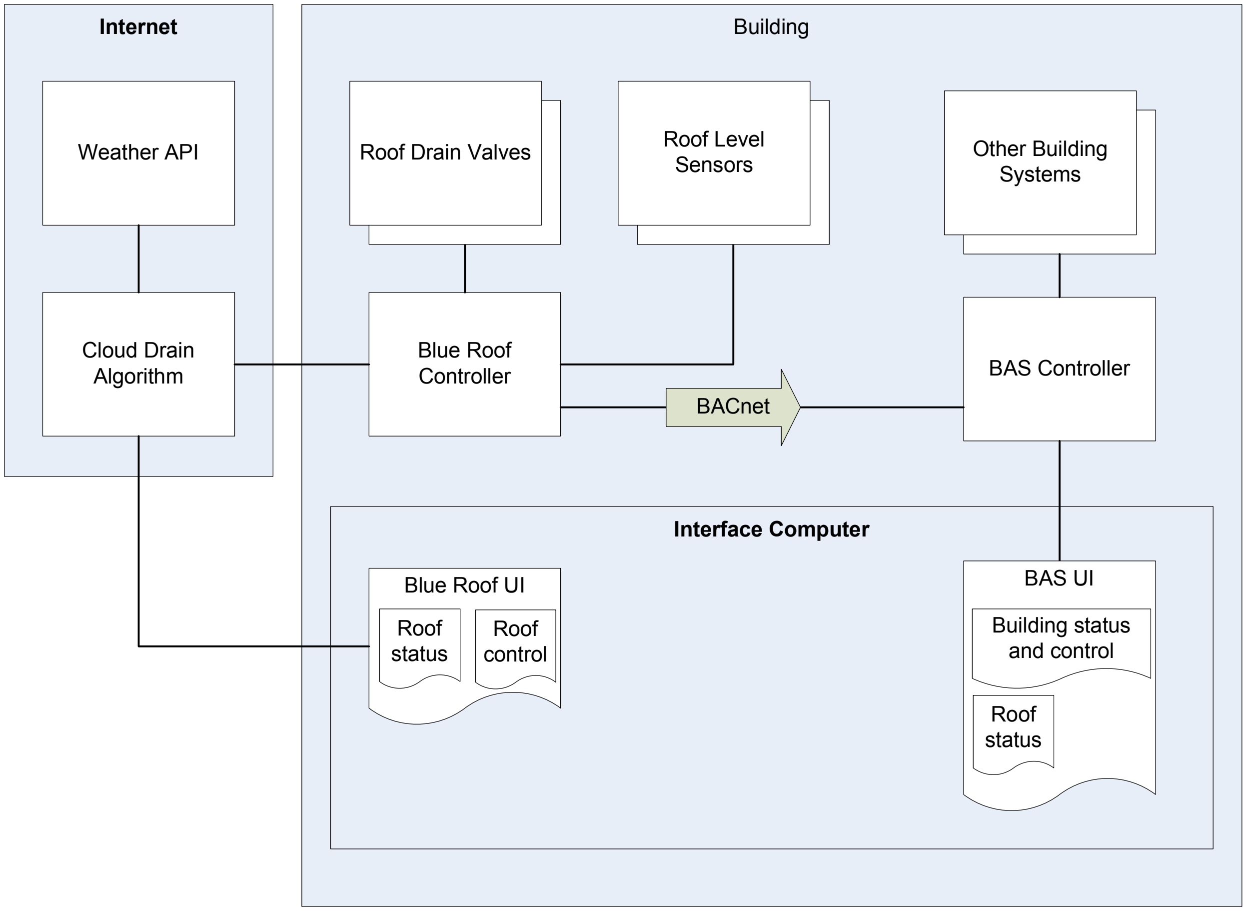
Source: RainGrid 2018

System has a separate blue roof controller running sensors, valves, and talking to the cloud algorithm.

Features:

- No integration effort
- Everything is monitored, calibrated and controlled through the separate user interfact (UI)
- Systems completely separate, no possibility of bad interactions
- Can't react to BAS-attached sensors like water demand, occupancy, etc.
- Need to look at two separate interfaces to see the whole building
- Cloud algorithm is updated and controlled by vendor

Monitoring Only



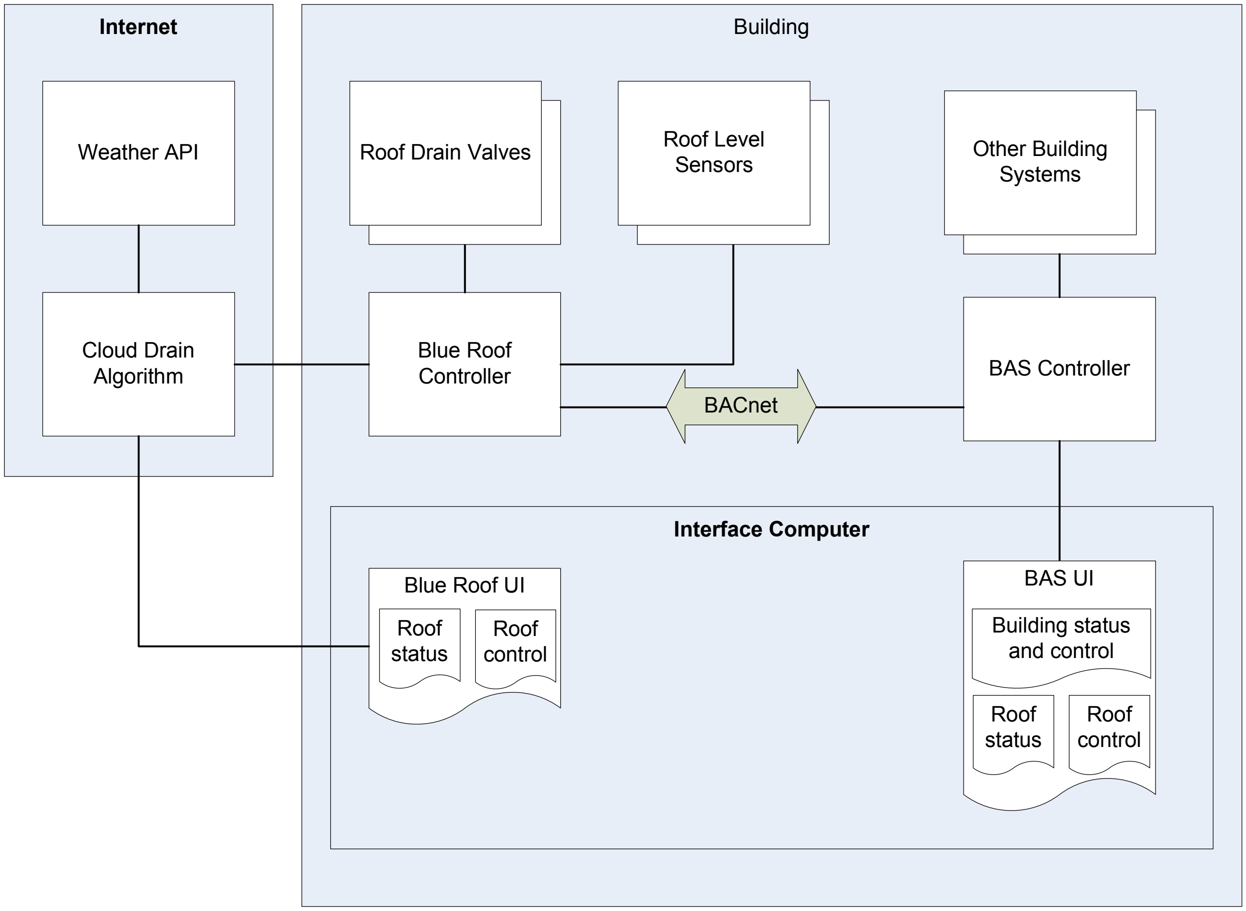
Source: RainGrid 2018

Similar to no integration, except with read-only BACnet (Building Automation and Control network) connection between BAS and roof controller.

Features:

- Minimal integration effort, need to export all required parameters through BACnet
- Can see status of system on BAS interface, but not change parameters
- Applicable to most BAS brands and models since BACnet is a well supported standard
- Separate UI still available and must be used for configuration

Monitoring and Configuration

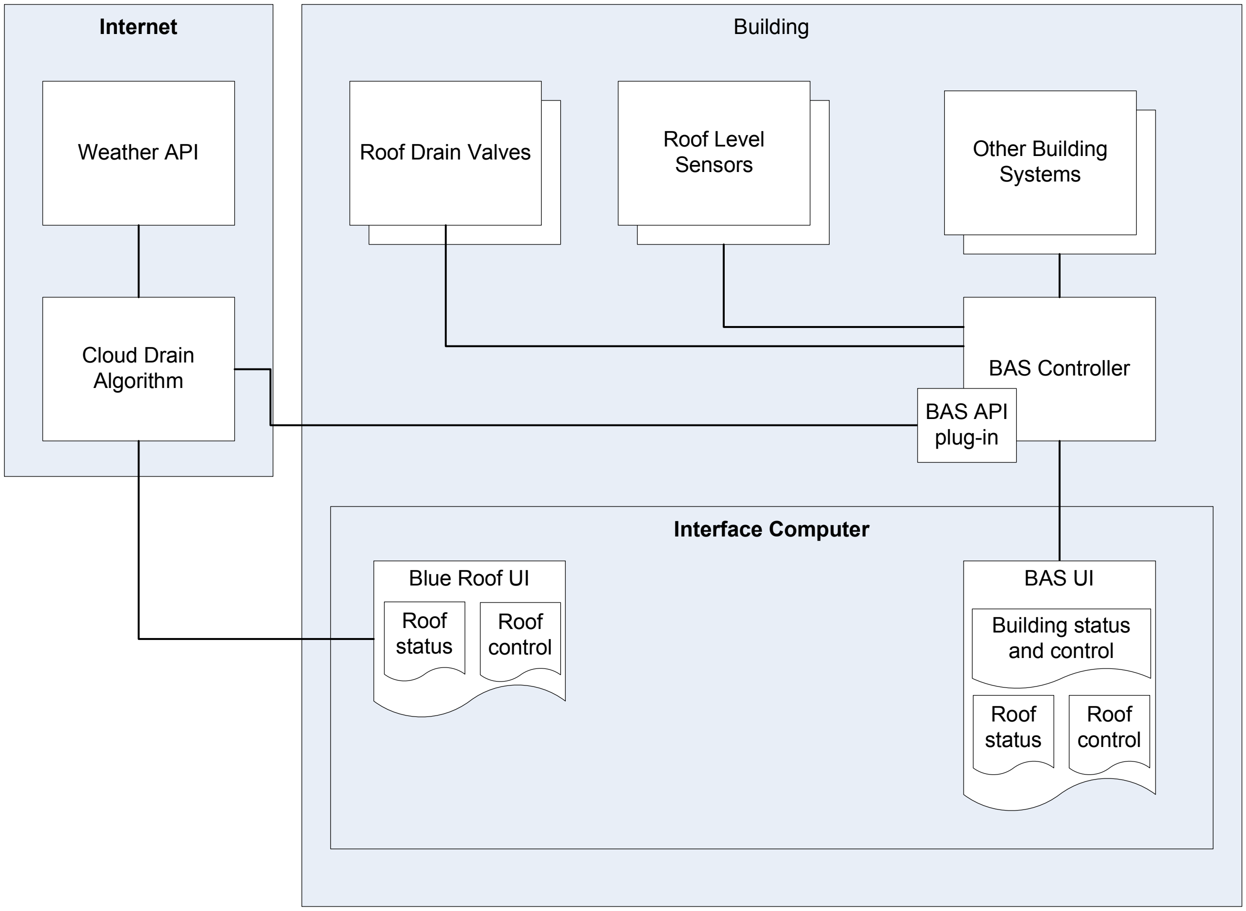


Source: RainGrid 2018

Same as no integration, but BACnet connection is bi-directional, allowing configuration as well as monitoring.

- Moderate integration effort, more BACnet parameters and controller behaviour changes based on extra inputs
- Everything done through separate UI can be done through BAS UI as well
- Can react to BAS events like water demand, other water systems, occupancy, etc.

BAS Plug-in Using Cloud Algorithm



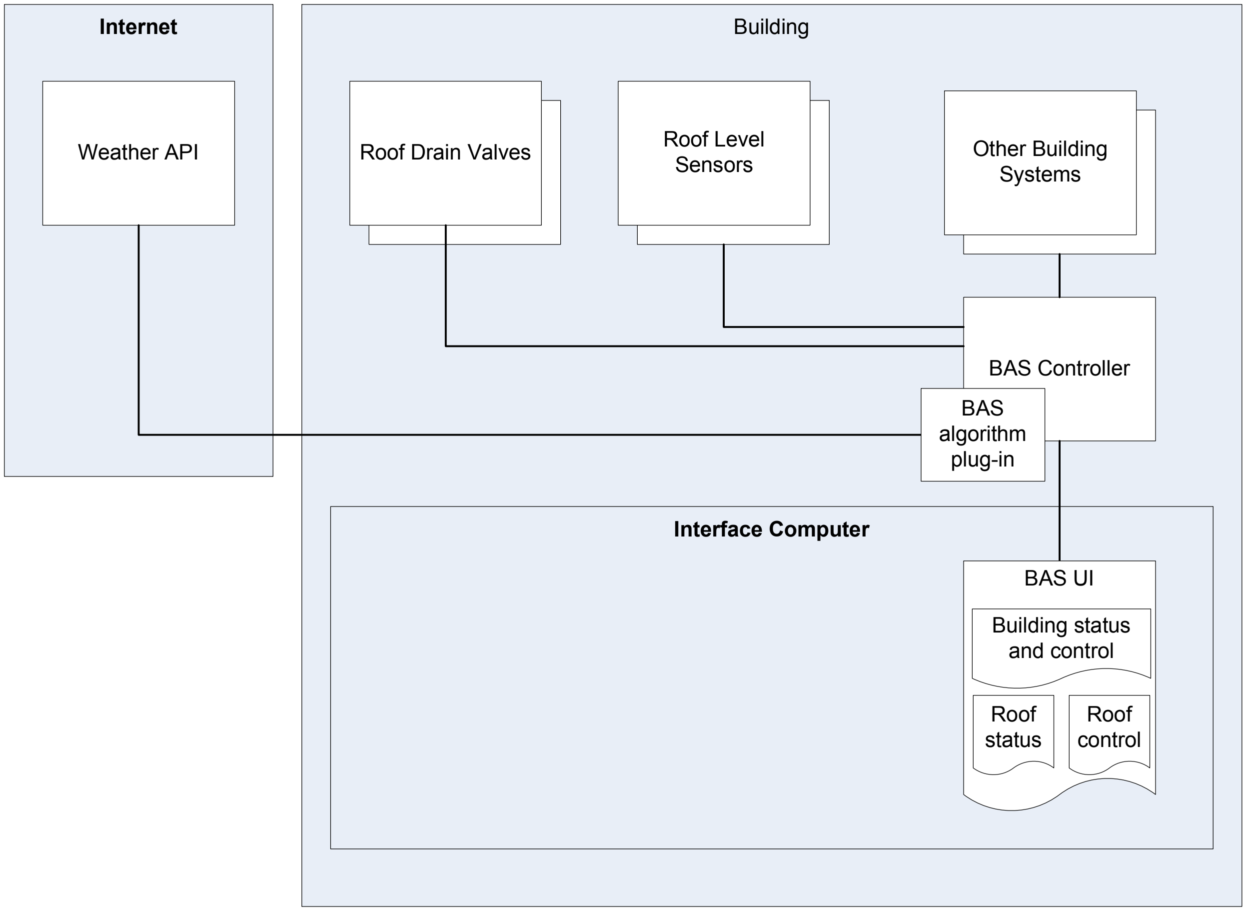
Source: RainGrid 2018

All sensors and valves are plugged into the BAS directly. The plug-in provides connection to the cloud API and BAS controls the roof based on the data from it and the sensors.

Features:

- High integration effort, need to write software plug-in for BAS
- Separate plug-ins need to be built for different BAS types
- Drain behaviour can be customized somewhat inside BAS based on available data from plug-in
- Plug-in may require updates when BAS is updated

BAS Plus-in with Algorithm



Source: RainGrid 2018

Same as plug-in using cloud algorithm system, but runs the algorithm locally and uses weather API directly.

Features:

- High integration effort, need to write plug-in for BAS, complete with drain algorithm
- Separate plug-ins need to be built for different BAS types
- No dependence on vendor cloud algorithm servers, algorithm runs right on the BAS
- No more vendor cloud UI either
- Need to update plug-in for BAS and weather API updates
- Plug-in can provide many customizations to change behaviour without involvement of vendor
- However, may still need to involve vendor for more complicated changes or updates

APPENDIX E: SUPPORTING MATERIAL FOR IoT AND RAIN HARVESTING SYSTEMS-RESIDENTIAL PILOT PROJECT

Although the study focuses on IC&I, RainGrid conducted a residential real-time rainwater harvesting pilot to test performance and inform recommendations for IC&I application and specifically for applicability to the CVC blue roof project.

Design goals:

One of the primary goal of a rain harvesting system is to minimize peak flow of a rain event. Non-automated cisterns frequently fail to do this because homeowners forget to or are unable to drain the cistern in time.

Reliability is the first design goal, since if the system is not working, it's as if there is no system, or worse, it may cause flooding by releasing the water at an inappropriate time.

Design goals for small house systems are different from large buildings: the small systems need to be installed in large quantities spread over an area to provide equivalent diversion to one large system. This requires controllers, sensors, valves, and miscellaneous hardware on every property. Therefore one of the main drivers for the design choices for the RainGrid system was cost per unit.

RainGrid's System Components

The RainGrid systems used in the Riverdale Pilot project consisted of the following components:

- 500 L cistern connected to house downspout
- Electric motorized ball valve to control outflow
- Pressure transducer at the bottom of the cistern to measure water level
- Custom built wireless controller for operating the sensors and the valve
- Custom gateway installed indoors to bridge between the wireless controllers and the Internet
- Cloud services providing API for the controllers and UI for home and system owners

System Operation

- Controller sends current sensor measurements to the cloud service every 30 seconds
- Cloud service checks rain forecasts for the exact location of the house, and combines that with the roof area measured during the install to determine total amount of water that will fall on the roof
- Cloud service sends responds to controller with the volume of the coming rain event
- Controller drains the right amount of water at least 6 hours before the event in the case when there is not enough capacity available

Specific Design Choices

Level sensor

Measurement Specialties U7100 pressure transducers were used in the Riverdale Pilot.

- The datasheet specifications looked great, high accuracy, built in temperature compensation
- Should not require zero calibration since they measure from the bottom vs. ultrasonic rangefinders measuring from top of container, need to know mounting height
- Hard to find ultrasonic sensor with short minimum range, water level cannot be close to top of cistern

Problems discovered over duration of the pilot project:

- The zero calibration was required due to variation between sensors
- Some sensors did not overwinter well, small amounts of water remained after draining, froze, expanded and stretched the sensor membrane, permanently affecting readings
- Small debris bypassed all filters in the cistern and got wedged in several sensors, affecting accuracy
- Sensors required exposure to atmosphere to measure tank pressure relative to it. The atmospheric orifice became clogged and resulted in incorrect readings

Solutions and recommendations:

- Calibration and additional filtering was added in firmware update to increase accuracy
- A lot of the problems were caused by the rough environment and the sensor being in direct contact with water and close to the ground
- RainGrid is testing ultrasonic rangefinders for the next version of the controller
- Flat roofs are very large containers, multiple sensors spread over the area are recommended to average out uneven surface level and to increase measurement accuracy

Valve

The valves used in the pilot were Tianjin Tianfei High-Tech Valve Co. CWX-25

- Standard sprinkler solenoid valves could not be used, they require minimum pressure to operate and a cistern has zero pressure when it's nearly empty
- Ball valves maintain state without using power, excellent for battery powered applications
- Specifications looked good, weather sealed, manual override in case of failure
- Position feedback, controller can sense if valve is open, closed, or in-between positions

Faulty weather sealing on some valves caused several types of failure:

- Position feedback stopped working, causing controller to keep trying to operate it until failure
- Complete failure due to motor seizing up
- Partial failure and high current draw, draining controller batteries prematurely

Solutions and recommendations:

- Problems caused by a harsh environment, all the components should be well sealed, or kept indoors
- Sanity checks on valve feedback sensors, and additional sensors such as current draw can be used to detect failure of the system early-on

Controller

- A custom controller was designed using common electronics components rather than using an existing industrial automation solution to keep unit costs low.
- Any kind of controller can be used as long as it can interface with the level sensors and valves
- Software/firmware updates allowed us to fix multiple problems without having to visit installations
- Control electronics and software are very reliable compared to sensors/actuators that interface with the environment, the only failures of controller board were because of incorrect assembly
- Many off-the-shelf hardware and software components available to build secure and reliable IoT devices

For a large building where there is existing building control infrastructure, industry standard controllers, sensors and actuators already exist and don't need to be built from scratch. Only software is required to make the building smart.

Cloud services

The pilot project used a single Virtual Private Server (VPS) to run all the cloud services for the controllers and users

- Standard VPS used instead of specialized cloud providers to allow any combination of off-the-shelf and custom services and software
- RainGrid has the expertise to develop completely custom software and web services
- Custom services written using standard libraries to be as simple and as reliable as possible
- All communications to controllers and end users encrypted using Transport Layer Security (TLS) for security and privacy
- Not as many analytics capabilities as specialized cloud providers, but easy to expand and data can always be exported and analyzed with third party services
- Remote controller upgrade ability built in from the start allowed quick fixes and feature additions after systems were installed

APPENDIX F: PERFORMANCE INDICATORS AND TARGETS

Climate Change Impacts	Indicator	Indicator Type	Baseline Conditions	Metric	Method of Quantification	What is the impact of the project?
Extreme Rainfall Causing potential damage to infrastructure (storm sewers), stream erosion, basement flooding, service disruption	Reduce pressure on existing downstream infrastructure by counteracting the effects of climate change Protect the integrity of conventional infrastructure from extreme weather events while extending the life expectancy of downstream stormwater infrastructure	Technical	The current performance of CVC's rainwater harvesting system without a blue roof or real time control system is being monitored Estimate average remaining service life of downstream storm sewer infrastructure based on extreme weather projections	Total volume (m^3) of stormwater removed from the storm sewer system Total peak flow reduction (m^3/s) to storm sewer system Additional conveyance capacity restored to downstream stormwater system Number of additional years of useful service life of downstream storm sewer infrastructure	Take an existing storm sewer network and estimate the peak discharge from a drainage area using the Rational Equation Method Based on the age of the network estimate the remaining service life based on original IDF curve parameters Based on the remaining service life assume premature surcharging due to extreme events and estimate loss of service life in years $Q=CiA$ Where: Q = Peak Discharge C = Runoff Coefficient i = Rainfall Intensity A = Drainage Area	Blue roofs with real time controls and rainwater harvesting cisterns on private lands may increase infrastructure resiliency to extreme weather
	Deferred or avoided capital and O&M expenditures for the Municipality	Financial	Estimate the life cycle cost to provide the same level of stormwater control on public lands	Return on investment to the municipality	• How do shifting capital and O&M costs from public lands onto private lands benefit the municipality? • Analyse the cost of a recent stormwater retrofit projects on public lands in terms of engineering	How will moving towards decentralized infrastructure on private property help reduce the current stormwater

Climate Change Impacts	Indicator	Indicator Type	Baseline Conditions	Metric	Method of Quantification	What is the impact of the project?
					costs, construction costs, land costs, and on-going Operation & Maintenance costs. • (Use the recent Matheson Pond retrofit in Cooksville Creek Watershed as a method of comparison) • Estimate the cost to operate a network of blue roof systems to provide the equivalent stormwater control as the pond retrofit	infrastructure deficit for municipalities across Canada
	Deferred or avoided operation and maintenance costs to the private landowner	Financial	Quantify the current operation and maintenance costs associated with CVC Head Office Current stormwater charge based on current performance Current water and energy costs associated with existing system	Return on investment to the landowner	• Estimate savings on the annual stormwater charge • Estimate annual water savings • Estimate annual energy savings • Estimate the avoidance of clean-up costs due to storm damage • Estimate reduced insurance premium costs • Estimate disruption costs to organization	Provide an alternative to other best management practices that has a lower pay back period and high performance

Climate Change Impacts	Indicator	Indicator Type	Baseline Conditions	Metric	Method of Quantification	What is the impact of the project?
Extreme Drought & Heat Potential amplification of vulnerabilities of water supply and sanitation systems in the Region	Deferred or avoided capital and O&M expenditures for the Region of Peel	Financial	The peak day ratio is the ratio of the highest daily water production volume in a year to the average daily water production volume in that same year. Peak day demands are expensive to meet as they drive infrastructure expansion.	Maintaining a low peak day ratio allows the Region to operate water supply systems more efficiently using existing infrastructure. Volume (m^3) of potable water offset with stormwater for flushing toilets and irrigation Reduction in 'peak day' demand by source off setting irrigation water during extended periods of hot, dry weather	• Estimate volume reductions during peak periods through irrigation and toilet flushing	The harvested rainwater can be reused to offset potable water use to maintain the peak day ration (and reduce the risk of exceeding the peak day ratio). Maintaining oeaj demands by offsetting potable water slows the rate of infrastructure expansion requirements especially for communities where the population is increasing.
	Reduction in GHG emissions	Technical	Past and current energy cost records for the CVC office The Region of Peel has quantified the energy savings associated with volume of water conserved	Mass of GHG reduced	• Estimate GHG emission reductions • Estimate electricity reductions	It is anticipated that a reduction in water demand due to rainwater harvesting reduces electricity use and GHG emissions associated with municipal water supply and pumping

Climate Change Impacts	Indicator	Indicator Type	Baseline Conditions	Metric	Method of Quantification	What is the impact of the project?
	Energy Cost Savings to Region of Peel and private landowner	Financial	Current energy costs for Region Energy costs for private landowner	Kilowatts of energy saved by reducing demand on potable water system Energy savings by not needing to treat the water to potable standards in the first place and not having to transport water via pumping stations. Water savings given that "at least 10% of the treated water does not reach end user because it is lost through the distribution system". Kilowatts of energy saved by cooling the roof via evaporative cooling	• Estimate GHG emission reductions • Estimate electricity reductions	- Support new greenfield developments where opportunities exist to downsize planned centralized infrastructure - Insulate landowners from rising water rates and energy costs, increased cooling demand costs, seasonal variation in energy prices - Reduce risk of increased black outs and brown outs such as power failure due to demand spikes

16.0 GLOSSARY OF TERMS AND ACRONYMS

16.1 Glossary

Blue Roof: a rooftop which attenuates or retains the rainfall which it receives, often in conjunction with a rainwater harvesting system.

Check dam: barriers on a sloped surface which temporarily detain or pond rainwater and release it slowly downstream, or in the case of a roof, to a drain.

Climate change mitigation: actions which aim to reduce greenhouse gas emissions, with the aim of moderating future temperature increases in rate and total amount.

Climate change adaptation: actions which aim to increase resilience to the known and predicted effects of climate change.

Evaporative cooling: reduction in temperature resulting from the evaporation of a liquid, which removes heat from the surface from which evaporation takes place.

Flow control drain: a device which slows the flow of water from a surface (e.g. a rooftop) and releases it at a controlled rate. Usually accomplished by placing a roof drain restrictor over an existing drain.

Internet of things: a network of devices that performs real world actions. While the internet consists of data exchanges between networked computers, tablets and phones, the IoT can include any electronic and mechanical device that can connect to the internet including coffee makers, door locks, fridges, rain gauges, and solenoid valves

Modular tray system: an array of plastic or aluminum trays which detain stormwater during rain events.

Pay-back period: the amount of time it takes to recoup an investment through profits or savings.

Peak flow: during rain events, peak flow occurs when the amount of runoff generated by an impervious surface is at its highest.

Pollution prevention: measures to prevent or reduce harmful chemicals from reaching storm sewers, including shutoff valves, dedicated fueling areas, dumpster management, spill response plans, etc.

Runoff volume: the total amount of runoff generated by an impervious surface or catchment, usually tallied over the course of a year.

Smart blue roof: a blue roof optimized for stormwater management with continuous monitoring and adaptive control, operated by an IoT network.

Stormwater infrastructure deficit: the shortfall in investment in stormwater systems needed to maintain those systems in their current condition.

Water quality treatment: measures for removing suspending solids and other contaminants from stormwater runoff.

16.2 Abbreviations

API: application program interface

ASTM: American Society for Testing and Materials, now ASTM International

BACnet: building automation and control network
BAS: building automation system
BMP: best management practice
BMS: building management system

C of A: Certificate of Approval (from the MOECP; now called Environmental Compliance Approvals)
CMAC: continuous monitoring and adaptive control
CoAP: Constrained Application Protocol
CVC: Credit Valley Conservation
CWWF: Clean Water and Wastewater Fund

DDS: Data Distribution Service for real-time systems
DSN: distributed sensor network

EASR: Environmental Activity and Sector Registry
ECF: English Cities Fund
EMF: electric and magnetic fields
EMI: electro-magnetic interference
EPDM: Ethylene Propylene Diene Monomers
EFVM: Electric Field Vector Mapping

FCM: Federation of Canadian Municipalities
FPGA: field programmable gate array

GHG: greenhouse gas
GTA: Greater Toronto Area

HMI: human machine interface

IC&I: industrial, commercial and institutional sector
IoT: internet of things
IIoT: industrial internet of things
ISO: International Standards Organization
ISP: Internet Service Provider

LSRCA: Lake Simcoe and Region Conservation Authority
LEED: Leadership in Energy and Environmental Design
LID: low impact development
LLAP: lightweight local automation protocol

MBR: modified bitumen roofing
MCIP: Municipalities for Climate Innovation Program

MNRF: Ministry of Natural Resources and Forestry
MQTT: Message Queueing Telemetry Transport
MQTT-SN: MQTT for sensor networks

NJDEP: New Jersey Department of Environmental Protection
NYDEP: New York Department of Environmental Protection
NYCSCA: New York School Construction Authority

O & M: Operations and Maintenance

PAC: programmable automation controller
PLC: programmable logic controller
PoE: power over ethernet
PVC: Polyvinyl chloride, a synthetic plastic polymer

RCNY: Rules of the City of New York
RF: radio frequency
RTAC: real-time automation controller
RWHS: rainwater harvesting system

SDL: superimposed dead load
SEML: Sensor Markup Language
SENML: Media types for Sensor Markup Language
SLLC: Student Learning and Leisure Centre
SPF: spray polyurethane foam roofing
SQL: Standard Query Language
SSI: Simple Sensor Interface
STEP: Sustainable Technologies Evaluation Program
SuDS: sustainable drainage system
SWM: stormwater management

Tc: Time of Concentration
TLS: Transport Layer Security
TPO: Thermoplastic olefin
TRCA: Toronto and Region Conservation Authority

UI: User Interface

VPS: Virtual Private Server

WES: Water Efficiency Strategy
WSN: Wireless Sensor Network

REFERENCES

[1] Intergovernmental Panel on Climate Change (2014). Climate Change 2014: Synthesis Report

[2] Environment and Climate Change Canada (2017). Climate Change and Variations Bulletin, Summer 2017

[3] Environment and Climate Change Canada (2015). Key Issues – Climate Change.

[4] Francis, David and Hengeveld, Henry (1998). Extreme Weather and Climate Change. Environment Canda, State of the Environment Reporting.

[5] Environment and Climate Change Canada (2016). Climate data and scenarios for Canada: Synthesis of recent observation and modelling results. Accessed at http://publications.gc.ca/collections/collection_2016/eccc/En84-132-2016-eng.pdf

[6] Muir, Robert (2018). Thinking Fast and Thinking Slow on Floods and Flow. Journal of Water Management Modeling, 26:C449.

[7] Environment and Climate Change Canada (2016). Climate data and scenarios for Canada: Synthesis of recent observation and modelling results. Accessed at http://publications.gc.ca/collections/collection_2016/eccc/En84-132-2016-eng.pdf

[8] Lejiang, Yu et al. (2016). Journal of Environmental Restoration Letters, 11 044003.

[9] Insurance Bureau of Canada (2018). Combatting Canada's Rising Flood Costs: Natural infrastructure is and underutilized option. Accessed at http://assets.ibc.ca/Documents/Resources/IBC-Natural-Infrastructure-Report-2018.pdf

[10] Federation of Canadian Municipalities (2016). Canada's Infrastructure Report Card. © 2016, Federation of Canadian Municipalities

[11] Environmental Commissioner of Ontario (2016). Urban Stormwater Fees: how to pay for what we need.

[12] International Institute for Sustainable Development (2013). Climate Change Adaptation and Canadian Infrastructure: a review of the literature. © 2013, International Institute for Sustainable Development.

[13] Statistics Canada (2016). Census Profile, 2016 Census. Accessed from https://www12.statcan.gc.ca/census-recensement/index-eng.cfm?MM=1

[14] Statistics Canada (2016). Population Projects for Canada, Provinces and Territories. Accessed from https://www150.statcan.gc.ca/n1/pub/91-520-x/91-520-x2010001-eng.htm

[15] CVC (2018). Economic Instruments to Facilitate Stormwater Management on Private Lands. Accessed from https://cvc.ca/wp-content/uploads/2018/02/CVC-Economic-Instruments-SWM-Private-Lands.pdf

[16] CVC (2018). Economic Instruments to Facilitate Stormwater Management on Private Lands. Accessed from https://cvc.ca/wp-content/uploads/2018/02/CVC-Economic-Instruments-SWM-Private-Lands.pdf

[17] CVC (2018). Economic Instruments to Facilitate Stormwater Management on Private Lands. Accessed from https://cvc.ca/wp-content/uploads/2018/02/CVC-Economic-Instruments-SWM-Private-Lands.pdf

[18] CVC (2018). Economic Instruments to Facilitate Stormwater Management on Private Lands. Accessed from https://cvc.ca/wp-content/uploads/2018/02/CVC-Economic-Instruments-SWM-Private-Lands.pdf

[19] Lefkowitz, J. R., Sarmanian, A. K., & Quigley, M. (2016). Continuous monitoring and adaptive control—the internet of things transforms stormwater management. Journal of the New England Water Environment Association, 50(1), 44–51.

[20] Kerkez, B., Gruden, C., Lewis, M., Montestruque, L., Quigley, M., Wong, B., … Pak, C. (2016). Smarter Stormwater Systems. Environmental Science & Technology, 50, 7267–7273.

[21] Roman, D., Braga, A., Shetty, N., & Culligan, P. (2017). Design and Modeling of an Adaptively Controlled Rainwater Harvesting System. Water, 9, 974.

[22] Environmental Commissioner of Ontario. 2016. Urban Stormwater Fees: How to Pay for What We Need.

[23] Infrastructure Canada. (2017). Clean Water and Wastewater Fund Program Overview [web page]. Retrieved from: http://www.infrastructure.gc.ca/plan/cwwf/cwwf-program-programme-eng.html.

[24] Ontario Ministry of the Environment and Climate Change. (2017). Policy Review of Municipal Stormwater Management in the Light of Climate Change [web page]. Retrieved from: https://www.ontario.ca/page/policy-review-municipal-stormwater-management-light-climate-change

[25] Zizzo, L., Allan, T., and Kocherga, A. (2015). Stormwater Management in Ontario: Legal Issues in a Changing Climate. A Report for the Credit Valley Conservation Authority. Retrieved from: https://cvc.ca/wp-content/uploads/2014/05/Stormwater-Management-in-Ontario_Legal-Issues-in-a-Changing-Climate_2014.04.29.pdf

[26] Henstra, D., and Thistlethwaite, J. (2017). Climate Change, Floods, and Municipal Risk Sharing in Canada. IMFG Papers on Municipal Finance and Governance, Monk School of Global Affairs. Retrieved from: https://munkschool.utoronto.ca/imfg/uploads/373/1917_imfg_no_30_online_final.pdf

[27] City of Guelph. (2017). Stormwater credit and rebate program starts January 1 [web page]. Retrieved from: https://guelph.ca/2017/12/stormwater-credit-rebate-program-starts-january-1/

[28] City of Waterloo. (2015). Stormwater Credit Program [web page]. Retrieved from: https://www.waterloo.ca/en/living/creditprogram.asp

[29] City of Victoria. (n.d). Rainwater Rewards Credit and Rebate Amounts [web page]. Retrieved from: http://www.victoria.ca/EN/main/residents/water-sewer-stormwater/stormwater/credit_rebate_amounts.html

[30] City of Philadelphia. (n.d.). Stormwater Grants [web page]. Retrieved from: http://www.phila.gov/water/wu/stormwater/Pages/Grants.aspx

[31] New York City Department of Environmental Protection. (2010). Rule Governing House/ Site Connections to the Sewer System. Retrieved from: http://www.nyc.gov/html/gbee/downloads/pdf/dep_rule_title15_ch.31.pdf

[32] Melton City Council. (2009). Guidelines for On-site Stormwater Detention [report]. Retrieved from: https://www.melton.vic.gov.au/.../building.../on-site_stormwater_detention_guidelines

[33] City of Marion. (2017). Stormwater Detention/Retention [report]. Retrieved from: https://cdn.marion.sa.gov.au/sp/Brochure-Stormwater-Detention-Retention.pdf

[34] City of Michigan. (1992). Roof Top Storage [report]. Retrieved from: https://www.michigan.gov/documents/deq/deq-wb-nps-rts_250896_7.pdf

[35] New York City Department of Environmental Protection (NYCDEP). (2012). Guidelines for the Design and Construction of storm water Management Systems. Retrieved from: http://www.nyc.gov/html/dep/pdf/green_infrastructure/stormwater_guidelines_2012_final.pdf

[36] New Jersey Department of Environmental Protection (NJDEP). (2017). Storm water Best Management Practices Manual Chapter 9.8 Blue Roofs. Retrieved from: http://www.njstormwater.org/bmp_manual/NJ_SWBMP_9.8.pdf.

[37] Philadelphia Water Department (PWD). (2015). Stormwater Management Guidance Manual. Retrieved from: http://www.phillywatersheds.org/doc/PWD-SMGM-v3_FullManual_JuneRelease_6.5.15.pdf

[38] New York City Department of Environmental Protection (NYCDEP). (2012). NYC Green Infrastructure Plan: 2012 Green Infrastructure Pilot Monitoring Report. Retrieved from: http://www.nyc.gov/html/dep/pdf/green_infrastructure/2012_green_infrastructure_pilot_monitoring_report.pdf

[39] City of Mississauga. 2018. Flow Control Roof Drainage Declaration. Retrieved from: http://www6.mississauga.ca/onlinemaps/planbldg/forms/building/PBFC_Flow%20Roof%20Drains%20Form_PDF.pdf

[40] Philadelphia Water. 2015. Stormwater Management Guidance Manual Version 3.0. Retrieved from: https://www.pwdplanreview.org/upload/manual_pdfs/PWD-SMGM-v3-20150701.pdf

[41] Philadelphia Water. 2015. Stormwater Management Guidance Manual Version 3.0. Retrieved from: https://www.pwdplanreview.org/upload/manual_pdfs/PWD-SMGM-v3-20150701.pdf

[42] Pazwash, H. (2016). Urban Storm water Management. Second Edition. Taylor & Francis Group.

[43] Stein, J., McLaughlin, J., and Bendernagle, L. (2012). Rooftop Control of Stormwater: A Sustainable Source Control Strategy in NYC Using Blue Roof and Green Roof Applications. Water Resources Impact, 14(4).

[44] New York City Environmental Protection. 2012. Guidelines for the Design and Construction of Stormwater Management Systems. Retrieved from: http://www.nyc.gov/html/dep/pdf/green_infrastructure/stormwater_guidelines_2012_final.pdf

[45] "How a Floating Switch Works", FPI Sensors International, [Online], Available: https://fpisensors.com/how-float-switches-work/

[47] "Liquid Level Control Probe - Conductivity Control", Advanced Control Technology, [Online], Available: http://www.actsensors.com/custom-sensors/liquid-level-sensors/control_probes.htm

[48] "Probe Level Sensor Working Principle", Water Level Controllers, [Online], Available: http://waterlevelcontrols.com/automatic-water-level-controller-working-principle

[49] Ultrasonic Level Sensor Working Principle", Water Level Controllers, [Online], Available: http://waterlevelcontrols.com/automatic-water-level-controller-working-principle

[50] "Introduction to Strain Gages", Omega Engineering Inc., [Online], Available: https://www.omega.co.uk/prodinfo/StrainGauges.html

[51] "How does an Electrical Strain Gauge Work?", HBM, [Online], Available: https://www.hbm.com/en/7328/how-does-an-electrical-strain-gauge-work/

[52] "Liquid Turbine Flow Meter Overview", Silver Automation Instruments Ltd., [Online], Available: http://www.silverinstruments.com/product/flow-measurement/liquid-turbine-flow-meter.html

[53] www.fueldump.co.uk/blog/wp-content/uploads/2016/08/turbine-meter.png

[54] "Rosemount 8705 Flanged Magnetic Flow Meter Sensors", Emerson, [Online], Available: www.emerson.com/en-us/catalog/rosemount-8705

[55] "Measuring or working principle of Vortex flow meter", Balaji Viswanath, [Online], Available: https://www.youtube.com/watch?v=MykH2aifGnA

[56] "Vortex Flow Meter", SHANGHAI WANGYUAN INSTRUMENTS OF MEASUREMENT CO., LTD., [Online], Available: http://en.wy4488.com/product_detail.aspx?cateid=18&id=117

[57] "The Vortex Flow Measuring Principle", Endress+Hauser, [Online], Available: https://www.youtube.com/watch?v=GmTmDM7jHzA

[58] S. Poddar, "What is an Actuator?," 9 November 2015. [Online]. Available: https://www.quora.com/What-is-an-actuator. [Accessed 15 May 2018].

[59] C. Gonzalez, "What's the Difference Between Pneumatic, Hydraulic, and Electric actuators?," 16 April 2015. [Online]. Available: http://www.machinedesign.com/linear-motion/what-s-difference-between-pneumatic-hydraulic-and-electrical-actuators. [Accessed 10 May 2018].

[60] Anonymous, "Four Types of Actuators," 6 June 2013. [Online]. Available: https://www.dvhardware.net/article63837.html. [Accessed 22 May 2018].

[61] T. Maesschalk, "The Four Major Applications of Electric Linear Actuators," 28 January 2016. [Online]. Available: https://www.dvhardware.net/article63837.html. [Accessed 28 April 2018].

[62] https://ussolid.com/3-4-npt-brass-electric-solenoid-valve-110-vac-normally-closed-water-air-diesel.html.html

[63] https://www.machinemart.co.uk/p/clarke-bip1000-1-electric-water-pump/

[64] http://www.nexusmodels.co.uk/festo-flow-control-valve-3mm-festo-tube-ideal-reducing-air-retract-speed-gro-qs-3.html

[65] N/A, "SmarTROLL Multiparameter Handheld," In-Situ Inc., 2018. [Online]. Available: https://in-situ.com/product-category/water-quality-testing-equipment/.

[66] Libelium, "Smart Water Sensors to Monitor Water Quality in Rivers, Lakes and the sea," Libelium World, 24 February 2014. [Online]. Available: http://www.libelium.com/smart-water-sensors-to-monitor-water-quality-in-rivers-lakes-and-the-sea/.

[67] D. Nield, "What Are The Advantages of Wired Networking?," Hearst Newspapers, 2018. [Online]. Available: http://smallbusiness.chron.com/advantages-wired-networking-71168.html.

[68] L. Acevedo, "The Disadvantages of Wired Technology," Hearst Newspapers, 2018. [Online]. Available: http://smallbusiness.chron.com/disadvantages-wired-technology-17833.html.

[69] I. Khan, "The Impact of Wireless Sensor Network (WSN) on Supply Chain Management," Bristlecone, 10 October 2014. [Online]. Available: https://www.bcone.com/IrfanTalks/the-impact-of-wireless-sensor-network-wsn-on-supply-chain-management/.

[70] IoT Anaylitics, "IoT Platforms the Central Backbone for Internet of Things," November 2015. [Online]. Available: http://iot-analytics.com/wp/wp-content/uploads/2016/01/White-paper-IoT-platforms-The-central-backbone-for-the-Internet-of-Things-Nov-2015-vfi5.pdf.

[71] B. "What You Need to Know About IoT Platforms," 2017. [Online]. Available: https://www.business.att.com/content/whitepaper/what-you-need-to-know-about-iot-platforms.pdf.

[72] B. "What You Need to Know About IoT Platforms," 2017. [Online]. Available: https://www.business.att.com/content/whitepaper/what-you-need-to-know-about-iot-platforms.pdf.

[73] AT&T Business (2017). What You Need to Know About IoT Platforms: How Platforms Stack Up in IoT. Retrieved from: https://www.business.att.com/content/whitepaper/what-you-need-to-know-about-iot-platforms.pdf

[74] Soubra, D. (2012). The 3Vs that define Big Data. Retrieved from: https://www.datasciencecentral.com/forum/topics/the-3vs-that-define-big-data

[75] Illunin, I. (2017). How to Choose Your IoT Platform – Should You Go Open-Source? Retrieved from: https://medium.com/iotforall/how-to-choose-your-iot-platform-should-you-go-open-source-23148a0809f3

[76] Ayla Networks (2014). How to Select the Right IoT Platform: Considerations Beyond Connectivity – Security, Flexibility, and Data Intelligence. Retrieved from: https://www.mouser.com/pdfdocs/SelectingtheRightIoTPlatformAylaWhitePaper.PDF

[77] Saltis, S. (2018). Comparing Open Source vs Closed Source Software. Retrieved from: https://www.coredna.com/blogs/comparing-open-closed-source-software

[79] http://www.ni.com/white-paper/52911/en/

[80] https://www.rainharvestingsupplies.com/rainwater-automation-kit-automation-controller/.

[81] http://www.cloudwatercontrol.com

[82] SCHWEITZER ENGINEERING LABORATORIES https://selinc.com/