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Integrating Asset Management to Achieve Infrastructure Sustainability and Resiliency in Stormwater Systems

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By

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ABSTRACT

As the world faces climate and resource pressures, there is an ever-growing demand for sustainable products and processes throughout the whole life cycle. Sustainable infrastructure has become one of the leading research topics in civil engineering. It refers to mitigating, decreasing, and even eliminating the social, economic and ecological impacts during the lifecycle of an infrastructure project, which includes its design, construction and operation. However, achieving sustainability is challenging and requires an interdisciplinary approach because of the many variables that need to be understood and assessed.

One field of expertise long practiced by municipal management but not necessarily by engineers is asset management. Asset management focuses on reducing risk while increasing the level of service. From an engineering perspective, physical characteristics dominate what should be assessed to improve infrastructure. What can be often missing is the perspective on how to effectively manage assets to best meet the community's needs, especially in situations where systems have been engineered to be as effective as realistically possible. Actively incorporating asset management approaches into sustainability assessment should significantly improve our understanding, analysis, and decision-making on how to engineer, maintain, modify, and even demolish infrastructure to meet our future challenges.

This research project will use a risk management framework to improve how a current stormwater system can be effectively managed. The framework will examine different mitigation factors. Using these factors, the framework will predict if a certain area is at a high or low risk. A case study will be undertaken using a mid-sized city to demonstrate the viability of the framework. The framework will assist in answering the question: will using an asset management approach improve infrastructure sustainability in stormwater systems?

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1. INTRODUCTION

1.1 Background

What is sustainable infrastructure? This question is increasingly common and while there are accepted definitions, there is little consensus on how to measure what constitutes actual sustainability. While physical parameters are useful fundamental indicators for assessing sustainability, they may be insufficient by themselves. A former doctoral student at the University of Windsor previously developed a functionality-survivability-sustainability (FSS) scale [1]. This scale can be used to determine how sustainable a current infrastructure system is: it may be functional, survivable (resilient) or in the best case, sustainable. The FSS system was tested on real-time, municipal data. The objective of the project was to apply the FSS framework to a mid-sized city and develop a baseline for future assessments. The project concluded that most of the infrastructure in Canada is functional, but their resiliency and eventual sustainability are being developed but not necessarily managed well. In summary, achieving sustainability for municipalities proves to be an ongoing challenge.

However, introducing asset management can help promote infrastructure sustainability. Ideally, the ability to prioritize major issues in the stormwater system should lead to more efficient use of budget and infrastructure resources, which should then help decrease environmental issues and major flooding events. This should also increase stakeholder satisfaction, principally that of homeowners that could be impacted by flooding. Despite the increasing implementation of asset management at the municipal level, there is a lack of guidance on how to incorporate and integrate asset management into the actual engineering of critical infrastructure systems. Curiously, many asset managers come from engineering backgrounds. While most engineering curricula do not include asset management, it appears to be a field many engineers transition into during their careers.

As an example, in 2016 and 2017, the City of Windsor experienced major flooding events. These events highlighted the challenges facing our infrastructure, particularly with respect to the above-mentioned need to achieve functional, resilient, and sustainable infrastructure. Flooding events have many economic, environmental and social consequences, and the frequency, intensity and duration of precipitation is increasing in the recent years [2]. To address flooding, the main solution from an engineering perspective is to increase the design capacity of the stormwater system. However, there are many issues with the current mitigation processes. Some of these issues include: the high cost to replace current system, limited land, and degrading infrastructure. Moreover, in some instances, the infrastructure is functioning as designed, but the circumstances surrounding its performance have changed. As a result, the solution to address such infrastructure challenges cannot consist of only building new infrastructure but to improve how it can be managed to better fulfill its functions.

1.2 Goal and Objective

The main goal of asset management planning is to reduce risk while increasing the level of service. There are currently many benefits to using asset management, but it is still primarily being used from a financial perspective. Many municipalities are now developing sewer master plans and managing risk from the city's perspective but there has been little done to manage the risks contributed by or controllable by homeowners. This latter observation is significant because of the increasing recognition that individual property flood risk adaptation measures will be critical as municipalities can only accomplish so much with stormwater infrastructure management.

The hypothesis of this thesis is therefore to investigate whether integrating asset management into current design practices will decrease risk. It is also important to maintain or increase the level of service and promote infrastructure sustainability as a larger goal; however, this thesis will focus primarily on the risk related research. As an additional outcome, the research will investigate what the collective efforts of many homeowners can accomplish when property level flood risk mitigation techniques are used.

2. ASSET MANAGEMENT

International standards ISO 55000 defines asset management as: "the coordinated activity of an organisation to realize value from assets." [3] Asset management involves balancing costs, opportunities or level of service and risks against the desired performance of assets to achieve the organizations goals. Many assets need to be managed from cradle to grave. The main objective from a financial standpoint is to minimize the costs of assets over the lifecycle, but from an engineering perspective, risk should be a critical factor in decision making.

2.1 Asset Management Objectives and Approach

- Providing a defined level of service and monitoring performance;
- Managing the impact of growth through managing the increasing demands;
- Developing cost-effective management strategies for the long-term that meet the defined level of service; and
- Identifying, assessing and appropriately controlling risks.

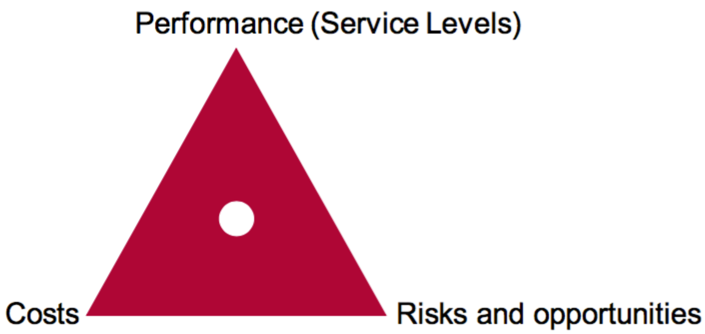


Figure 1- IPWEA Asset Management Goals [4]

There are multiple drivers and challenges that need to be organized and balanced. It depends on the perspective as to what driver is the most important. From a financial perspective, cost is the most important driving factor. From a customer perspective, level of service and performance is more important. The most important factor for an engineer should be the integration of risk and increasing levels of safety. Therefore, the differing opinions make it difficult to reach a consensus. The main focus of this research is to reduce the likelihood and impact of a basement flood.

Figure 2- Asset Management Drivers [5]

Asset Management Planning steps include:

1. Create an asset inventory providing information about the current value, the age and current state of assets involved.
2. Create a demand management plan to find out the current demand, how the demand will increase or decrease based on population and climate changes, and how the demand will impact the current level of service.
3. Examine the current level of service and customer expectations and provide ways to improve.
4. Examine the lifecycle of the existing assets, which includes operations, maintenance, renewal and upgrade. Provide a financial summary and start a cost benefit analysis to prioritize the capital budget.
5. Manage the risks by seeing where the highest risk is. Risk management matrix will help find the higher priority. For example, is a high risk, low consequence a higher priority than a low risk, high consequence? The risk management plan will be used to prioritize the risks and increase safety levels, which also reduces costly emergency expenditures and increased customer satisfaction.
6. Finally, develop a monitoring and improvement program to determine the current asset management planning gaps and establish procedures to improve.

2.2 Engineering Design vs. Asset Management Approach

The typical engineering design process has many similarities to the asset management framework observed in Table 1, but there are also many differences that could be incorporated into the current engineering design process. A design stems from the customer need, and therefore it generally anticipates the level of service. However, the current engineering design process needs to better consider a lifecycle asset management approach that not only looks at how a system will currently perform, but how it will perform in 30 years under the pressure of changing climate, possibly scarcer resources, and other unforeseen constraints.

Table 1- Engineering Design vs. Asset Management Correlation

Typical Engineering Design Process		Asset Management Process
Customer Need	⟷	Levels of Service
Problem Definition	⟷	Optimized Decision Making
Data & Information Collection	⟷	Risk Assessment and Management
Development of Alternative Designs	⟷	Information Systems and Data Management
Selection of Optimal Design	⟷	Measure Levels of Service
Implementation of Design [6]	⟷	Life Cycle Asset Management

The mid-sized city that was used for the case study demonstrated the lack of level of service research. There currently is no survey to assess how it is performing socially, and what the customers concerns about flood protection are. The city has just recently performed a survey on the perception of stormwater and basement flooding protection. There was also an asset management plan for stormwater, but it did not address the physical state of the assets, and instead focused on budgetary matters. Asset management provides a structured means to integrate the cost, level of service, and risk into a single platform. Asset management moreover requires evaluating the value of infrastructure to all members of society, including economic, ecological and social benefits and costs, therefore works towards achieving infrastructure sustainability [7].

As asset management increases in popularity through informing decision makers, it is important to see if asset management is being taught to engineers at an undergraduate level. Most engineering schools teach selective asset management principles throughout their degree, but there are few schools that have a designated undergraduate asset management course. However, there is a desire to change how maintenance and associated decisions are made. Decision-making is moving from the routinely subjective norm, to using systematic, holistic, data-driven, life-cycle and risk-based decision processes that are clearly aligned with the organization's strategic plan. Moving away from subjective decision making requires skills, techniques and processes that may not be part of the historical toolbox of those currently responsible for operating and maintaining engineering assets [7]. The Royal Melbourne Institute of Technology believes that two areas need to be provided with more course time. These include Asset Management and Environmental Engineering [8]. There is a growing demand for higher education in infrastructure asset management, as most engineers have to manage assets at some point in their career. The University of British Columbia in partnership with the Canadian Network of Asset Managers are proposing a graduate level asset management course. In this proposal they showed various schools that had asset management courses. Most of the courses offered were only seen at a graduate level, therefore most of the undergraduate students are not exposed to the framework until entering the workforce [9]. There are also many courses offered for finance majors, thus promoting this research to bridge the gap between finance and engineering asset management. Asset management could be a driver for attaining infrastructure sustainability. The main aspects of asset management parallel the triple bottom line interpretation for sustainability.

Table 2- Sustainability vs. Asset Management

Sustainability		Asset Management Process
Environmental	⟷	Risk
Social	⟷	Level of Service
Economic	⟷	Cost

3. LITERATURE REVIEW

Asset management and infrastructure sustainability are often treated as related but still separate subjects. Instead, the goal of this research is to integrate asset management to promote infrastructure sustainability practices, using stormwater systems as an example of how this can be accomplished.

While asset management has been an emerging concept for many years and an increasingly accepted practice, there are still many different interpretations of it. The implementation of sustainability has also become an objective or initiative for many organizations, but it is also difficult to define, can be interpreted differently, and can be approached in multiple ways. This literature review will:

1. First examine the similarities and differences between asset management and sustainability.
2. Determine if there are currently any risk management plans in place for stormwater.
3. Examine the homeowner's perceptions of flood management.
4. Investigate the preferred approach to improve the current perception.
5. Finally, investigate any attempts that integrate the two approaches.

If the review shows little evidence of the integration of the two practices, the asset management process will be assessed to determine how it can promote sustainability practices. Asset management is more well defined in concept and process than sustainability, meaning it may be easier to integrate sustainability goals into an asset management framework. The asset management framework is modified to include sustainability, a case study examining one area of the stormwater system for a mid-sized city will be undertaken. Asset management will be integrated into the current engineering design process to assess its contribution to decision-making and design [10].

3.1 Promote Sustainability and Resilience

The Report Card for America's Infrastructure [10] stated that sustainability and resiliency must be an integral part of improving the nation's infrastructure. Sustainable will not only preserve our high quality of life and environment we enjoy today but improve conditions in the future. Sustainability focuses on the triple bottom line approach, which concentrates on environmental, economic and social impacts. Another widely accepted definition from the Sustainable Sites Initiative "is the design, construction, operations, and maintenance practices that meet the needs of the present without compromising the ability of future generations to meet their own needs." Asset management and sustainability may differ in certain aspects but share many of the core concepts.

3.2 Definition of Engineering Asset Management (EAM)

According to Alfatih, Leong, and Hee [11] asset management has been generally accepted and defined as a cost-effective approach for asset operation, maintenance, upgrade and disposal. There are many different types of asset management, but the main focus for this research is on the Engineering Asset Management (EAM) approach. EAM manages engineering assets, such as equipment, building, and inventories. Many municipalities and government authorities have started to implement asset management in financial planning because they believe this framework will help achieve the organizations' goals for providing effective service at the lowest possible life cycle cost. Most of the literature on EAM focused on two important aspects: 1) the technology and the communication technology required to manage data relating to assets; and 2) the decision-making techniques to manage engineered assets. Understanding the concept of EAM helps inform good decision-making, manage risks, minimize lifecycle costs and improve communications internally and externally [12].

3.3 A Framework for the Engineering Asset Management System

It is important to understand how current asset management frameworks are being used. El-Akruti and Dwight [12] find that engineering asset management is a controlling element within organizations but is not well defined or understood [13]. Asset management varies in interpretation, but it is proposed that there are two main aspects of asset management: 1) the life cycle management of physical assets, and 2) the holistic system control of asset-related activities directed at achieving organizational strategy. The asset management and sustainability life cycle analysis has many of the same core concepts. According to Ouertani [13], the asset life cycle includes 4 main stages: acquire, deploy, operate/maintain, and retire. Asset management can be viewed from many different perspectives based on the organizational management levels. Combining the perspectives into one single framework that further merges sustainability related issues would advance how asset management can help promote resilient and sustainable infrastructure. However, asset management is only now starting to consider how to incorporate sustainability related issues. This research is focused on how sustainability from an engineering perspective can be effectively included within asset management.

3.4 A Risk-Based Approach to Sanitary Sewer Pipe Asset Management

Wastewater collection systems are an important component of any water system. Baah [14] said due to aging and inadequate asset management practices, the wastewater collection assets are in a state of rapid decline and urgent attention. In this study, a risk matrix and a multi-criteria decision matrix was used to assess the risk of sewer pipe failure. If the issues are outlined, future planning, rehabilitation and maintenance programs may become a priority. This assessment had two components: 1) a sewer deterioration model which predicts the state of the assets; and 2) a model that estimates the impact if a pipe were to break. The consequence of failure model depended on many different factors, such as proximity to schools, parks, rivers, and so on. It was found that there are many pipes in the system with a high risk of failure. The methodology of this model is very general, making it easy to adapt to different types of cities. The main issue is the model was mainly based on asset management and risk assessments. It did not include the environmental, social and economic impacts associated with the risks. This demonstrates how current asset management approaches are limited in their ability to deal with sustainability.

3.5 Sustainability Evaluation of Pipe Asset Management Strategies

According to Matthew, Piratla and Koo [15] the consequences associated with pipe failures can be widespread impacting service, while potentially causing damage, affecting traffic and contaminating water. Pipe asset management strategies have been adopted to reduce failures. The main question of Matthew, Piralta and Koo's [15] research is what pipe asset management strategy is the most sustainable. The three main strategies include a run-to-failure approach, a preemptive replacement, and a balanced approach between the first two. This is an extremely common question among many decision-makers. The evaluation focused on five main areas: quality of life, leadership, resource allocation, natural work, and climate and risk. Therefore, it integrated the triple bottom line approach with the asset management risk assessment. There were 144 questions answered and the results concluded that the balanced approach was the preferred alternative, mainly because it had a less disruptive nature of repair, and it has a use of condition assessment to determine when to perform repairs. This approach showed some integration of sustainability and asset management. It was a great tool for a decision maker to follow, as it was understandable for any end-user. The main issue with this research is that it focused more on management strategies than actual risk. Most of the municipalities already recognize that a balanced approach should be used because maintenance is required for an asset to reach the maximum service life.

3.6 Homeowners' Perceptions of Property Level Flood Risk Adaptation Measures

What is the role of the homeowner in mitigating risks to infrastructure from flooding?

> "There is a growing body of research that suggests that property-level flood risk adaptation (PLFRA) measures have the potential to benefit homeowners by reducing the impact of flooding on households. Emphasis has, therefore, been placed on the implementation of PLFRA measures, and yet despite this, the take-up among the at-risk residents in England is low." [16]

This research article examined why homeowners are not using the risk adaptation measures currently in place today. It lacked an education section to show how using the measures could be beneficial to the community as well as the government. The current lack of education and a communication with the residential level could outline why the current uptake of PLFRA measures is extremely low. Currently, many of the homeowners believe that the stormwater and flood management is the responsibility of the government. If a study is done using the risk management process, it could hopefully inform homeowners and government officials that integrating asset management into current engineering will help achieve infrastructure sustainability.

3.7 Intra-utility Performance Management Model (In-UPM) for the Sustainability of Small to Medium Sized Water Utilities: Conceptualization to Development

"Over the last several years, water utilities have been very keen towards effective asset management due to several emerging factors, such as increasing number of customers and their expectations, awareness towards water resources conservation, environmental and climate change issues, lack of trained personnel, stringent regulatory requirements for energy conservation and public health safety, and financial challenges." [17] Most of the water utilities use effective performance assessment, which is comparing a utility's performance with other similar utilities. This research was used to develop a model for performance management of small to medium sized water utilities. The purpose is to help utility managers prioritize their investments, and this article focused on sustainability assessment. This research proved to be different than other models based on the use of Fuzzy Rule Based Modeling (FRBM). The fuzzy set theory was developed by Zadeh [18] to methodically incorporate human reasoning in decision-making. This model is used to deal with imprecise knowledge in the form of if-then rules and can help where the inputs are subjective. The research concluded that the model is an effective tool for a sustainability assessment.

3.8 A Multi-Criteria Decision Support Framework for Sustainable Asset Management and Challenges in its Application

According to Bristol [19], the Institute of Asset Management defined the goal of asset management as “the optimum way of managing assets to achieve a desired and sustainable outcome.” Based on Niekamp, Bharadwaj, Sudhukhan, and Chryssanthopoulos [20] an optimal solution can be achieved by balancing performance quality, cost and risk over the whole life cycle by integrating economic, environmental and social factors in a rational decision-making process; essentially integrating sustainability into the asset management framework. A multi-criteria decision analysis was used to identify optimum solutions. The first step was to incorporate environmental impacts through a life cycle assessment. The next step was to look at the risks and uncertainty using asset management framework. The last step in this particular research was to find the tools and techniques to address the challenges. One of the main findings in this research is that, “it is widely accepted that the optimum solution for a decision-maker facing a multi-objective problem is often not straightforward and may not even exist” [21]. This method is a suitable method for a sustainability analysis, but how can an optimum solution be reached? Based on the research of Niekamp [20], a major aspect that is neglected in sustainability assessment is the integration of risk. The authors applied the framework to a case study in the marine industry. This research is done within industrial and production engineering and is therefore more focused on the improving the process and less on the final results. They did however identify some important challenges with using a MCDA for sustainable decision-making, which included lack of data availability, different opinions on weighting, as well implementing the framework.

One major issue of this research is that the framework was very difficult to follow. For an end-user with little knowledge of the integration of the two frameworks, it would require multiple training exercises to properly use the MCDA. Another issue is this research integrated asset management into a sustainability framework. There is very little research integrating sustainability into an asset management framework. The asset management process is more widely defined and may make it easier for decision-makers to understand.

3.9 Incentives for Stormwater Control

Municipalities have provided multiple incentives to increase implementing green projects. To deal with the problems caused by stormwater runoff, many cities have adopted stormwater "best management practices." The practices can range from, for example, educating a homeowner to water the grass in the evening when it evaporates less, to installing retention ponds in new developments. Convincing commercial properties to participate in stormwater runoff control is done usually through a command-and-control policy, such as a regulating body legally requiring commercial owners to install low impact developments. Based on the literature, researchers have found that residential homeowners respond well to economic incentives to participate in stormwater reduction. In addition, the public responds well to education about the stormwater issues. In most cases, relying on educational material instead of monetary incentives is less costly [22]. Based on this study, using education to motivate homeowners is a cost-effective beneficial option, along with the additional option to provide monetary incentives.

3.10 Using the Balanced Scorecard as a Strategic Management System

The literature above examined at the current perception of stormwater management. The engineers currently have a lack of ability to communicate the risks and mitigation techniques to the homeowners. There are many homeowners that are not educated about the possible risk reduction that can occur by implementing mitigation techniques. Based on the above review, there have been multi-objective analyses, performance management models, and sustainability assessments, but what may currently be missing is a tool that can easily communicate the risks and possible reduction techniques. As an example, the Harvard Business school uses a balanced scorecard to communicate progress with its own internal staff. This scorecard supplemented traditional financial measures with three perspectives: customers, internal business processes and finances, and learning and growth. Harvard found that the scorecard was an effective communication tool because providing its employees with individual scorecards helped them better understand how their own productivity supports the overall strategy of the school. "Building a scorecard can help managers link today's actions with tomorrow's goals." [23] In a similar manner, using a scorecard approach can potentially help an individual homeowner understand the issues related to flood management by demonstrating how much of a difference a homeowner can make in risk reduction through participating in the implementation of low impact developments. Based on the review, a scorecard offers significant potential communication and educational value for interactions between a city and homeowner.

3.11 Linking Asset Management with Sustainability: The Australian Sector

According to Marlow, Beale and Burn [23], asset management should be a key vehicle for delivering the sustainability goals of water utilities because assets are intimately linked with the delivery of triple-bottom-line outputs. The goal of this article was to conduct a series of interviews with water professionals from around Australia to find linkages between asset management and sustainability. There were three main sections in the interview. The first section was meant to see the different opinions on the meaning of asset management and sustainability and the link between the two. Depending on the interviewee, the interpretation of what both meant was very different. For example, some professionals believed sustainability was based on financial longevity, whereas others believed it was anything labeled environmental. The lack of a common understanding on the definitions of asset management and sustainability could be an obstacle to integrating different assessment approaches. There were a few water professionals that believed there was no difference between asset management and sustainability. One asset manager noted, "Sustainability is a broader outward-looking approach than asset management since it requires consideration of stakeholders and the environment" [23]. However, the majority response for the link between asset management and sustainability related to decision-making. Many believed that the critical link is the process in place to support decision making for engineers, which is where sustainability issues are considered. Therefore, it is believed that the most significant difference will be achieved at the system design phase. The next section of the interview examined the successes and remaining challenges. Many believed that the resilience of existing assets and the level of service provided to customers were current successes. The remaining challenges were found to be willingness to pay for sustainability, a need to develop a better understanding of asset management tradeoffs and sustainability in broader system terms, as well as evolving the data, information and tools to support better decision-making. This research found that there were more issues with the people than the assets themselves. In conclusion, the research of Marlow [23] provided insight to the "business-as-usual" decisions when decision makers have poor data, inadequate tools, and only a vague definition of sustainability. This article provided significant insight into the different opinions and challenges integrating separate frameworks focused on asset management and sustainability. The research supports that sustainability and asset management as approaches should be integrated, but this has currently not been achieved, and attempts to date fall short.

3.12 Summary of Literature

Given the gaps in the current frameworks, will the integration of asset management and sustainability help attain infrastructure sustainability in stormwater systems? The goal of this research is to use asset management to achieve sustainability practices. The literature review investigated the current approaches for the research of this topic. Asset management has many different definitions, but commonalities focus on a cost-effective approach for asset operation, maintenance, upgrade and disposal [11]. Sustainability also has many different definitions, but it frequently takes the triple bottom line approach, which focuses on environmental, social and economic impacts. The literature review also highlighted the similarities and differences between the two approaches. A key element that is common between the two is the focus on lifecycle assessment, which includes the design, construction, operation and maintenance, repair and replacement, as well as disposal of a product or process. The main differences are that sustainability is much broader and focuses on natural resources, environment, and ecosystems. Asset management focuses on risk, cost, physical assets and the customers. Focusing on the core concepts of both frameworks may make it easier to integrate. The research to date is not easy to follow for non-specialists, and for the most part, integrating asset management and sustainability is difficult. The literature review highlights many of these gaps in the past research. It primarily focuses on assessing the risk of pipe sewer failure and predicting the state of the assets, and therefore leaves out other important risk factors that will be incorporated in this research. The literature on property level flood risk mitigation techniques focused on the homeowners' perceptions but more importantly did not address ways to change the perception and educate homeowners on the risks they could mitigate. Managing the risks from both sides will help the stormwater management and demonstrate that asset management can help attain infrastructure sustainability. There is a significant disconnect with who is responsible for dealing with flooding and this stems from the lack of communication and education. However, asset management with its defined approach provides a platform to provide information to the homeowners, as well as the engineers and municipalities. The literature review revealed that current approaches to stormwater management are more reactive than proactive. There is currently no step-by-step approach to managing the risks associated with basement flooding. There were multi-objective analyses, and risk-based approaches, but they lacked a proper structure to deal with the overall circumstances that most municipalities face. The risk scorecard that will be formed in this paper can be used as a tool to manage the current stormwater assets, reduce the risk and cost, while increasing the level of service through education.

4. METHODOLOGY

To test the effectiveness of integrating asset management into current engineering practices for a stormwater system, the following assessment and then case study development will be undertaken.

The first step in the process was to design an asset management plan for underground infrastructure in the City of Windsor, the city data was used in the case study. This plan outlined the current gaps in the engineering process and narrowed the focus to the integration of risk reduction.

The next step in the procedure was to analyze the effects of flood-resilience technologies for the homeowner. A cost-benefit analysis was done to inform a consumer about what technologies will be the most beneficial. Some examples of homeowner activities include downspout disconnection, distributing rain barrels, and installing backflow preventers.

A case study using the City of Windsor will evaluate what are the potential benefits of integrating asset management practices with sustainability approaches to attain infrastructure sustainability in a stormwater system. After recent flooding in the city, the residents were outraged by flooded basements. The city has recently suffered two- 1 in 100-year storm events in the last two years; Figure 3 shows 2017 event.

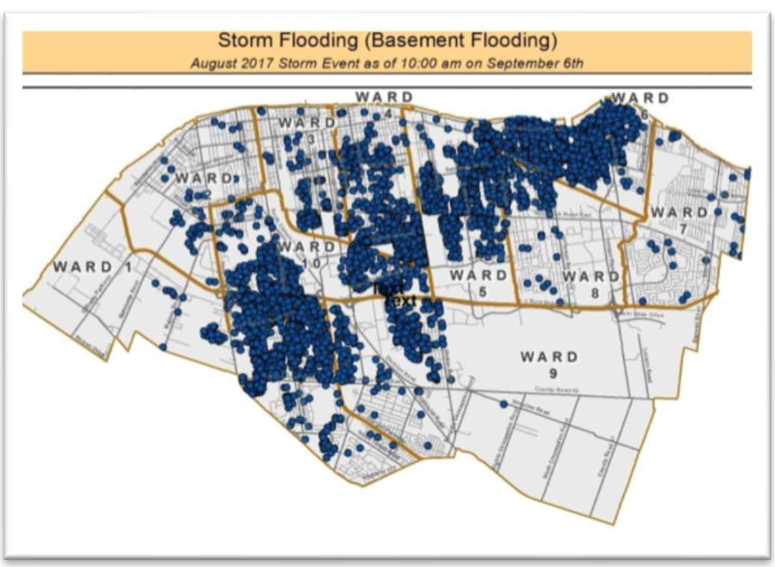


Figure 3- August 2017 Flooding Event [24]

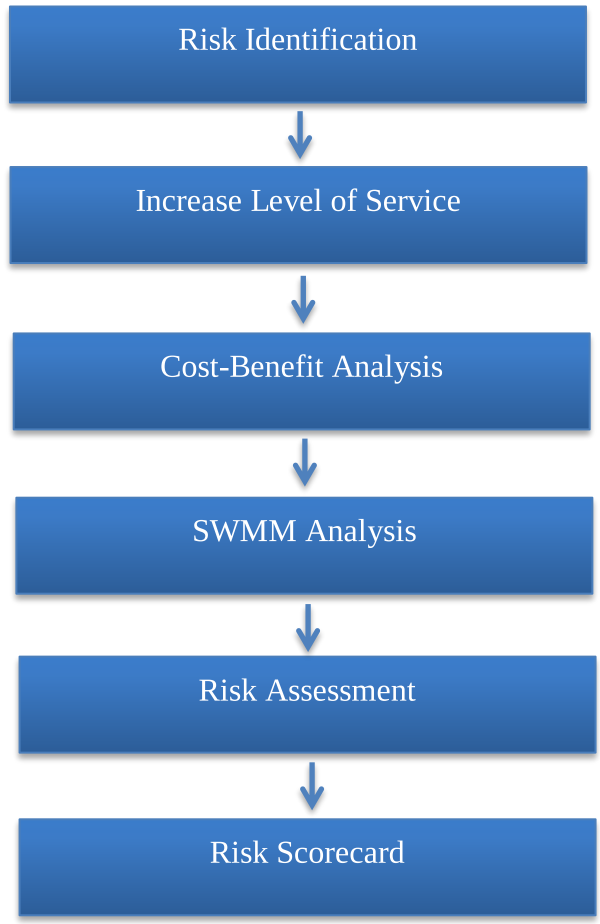
A record breaking 6000 homes were flooded in the most recent storm event. Over 100 mm of rain was received in the area over 6 hours: there is currently no sewer system in the US or Canada that could have effectively managed that amount of precipitation. The system was performing as it was supposed to and “changing every sewer line would take over 30 years,” [2] so there is no immediate, physical solution. Instead, the most appropriate solution could instead be to manage the risks using an asset management framework.

The research team collected data from the mid-sized city to start the risk assessment. A Stormwater Management Model (SWMM) was used to model the flooding reduction based on what low impact development (LID) was introduced. Thirty-one different combinations of LIDs we modelled to find out the percent reduction per square foot of LID introduced.

The next step was to perform a risk assessment of both the LIDs, as well as other property level mitigation techniques. The impact was assessed based on the LIDs implemented and the SWMM model created in the last step. The likelihood was found using a multi-objective analysis of the property level mitigation techniques.

The last step was to use the data from the risk assessment to create a risk scorecard. The scorecard is completed out by a homeowner and it will evaluate their current level of risk based on the Impact vs. Likelihood. The property level mitigation techniques will be the risk reduction factors. This is also a risk treatment framework because the homeowner can re-do the analysis with different combinations of mitigation techniques and the cost analysis to find out what technique would be the most beneficial. This will also benefit the engineers, because they will see the actual number of mitigation techniques implemented and will help decision makers prioritize upgrades and subsidies. These steps are shown in Figure 4. This analysis therefore focuses on the individual stakeholder (a single homeowner), while it is possible to customize the analysis for individual homeowner differences, the intent of this research is to focus more on general outcomes that can be reasonably extrapolated from a single homeowner analysis.

Figure 4- Asset Management Process



5. ASSET MANAGEMENT APPLIED TO CITY OF WINDSOR CASE STUDY

5.1 Asset Management

An asset management plan was used to determine the current state of the assets for the case study. The first step of the plan was to lay out the goals and objectives that asset management plan would help reach, such as sustainability and economic efficiency. The next step would be to observe the demand drivers, such as population increase, and how this would affect the current services provided. The last step in the plan will determine the current age and state of the assets. The plan also assessed the current level of service and ways to improve the plan. The main gap in the asset management plan was the lack of risk management, and therefore raised the need for a risk management scorecard.

Table 3- Goals and Objectives of Asset Management

Goal	Objective	How Goal and Objectives are addressed in AM Plan
Sustainability	Safe, sustainable, effective and efficient infrastructure.	The asset management plan focuses on cost, risk and level of service, which is related to the triple bottom line approach of environmental, social and economic factors.
Economic Efficiency	Optimal use of existing infrastructure. The provision of infrastructure in a coordinated, efficient and cost-effective manner.	This plan will outline the current availability of resources and help with the allocation and decision making to best suit the City.
Resiliency	The ability to recover quickly after a major flooding event.	More proactive risk management planning will create a less severe event and therefore increase

		response times and emergency management.
Environment	Protection of the environment by minimizing impact to natural heritage features.	The environment can be directly harmed by a break or leak in the linear asset. This plan will outline where the major risks are and how to prioritize them.
Community Expectations	Decrease the level of risk while increasing the level of service.	The plan will increase the current level of service and community expectations and will drive the use of a customer satisfaction survey.

Table 3 shows how asset management outlines the goals and makes them more achievable. Current asset management focuses more on the financial aspects rather than engineers using it for the physical aspects. Stormwater data from a mid-sized city was used for this asset management plan. Asset management outlines the demand drivers and how they impact the current service levels as shown in Table 4. As the population, demographics, rain intensity and consumer expectations increase, the services provided are expected to increase. The age profile and rating of the current system in figure 5 and 6 are also included to demonstrate what needs to be prioritized to get the best system possible. The main goals for the demand management plan in table 5 include: increasing green infrastructure, managing the current assets the best possible way, and providing plans to increase flood protection.

Table 4- Demand Drivers, Projections and Impact on Services

Demand drivers	Present position	Projection	Impact on services
Population Change	218270	Increased by 3.1% since 2011	Small increase in demand
Demographic Change	Median age is 40.1	Median age increased to 42.1 since 2011	Small increase in demand
Climate Change	Large increase in rain intensity and duration	Will most likely keep increasing	Large increase in demand
Consumer Expectations	High	Increasing	Increase demand for more flood protection services

Table 5- Demand Management Plan

Demand Driver	Impact on Services	Demand Management Plan
Population Change	Small increase in demand	Increase green infrastructure to offset the higher demand on the system.
Demographic Change	Small increase in demand	Increase green infrastructure to offset the higher demand on the system.
Climate Change	Large increase in demand	Prioritize the capital upgrade and renewal activities for the linear assets to decrease risk
Consumer Expectations	Increase demand for more flood protection services	Provide downspout disconnection, eeling services and plans to increase flooding protection

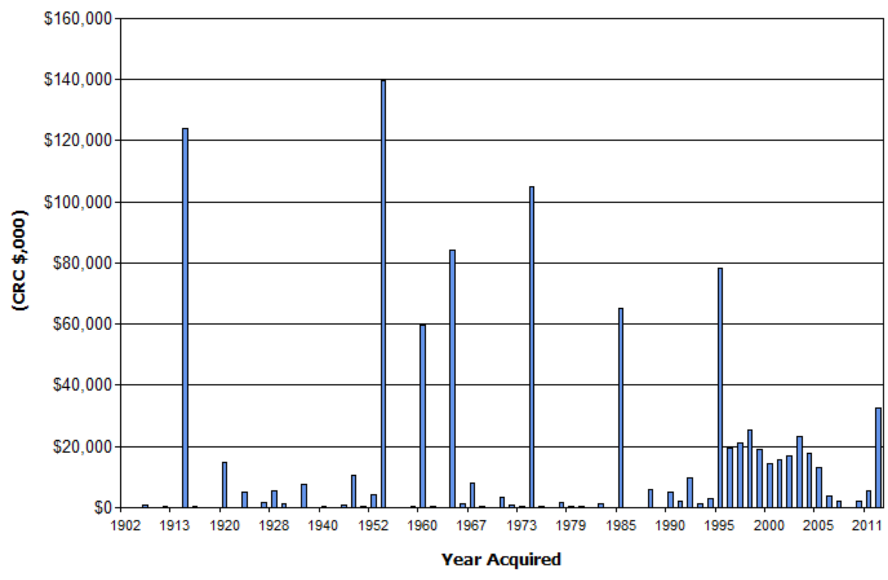


Figure 5- Asset Age Profile [4]

The majority of the sanitary and stormwater assets were acquired in 1952 and are now nearing their end of their useful life. It will take years to replace the current infrastructure in place, so an immediate treatment plan is to manage the risks from a homeowner level. To replace every pipe in the City of Windsor, it would cost upwards of $3,000,000,000 which is not realistic nor feasible.

Figure 6- Asset Rating [4]

Overall the condition of the City's assets is fair. 50% of the City's stormwater and sanitary asset inventory is in good to very good condition, 40% is in fair condition, and about 10% is in in poor to very poor condition. However, as seen above in the age profile, many of the sewers are reaching their useful lives and this could significantly alter the overall rating in subsequent years. Given that wastewater and storm water collections systems comprise over 25% of the City's assets, this is an area that will be the focus of future condition assessment programs.

Table 6- Condition Grading Model [4]

Condition Grading	Description of Condition
1	**Very Good**: only planned maintenance required
2	**Good**: minor maintenance required plus planned maintenance
3	**Fair**: significant maintenance required
4	**Poor**: significant renewal/rehabilitation required
5	**Very Poor**: physically unsound and/or beyond rehabilitation

5.2 Level of Service

As the chance of flooding increases, many Canadians are currently unaware of the risk they currently face, and what steps they could take to mitigate that risk. A new study titled, *Canadian Voices on Changing Flood Risk,* surveyed 2,300 people living in high-risk flood zones across Canada. It found 94 per cent of people surveyed did not know their homes were at risk, and most have taken no action to protect their homes from floods [25]. On average, the Canadian government pays out about $1 billion per year in disaster relief and about 75% is used for flood damage. If the homeowners knew the risks, and what steps they need to take to decrease risk, the Country may be able to spend more money on creating more resilient stormwater systems, by increasing subsidization for low impact developments, as well as other mitigation techniques.

In the most recent flood in Windsor, the city received about 230 mm of rain in less than 24 hours with about $124 million in insured losses. The City estimates that uninsured losses were three times that amount, totaling $0.5 billion in economic losses from one storm event. Extreme rain events and average precipitation appear to be increasing: the average precipitation has increased by 125 mm since 2000 and is still rising.

Table 7- Precipitation Average

	Before 2000	After 2000
Precipitation Average	918 mm/year	1043 mm/year

"It is simply a matter of time before all homeowners experience overland flooding, so preparedness should be in place now." [26] Most insurance companies offer sewer-backup insurance, but there are very few companies that offer overland flood insurance. This type of flooding is any flooding that enters through cracks in foundation, windows, and doors. Some people feel "cheated" when no disaster occurred after they had purchased insurance. A year in which a flood insurance premium was paid but there was no flood is regarded as a year when they "guessed wrong". People buy insurance immediately after a flood but cancel it quickly; and when a flood does occur, few houses are insured. As time passes and no flood occurs, they regard the probability of flood as diminished and are no longer interested in buying insurance even if the insurance is subsidized, because they believe the probability is low. Many insurance companies are implementing a 30-day waiting period from the date the policy is purchased to prevent people from purchasing insurance only when a large storm is approaching. [27]

Considering all the previously discussed factors, there needs to be possible mitigation techniques a homeowner can use to prevent their homes from flooding. Property level flood mitigation techniques include anything a homeowner can add to their home. The next chapter will explain what these techniques are, the cost of each technique and the benefits they provide. Adding in these will reduce the risk of flooding and may also reduce the cost of flood insurance premiums. Self-protective behavior by residents of flood-prone urban areas can reduce monetary flood damage by 80% and reduce the need for public risk management. But, research on the determinants of private households' prevention of damage by natural hazards is rare [28]. One of the goals of this research paper is to increase the perception about who is responsible for addressing flooding events, and therefore increase the level of service and customer satisfaction levels.

Based on the information provided by the City of Windsor, Tables 8 and 9 were developed to illustrate key elements in an AM plan that can be used for benchmarking. The customer service levels are based on three factors including quality, function and capacity. Level of service would be a social factor in sustainability terms. It refers to increasing customer satisfaction by providing good services. The improvement plan demonstrated the lack of customer satisfaction surveys, as well as the integration of risk.

Table 8- Customer Service Levels

	Expectation	Performance Measure Used	Current Performance	Expected Position in 10 Years based on the current budget.
Service Objective: Provide guidelines for the scope of current and future services offered and manner of service delivery and define general levels of service that the community wishes to receive.				
Quality	Storm water assets are in good condition	Organizational Measure % of buildings with very good/good (1,2), fair (3), and poor/very poor (4,5) functionality	50% very good/good 40% fair 10% poor/very poor	Expected to increase
	Appropriate storm water and sanitary quality before discharges enter the receiving environment	Removal efficiency of contaminants	95 % efficient	Efficiency is expected to increase
	Confidence levels			High
Function	Both stormwater and sanitary services do not cause health and safety issues	Number of pipes checked with closed-circuit television	Majority of pipes have been checked	All the pipes are expected to be checked
	Providing appropriate mitigation measures	Customer service requests related to downspout disconnection	1184 requests in 2017	Service requests are increasing
	Confidence levels			Medium
Capacity and Use	Stormwater and sanitary assets meet water demand	Customer service requests related to flooding	6877 complaints in 2017	Service requests are decreasing
	Confidence levels			Low

Table 9- Improvement Plan

Task No	Task	Responsibility	Resources Required	Timeline
1	Update and revise the Plan to reflect changes in the asset portfolio and business practice	Corporate Asset Planning	Internal	Annual
2	Develop Community and Technical level of service practices	Corporate Asset Planning	External and Internal	2018
3	Develop a more in depth risk management and investment prioritization approach	AM Network, Finance, Asset Planning	Internal	2019
4	Develop a Data Improvement Plan	Asset Planning, Finance	Internal	2019
5	Improve CCTV program to outline better planning and funding allocations	Public Works	Internal	2018
6	Establish more asset management procedures and guidelines to standardize asset management practices	Asset Planning	Internal	2017
7	Establish a Risk Management Plan	Asset Planning	Internal	2018
8	Community Satisfaction Survey	Asset Planning	Internal	2018

As part of the asset management plan, an improvement plan was added at the end to account for the current gaps in the plan and goals to work toward addressing these gaps. One key asset management technique that was outlined in the improvement plan above is a risk management approach. There was a lack of attention to risk in the current asset management plan, and this constituted a significant gap.

5.3 Cost-Benefit Analysis

A low impact development (LID) refers to systems that mimic natural processes to increase sewer capacity and protect water quality and result in increased infiltration, and reduced runoff and outflows. A property level flood risk mitigation technique is any measure that a homeowner can implement to reduce the risk of flooding around the home. This chapter is used to outline the different low impact developments, as well as property level flood risk mitigation techniques that can be used by a homeowner to reduce the overall risk. It will outline the benefits, as well as the costs associated with each of the techniques. The costs and physical sizes below are estimated based on average costs in the focus area and may not reflect the exact costs in a different geographic area. It would be expected that the user of this methodology would find area specific information for a full analysis.

The 5 LIDs being considered in this case study include:

1. Downspout Disconnection
2. Rain Barrel
3. Infiltration Trench
4. Permeable Pavement
5. Rain Garden

The risk mitigation techniques include:

1. Sump pump
2. Backwater valve
3. Gutter Maintenance

4. Checking foundation and window wells for cracks
5. Lawn grading

5.3.1 Downspout Disconnection

Downspout disconnection is the process of separating roof downspouts from the sewer system and redirecting roof runoff onto pervious surfaces, such as the lawn. This diverts the stormwater from directly entering the system.

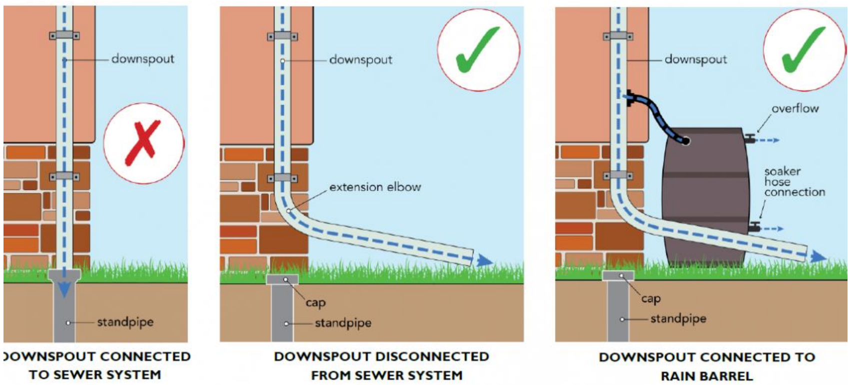


Figure 7- Downspout Disconnection [29]

Cost

The total cost is comprised of the materials used (downspout extensions, elbows and splash pads) as well as the labour. It is estimated that the cost is approximately $100.

Benefits

There are several benefits once a downspout is disconnected. For a 140m^2 roof and an average of 0.9m of rain per year, a downspout disconnected diverts about 130,000 litres of water per year from directly entering the system. Since it can divert such a substantial amount of water, it reduces basement flooding, reduces sewage treatment expenditures, increases sewer capacity and reduces need for costly trunk sewer projects.

5.3.2 Rain Barrels

A rain barrel is used to collect and store rainwater runoff to be used for non-potable water needs, such as watering plants or washing vehicles.

Figure 8- Rain Barrel [30]

Cost

Rain barrels cost approximately $100, however quantity and size of the equipment may affect the overall cost.

Benefits

- For every inch that falls on a 1000 ft^2 roof, around 600 gallons can be conserved.
- Lowers water bill by helping most homeowners conserve about 1300 gallons of water per year by using the rain water for watering the garden or filling up the pool.
- Help garden thrive
- Reduce stress on water supply
- Preserves water quality [31]

5.3.3 Sump Pump

A sump pump is used to remove water from the sump pits in the basement floor. Water flows into the sump pit through drains and the water tile. The sump pump is used to pump water away from the building.

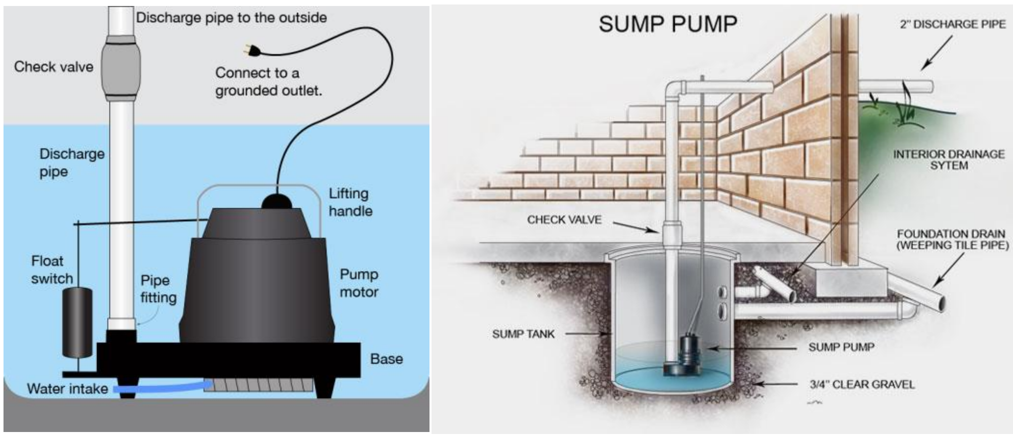


Figure 9- Sump Pump [32]

Cost

$1200 average

Benefits

- Prevent flooding damage
- Reduces threat of mold
- Reduces the risk of fire [33]

5.3.4 Battery Backup Sump Pump

Either a battery back-up added to original sump pump or a second pump that is powered by batteries.

Figure 10- Battery Backup [33]

Cost

Overall, the cost of the battery backup is in the range of $500-$1000 for the equipment as well as installation.

Benefits

- Back-up incase the power goes out.

5.3.5 Backwater Valve

A backwater valve is a backflow prevention device used to prevent outbound water from re-entering the house. It is used to prevent raw sewage from backing up into the home through toilets and showers.

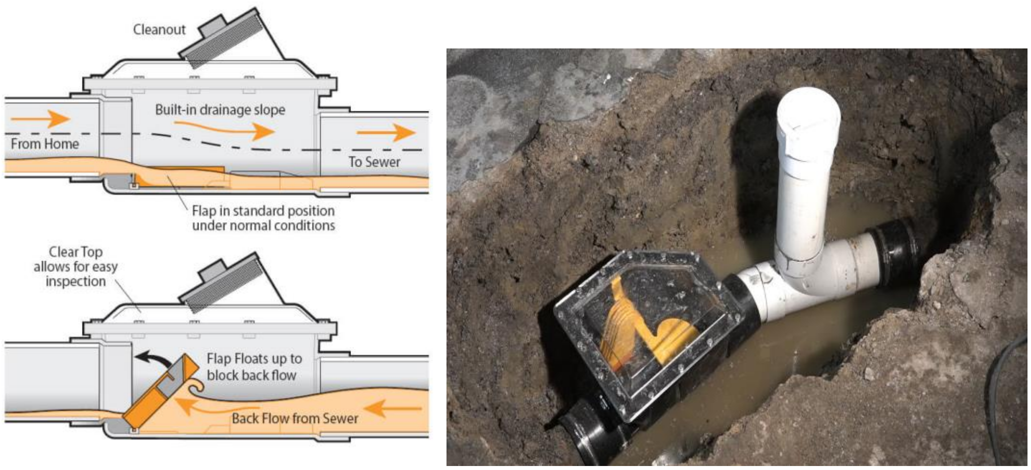


Figure 11- Backwater Valve [34]

Cost

- Initial Construction - around $300
- Retrofitting- $1000 - $2000
- (Subsidy is covering up to $1000) [35]

Benefits

- Prevents wastewater from entering home.

5.3.6 Check for Foundation Leaks

Foundation cracks are a common cause of flooded basements. There are many cracks that aren’t detrimental and can just be filled with epoxy, but some are a serious issue. Cracks in the foundation causes seepage into the house.

Figure 12- Foundation Crack [36]

Cost

Indoor Crack repair - $450 (epoxy or polyurethane injections)

Exterior Crack Repair- $1200

Benefits

- Prevents stormwater from entering home.

5.3.7 Cleaning Gutters

When gutters are clogged with debris and leaves, it hinders the drainage of water which can allow it to pool around the foundation of the house and possibly cause ceiling and floor damage.

Figure 13- Gutter Maintenance [37]

Cost

To be professionally cleaned the prices are as follows:

- A single-story 1,500 square-foot home with 150 linear feet of gutters: $70 and $200.
- A single-story 2,000 square-foot home with 160-180 linear feet of gutters: $90 and $225.
- A two-story 2,500 square-foot home with 200 linear feet of gutters: $100 to $250. [38]

Benefits

- It protects exterior siding, windows, doors, basements and foundations from significant water damage.

5.3.8 Infiltration Trench

Infiltration trenches are shallow excavations with rubble or stone that create temporary subsurface storage of stormwater runoff, thereby enhancing the natural capacity of the ground to store and drain water. Infiltration trenches allow water to exfiltrate into the surrounding soils from the bottom and sides of the trench. *[39]*

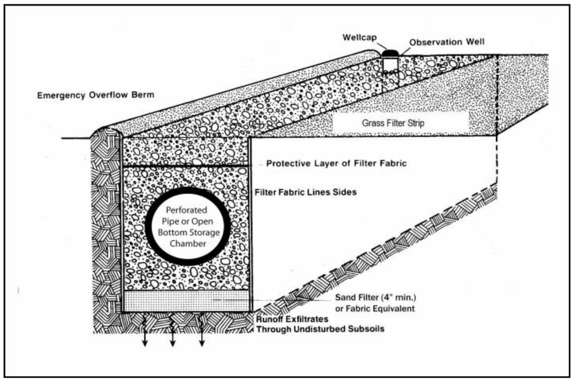


Figure 14- Infiltration Trench [39]

Cost

The construction cost of Infiltration Trenches can vary greatly depending on the configuration, location and site-specific conditions. Cost data typically assume that the Infiltration Trench has been professionally installed and not installed by the homeowner, possibly even hand dug. [40]

Benefits

- Infiltration can significantly reduce both runoff rates and volumes.
- Infiltration provides a significant reduction in the pollutant load discharged to receiving body.
- Can be incorporated easily into site landscaping and fits well beside roads. [39]

5.3.9 Pervious Pavement

Permeable pavement (also known as pervious or porous concrete) is a specific type of pavement with a high porosity that allows rainwater to pass through it into the ground below. Through this movement, pervious concrete mimics the natural process that occurs on the ground's surface, consequently reducing runoff and returning water to underground aquifers. It also traps suspended solids and pollutants, keeping them from polluting the water stream. *[41]*

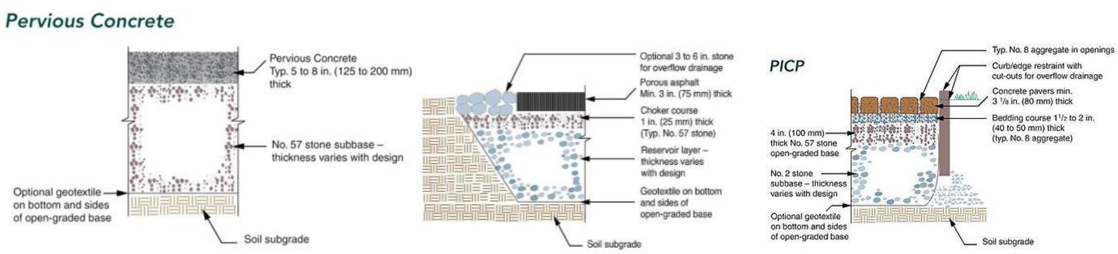


Figure 15- Permeable Pavement [42]

Cost

Table 10- Driveway Cost Analysis [42]

Driveway Cost Analysis				
Material	Surface (in)	Base (in)	Cost ($)	Cost/Sqft ($)
Porous Asphalt	3	9	4330	5.4
Typical Concrete			4800	6.0
Pervious Concrete	6	9	7470	9.3
Permeable Pavers	Paver	9	11760	14.7

Benefits

- Eliminates runoff
- Recharges groundwater

- Traps suspended solids and pollutants
- Reduces surface temperatures and, therefore, the heat island effect
- Eliminates the need for retention basins and water collection areas
- In winter conditions, typically requires much less salt or other de-icing products than traditional pavement types
- Low life-cycle costs with an equal life expectancy to that of regular concrete: 20 to 40 years when correctly installed [19]

5.3.10 Lawn Regrading

This is when a lawn is smoothed out at certain angles. The slope of the soil near a home can significantly improve rainwater drainage.

Figure 16- Lawn Regrading [43]

Cost

Average cost - $1500

Benefits

- Reduced foundation shifting
- Improved drainage and flood protection

5.3.11 Rain Garden

Rain gardens allow for the collection of rainwater from runoff from driveways, downspouts and sidewalks. They are dug in yards as a shallow depression planted with several local flowers. The soil and mulch in the top layers of the garden as well as the plants filter any pollutants from the runoff and the water is collected in the basin. The purpose of the rain garden is to reduce the amount of polluted runoff entering the storm water system and natural water bodies.

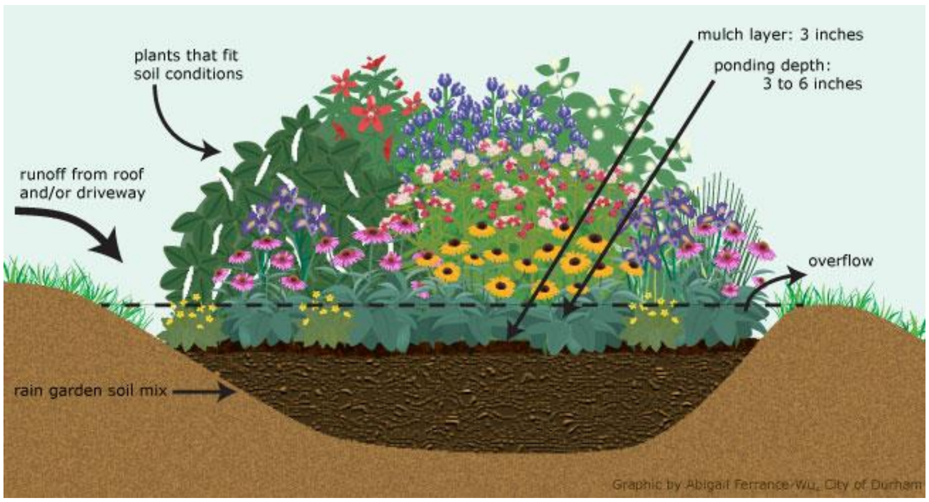


Figure 17- Rain Garden [44]

Cost

For 90 m sq. rain garden - Do it yourself- $90-$450

- Professional- $900-$1800 [45]

Benefits

- Conserve municipal water resources by reducing the need for irrigation
- Create a natural infiltration of rainwater into the soil
- Reduce runoff of fertilizers, pesticides, and other chemicals from washing off your lawn, rooftop and driveway
- Improve local water quality
- Reduce garden maintenance
- Increase garden enjoyment

The cost analysis in table 11 is used to summarize the different costs for each mitigation technique above to assist in finding the highest benefit to cost ratio.

Table 11- Cost Analysis

LID	Cost
Permeable Pavement	Pavers- $14.70/sq. ft. Pervious Concrete – $9.30/sq. ft. Porous asphalt- $5.40/sq. ft.
Downspout Disconnect	$100 / downspout unit
Infiltration Trench	professional- $8/ linear ft. Do it yourself- $2.25/linear ft.
Back-flow preventer	$1000 - $2000
Battery Back Up Sump Pump	$1,200
Sump Pump	Average- $1148
Cracks	Indoor Crack repair - $450 Exterior Crack Repair- $1200
Clean gutters	average- $200
Rain Barrel	$100/ 55-gallon unit
Regrading Yard	Average- $1,528
Rain Garden	Do it yourself- $90-$450 Professional- $900-$1800

Table 12- LID Cost

LID	Units	Total Cost
Rain Garden	30	$1,000.00
Rain Barrel	4	$400.00
Downspout Disconnection	1	$100
Infiltration Trench	90	$2,361.60
Permeable Pavement	90	$9,270.00
Total LID Cost	**$13,132**	
Average Flooded Basement Cost	**$42,000**	

A cost analysis was undertaken in table 12 to estimate the cost of implementing 5 LIDs onto a property. The downspout disconnection and rain barrel are the least expensive mitigation techniques and the permeable pavement is the most expensive. In the risk analysis below, the cost benefit analysis will be performed again to determine the most cost-effective LID combination. The cost of implementing these LIDs may seem expensive, but it is only 30% of the cost of an average flooded basement. The cost also significantly drops if the permeable pavement option is completely removed to only $3800. There are many variables with the cost as well: the homeowners can opt to install an infiltration trench and rain garden by themselves to reduce cost. In addition, the cost of permeable asphalt is less than the cost of a non-permeable concrete driveway.

There are currently subsidies for mitigation techniques as seen in table 13, but the uptake rate is extremely low. The sump pump and backflow preventer subsidy has been offered since 2011 and only 7% of the cities residences have used this offer. There are many variations in cost and becoming aware of the costs and savings could help homeowners better understand their responsibility, and hopefully increase the current uptake in services offered.

Table 13- Mitigation Costs

Mitigation Techniques	Total Cost	Current Subsidies
Sump Pump	$ 1,150.00	$ 1,500.00
Battery Backup	$ 1,200.00	$ -
Backflow Preventer	$ 1,500.00	$ 1,000.00
Crack Repair	$ 1,000.00	$ -
Regrading Yard	$ 1,500.00	$ -
Gutter Maintenance	$ 200.00	$ -
Cost	$ 6,550.00	$ 2,500.00
Total Cost	**$**	**4,050.00**

6. RISK ANALYSIS AND TREATMENT UNDER AM ON CITY OF WINDSOR CASE STUDY

The risk assessment process within the asset management process identifies credible risks, the likelihood of the risk event occurring, the consequences should the event occur, develops a risk rating, evaluates the risk, and develops a risk treatment plan for non-acceptable risks. [4]

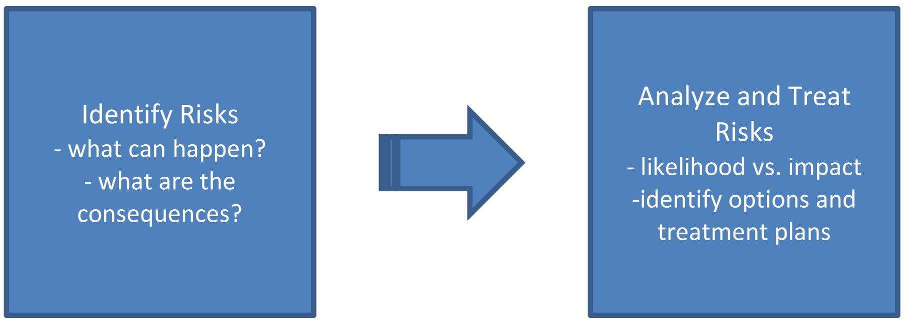


Figure 18- Risk Management

As seen in Figure 17 above, the asset management process provides risk management guidelines. In this analysis, the process will be streamlined to include analysis and treatment in one step. Typical risk management approaches are:

1. Identify any risks associated with a service. This step is used to identify "what can happen, where and when" to a typical service. For example, a flooded basement.
2. Start the risk analysis. The objective of this analysis is to separate the minor acceptable risk from the major risks.
3. Examine the likelihood or chance of an event occurring and create descriptors. For example, if it is a "rare" likelihood it may only occur in exceptional circumstances.
4. Assess the consequences or impact of an event occurring. If there is a "high" consequence of flooding, there may be a foot of water in a basement. These descriptors are provided in this step.
5. Use a risk assessment matrix to compare the likelihood against the consequences of an event occurring to develop a risk rating.

6. The last step would be to look at risk treatment options, such as typical ways to reduce the risk. In this case, a low impact development may be a treatment option for basement flooding.

Table 14- Risk Management

Service or Asset at Risk	What can Happen	Risk Rating (VH, H)	Risk Treatment Plan	Residual Risk
Stormwater	Increased basement flooding	VH	Risk Management Plan: includes LID's and property level mitigation techniques	L

The resilience of our critical infrastructure is vital to customers and the services provided. To adapt to changing conditions and grow over time requires understanding the system capacity to respond to possible disruptions and to absorb disturbance, and for key personnel to act effectively in a crisis to ensure continuity of service [4]. If we have more risk management planning before an emergency, when one occurs it will be less severe, and therefore decrease response times and increase emergency management.

6.1 Risk Management

The first step in the risk assessment was to identify the risk and treatment methods. For this project, the risk is basement flooding and the possible treatment methods included any homeowner flood risk mitigation techniques, as outlined in the cost-benefit analysis above. For this case study, the current engineered system is assumed to be functioning as intended, and indeed, all reports indicate that the system is functioning as designed. Low impact developments are the main risk management options that asset management has identified to pursue in place of redesigning the entire stormwater system.

6.1.1 Stormwater Management Model

A stormwater management model (SWMM) was used to identify the typical flooding from a 100-year storm event and different low impact developments were introduced in different combinations to demonstrate the reduction in flooding. A small area was chosen within South Windsor for the case study. This area was used because the connections were constrained to this area with no inflows coming from other areas. The area is found to be North of Cabana, South of Grand Marais, East of Askin and West of McKay. There are 1106 properties in the model, with a total area of 1.1 Million m^2. Figure 18 outlines the study area below.

Figure 19- Stormwater Management Area and Model

6.1.2 Data Requirements

The research team was provided with the rain gauge locations as well as the updated rain gauge raw data. In Figure 20 below, the rain gauge at Fire Station #5 was used for the SWMM analysis, as it was in the area chosen for the model. There is a sample of the table below, showing the data provided as well as an image of the full time-series data. The analysis started on August 17, 2017 and ended on August 29, 2017. These dates were chosen as it was one of the largest flooding events recently seen in the City with over 6000 homes flooded. The rain gauge recorded the intensity at 15-minute intervals and the period from August 28-29 received a large amount of rain.

Table 15- Rain Gauge Time Series

Date	Time	Intensity (mm/hr)
8/17/2017	7:29	0.4
8/17/2017	7:44	23.2
8/17/2017	7:59	7.2
8/17/2017	13:29	2.4
8/17/2017	13:44	2.8
8/17/2017	13:59	2.8
8/17/2017	14:14	1.2
8/17/2017	14:29	4
8/17/2017	14:44	4
8/17/2017	14:59	5.2
8/17/2017	15:14	20.8
8/17/2017	15:29	5.2
8/17/2017	15:44	0.4

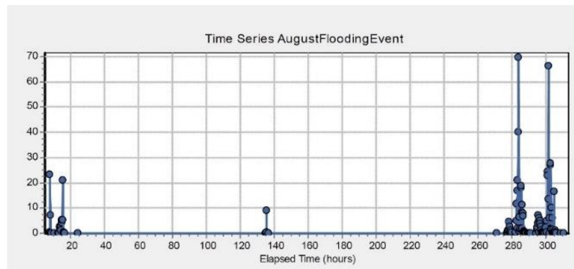


Figure 20- Times Series Graph

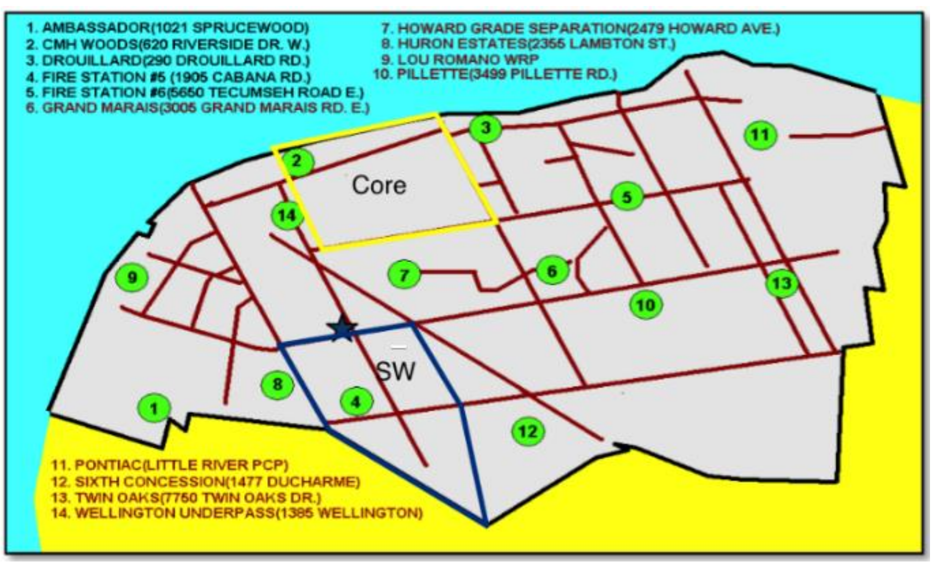


Figure 21- Rain Gauge Data

The Horton Infiltration Method was chosen to predict runoff rates in the analysis. The Horton method examines the intensity, as well as time of rainfall. The parameters were chosen based on the soil properties in the Essex County area. The evaporation rates were estimated using the 2017 temperature data for Essex County. [46]

Infiltration Method	HORTON
Property	**Value**
Max. Infil. Rate	5
Min. Infil. Rate	1.18
Decay Constant	4
Drying Time	7
Max. Volume	0

Figure 22- Horton Infiltration

A variety of data is required to run the SWMM model. The data includes areas, invert elevations, pipe materials and sizing. The City of Windsor's open data platform called MappMyCity [47] was used to collect the data required to run the model.

Description

ID: 26393
PipeType: RCP
Pipe Size: 1200mm
Pipe Length: 129.573m
Slope: 10
Pipe Shape: CIRC
Upstream Manhole: 8R546
Upstream Elevation:179.915
Downstream Manhole:8RJ1620
Downstream Elevation: 0
Installed Date: 20541
Actual date: Y

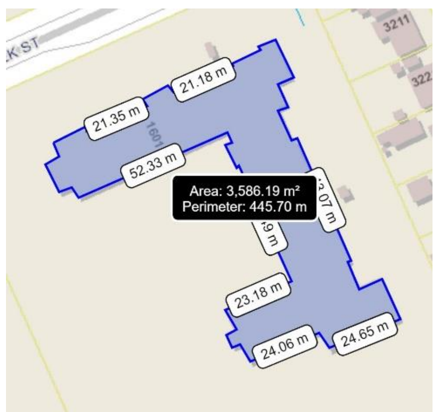


Figure 23- MappMyCity Data [47]

The area of the buildings and pavements were used to find the percent impervious of each subcatchment. As seen in figure 22 above, the area was found using measurement tools. Other important statistics were found on MappMyCity, such as the pipe type, the size, the shape and the elevations. The lengths and area of each subcatchment were calculated using the coordinate system provided by the open data platform.

Typical Depression Storage Values	
Impervious surfaces	0.05 - 0.10 inches
Lawns	0.10 - 0.20 inches
Pasture	0.20 inches
Forest litter	0.30 inches

(Source: ASCE,(1992), *Design & Construction of Urban Stormwater Management Systems*, New York, NY)

Surface	n
Smooth asphalt	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Brick with cement mortar	0.014
Vitrified clay	0.015
Cast iron	0.015
Corrugated metal pipes	0.024
Cement rubble surface	0.024
Fallow soils (no residue)	0.05
Cultivated soils	
Residue cover < 20%	0.06
Residue cover > 20%	0.17
Range (natural)	0.13
Grass	
Short, prarie	0.15
Dense	0.24
Bermuda grass	0.41
Woods	
Light underbrush	0.40
Dense underbrush	0.80

Source: McCuen, R. et al. (1996), *Hydrology*, FHWA-SA-96-067, Federal Highway Administration, Washington, DC

Figure 24- Depression Storage and Manning's n Values

The figure above provided the Manning's n values, as well as typical storage values. The N-Imperv, N-perv, Dstore-Imperv and Dstore-Perv were estimated using these figures. The N-Imperv for asphalt and concrete was estimated to be 0.01 and the N-perv for grass was estimated to be 0.1. The Dstore-Imperv was estimated 0.05 and the Dstore-Perv was estimated as 0.1 for lawns.

Junction J127

Property	Value
Name	J127
X-Coordinate	332780.428
Y-Coordinate	4681017.144
Description	
Tag	
Inflows	NO
Treatment	NO
Invert El.	179.886

Conduit C134

Property	Value
Name	C134
Inlet Node	J126
Outlet Node	J127
Description	
Tag	
Shape	CIRCULAR
Max. Depth	1.2
Length	152.18
Roughness	0.01

Subcatchment S105

Property	Value
Rain Gage	Gage1
Outlet	J49
Area	0.31
Width	500
% Slope	0.5
% Imperv	40
N-Imperv	0.01
N-Perv	0.1
Dstore-Imperv	0.05
Dstore-Perv	0.1
%Zero-Imperv	25
Subarea Routing	OUTLET
Percent Routed	100
Infiltration	HORTON

Figure 25- Typical Junction, Conduit and Subcatchment

This figure shows a typical junction, conduit and subcatchment found in the stormwater management model. Overall, the area was split into 202 subcatchments, 154 junctions, 184 conduits and 9 outfalls. This model created was used to simulate the amount of node flooding that occurred during the August storm event. It will be compared to 30 other scenarios, which will include low impact developments such as rain barrels, downspout disconnection, permeable pavements and infiltration trenches. This model will be used to validate if the LID's reduce the incidence of flooding and what LID provides the most reduction.

6.1.3 Status-Quo Analysis and Output

Using the rain gauge data from a 100-year storm event proved that there was an extremely large amount of flooding. As you can see from the image below, this is the water elevation profile for one street in the analysis. The stormwater main is full throughout most of the conduit and 9 out of the 13 nodes are overflowing.

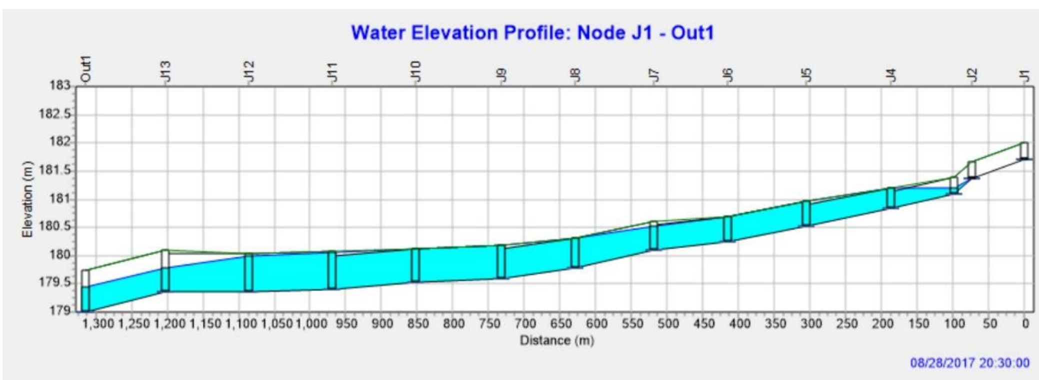


Figure 26- Status Quo Maximum Flooding Profile

The analysis ran for 12 days. There was a small amount of rain on day 1. The graph below shows that day 11 and 12 experienced the most amount of flooding.

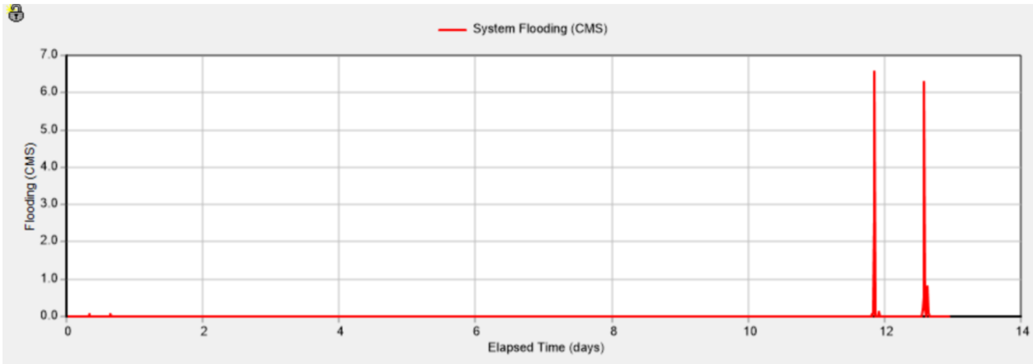


Figure 27- Total Flooding (CMS)

In this analysis, there was a total of 58 nodes flooded for an average of 0.7 hours. The total system flood volume is 18.54 CMS, which is about 5000 gallons per second.

Table 16- Status Quo Flooding Reduction

Scenario	# of Flooded Nodes	Average Hours Flooded	Maximum Rate (CMS)	Total Flood Volume (CMS)
Status-quo	58	0.687	0.142	18.54

6.1.4 Mitigation Techniques

There are many low impact developments that can be added to reduce the incidence of flooding. Five LIDs were chosen for the SWMM analysis. These include downspout disconnection, rain barrels, rain gardens, permeable pavement and infiltration trenches. The LIDs were analyzed using 31 different combinations of scenarios to compare the reduction of flooding for one LID to multiple in series. The scenarios are below:

1. Status-quo
2. Downspout disconnection
3. Rain barrels
4. Infiltration trench
5. Pervious Pavement

6. Rain Garden
7. 2 LIDs
8. 3 LIDs
9. 4 LIDs
10. 5 LIDs

1. Downspout Disconnection

The average home in the area was determined to be 150 m^2. The surface roughness was determined using typical Manning's n values for asphalt shingles. [48] A typical roof slope for Ontario is 4 in 12 inches or 33%. It is important to note that a downspout disconnect does not remove water from the system, it diverts the water from directly entering the stormwater system and does not decrease the percent impervious. [49]

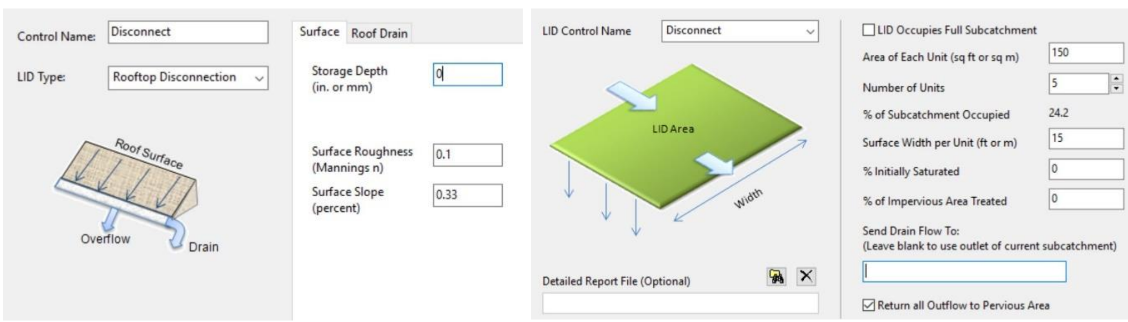


Figure 28- SWMM Downspout Disconnection

2. Rain Barrel

A typical 55-gallon rain barrel was chosen with a height of 914 mm and a radius of 165 mm. The drain is placed at the top of the barrel as an overflow, in the event of a large storm. There were 4 rain barrels placed on each property and this only occupied 0.2% of the total subcatchment area.

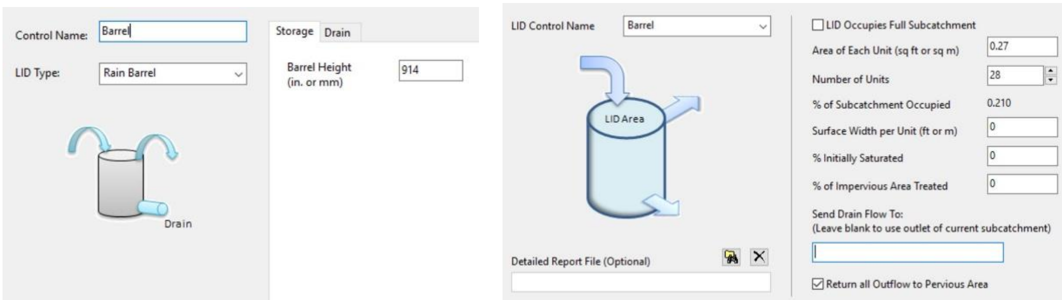


Figure 29- SWMM Rain Barrel

3. Infiltration Trench

The infiltration trench that was used as an example has a 914-mm depth. Three different infiltration trench scenarios were used to see if the percent reduction was linear. A 90m^2 area was used for each property. The other scenarios included a 200m^2 area, a 1m^2 area, as well as a 90m^2 area placed in 50% of the subcatchments. The surface roughness was determined using Manning's n values, the storage was determined using the depth and a standard void ratio of 40% and there was no drain used in this situation. The infiltration trench provides a large reduction in the impervious area. The equation used to decrease the original imperviousness is: (1 - u) *p / (100 - p*p).

u = % of subcatchment occupied by LIDs

p= original percent impervious

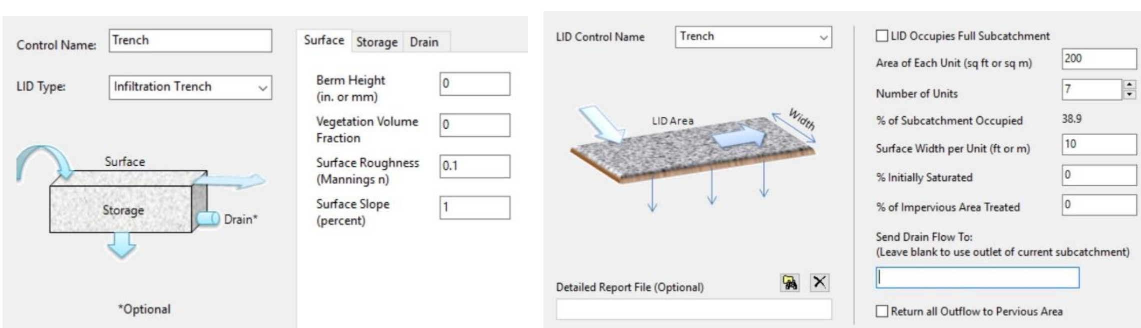


Figure 30- SWMM Infiltration Trench

4. Permeable Pavement

Permeable pavement is the most complex of the four mitigation techniques, as it has 3 layers. A typical driveway area of 90 m^2 was used for the analysis. A typical permeable pavement installation includes 153 mm thick pavement, 900mm thick soil and 450 mm of rock storage.

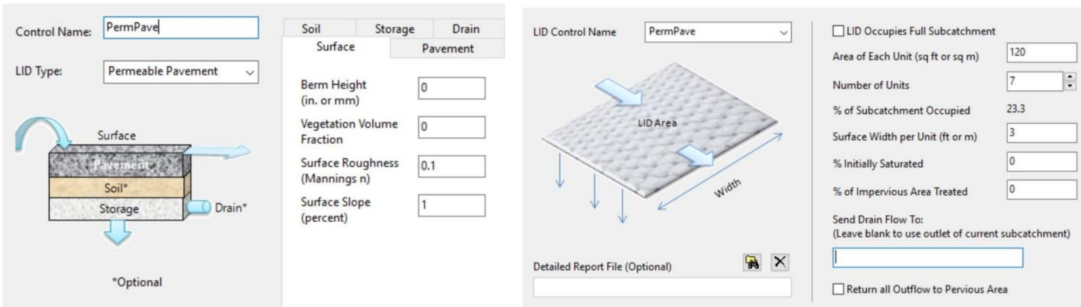


Figure 31- SWMM Permeable Pavement

5. Rain Garden

A 30 m^2 area was chosen as a typical rain garden for the analysis. It included a berm height of 90 mm, 450mm of soil depth, and a seepage rate that is the same as the minimum infiltration rate for the areas soil properties.

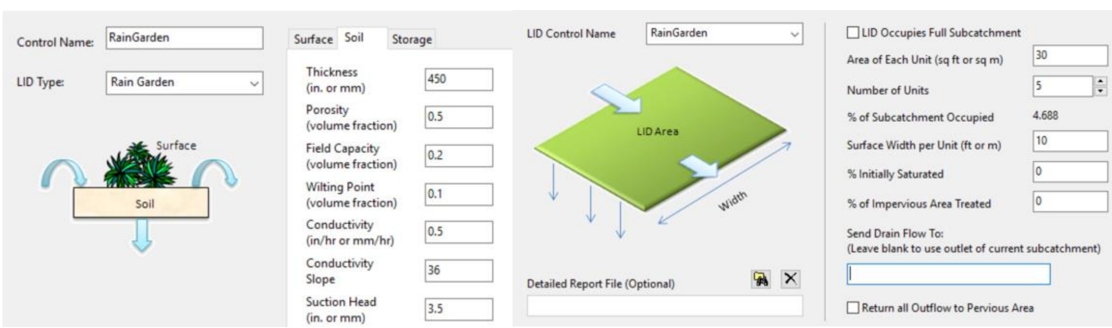


Figure 32- SWMM Rain Garden

6.1.5 LID Analysis and Outputs

As mentioned above, 31 scenarios were tested using EPA SWMM to model the reduction in flooding from the original status-quo model. The 5 LIDs were modelled in every possible combination. For example, for the two LID scenario, a downspout disconnect was modelled with all four other scenarios. There are 4 graphs shown below, these graphs are used to show the reduction in flooding, runoff and infiltration for 8 of the 31 scenarios. The first image shows the flooding for the total 12-day analysis, as well as the 2-day analysis where the most flooding was noticed. Both images demonstrate the reduction in total flooding. The scenario with 5 LIDs has a much lower total flooding than the original and the rain barrel scenario. This analysis is used to display the efficiency of each LID. All the output images have similar results, with the same reduction in total flooding, outflows, as well as runoff.

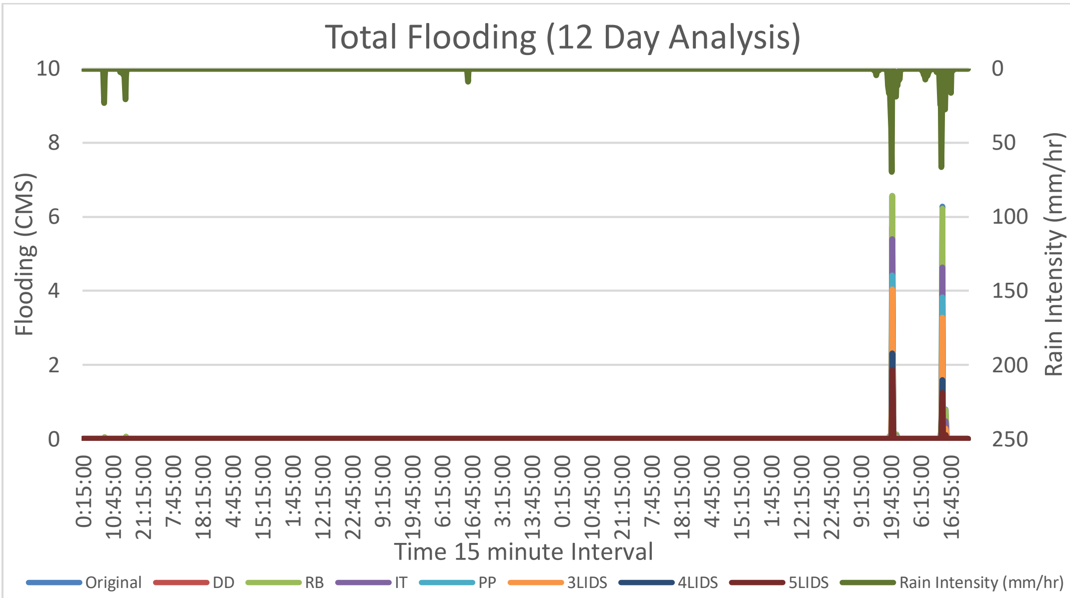


Figure 33- Total Flooding (12 Day Analysis)

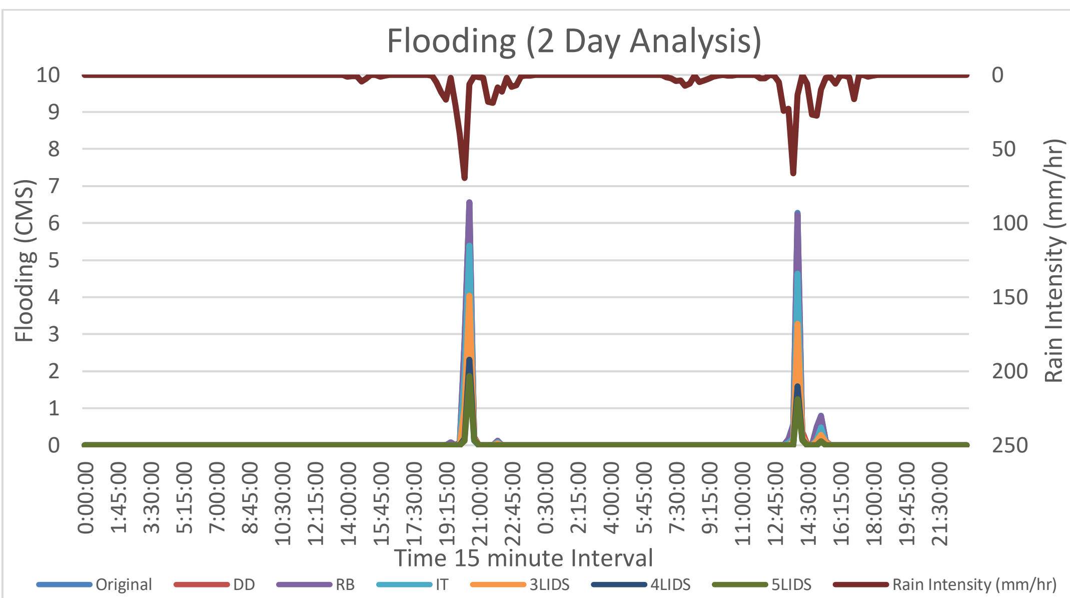


Figure 34- Total Flooding (2 Day Analysis)

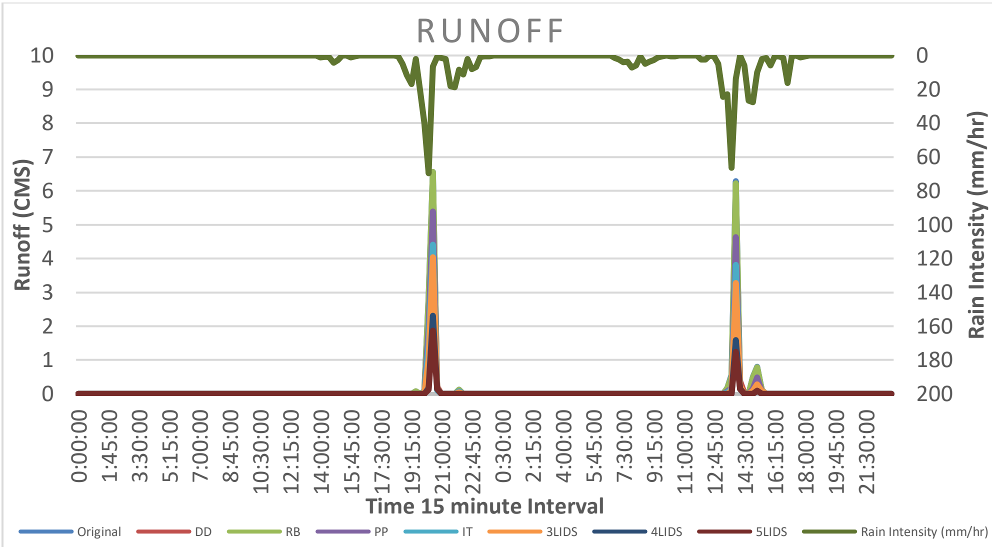


Figure 35- Runoff

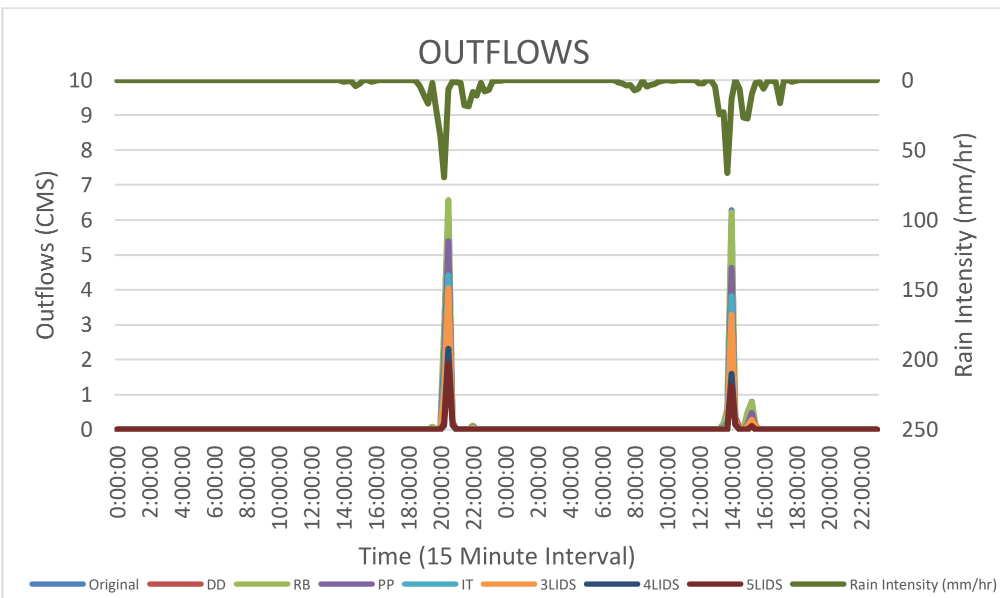


Figure 36- Outflows

The next step in this analysis was to outline the amount of flooding in each scenario and find the percent reduction. The goal of this section is to find out which scenario provides the most flooding reduction. In a previous chapter, a cost-benefit analysis was performed to find out the costs associated with each LID. The final percent reduction will be compared to the cost to find the best scenario, the most cost-effective and the worst scenario. The chart below provides information from every scenario. The analysis found that 5 LIDs provided the most reduction in flooding, and the rain barrel showed the least reduction.

Table 17- SWMM Analysis Flooding Reduction

LIDs	SWMM Scenario	Flooding (CMS)	Percent Flooding Reduction
No LID	Original	18.54	0.00
1 LID	DD	14.18	23.52
	RB	18.35	1.02
	PP	10.58	42.93
	IT	13.27	28.43
	RG	16.84	9.17
2 LIDs	ITDD	9.38	49.41
	PPDD	7.68	58.58
	PPIT	7.22	61.06
	PPRB	10.43	43.74
	RBDD	13.98	24.60
	RBIT	13.15	29.07
	RGDD	12.29	33.71
	RGIT	11.69	36.95
	RGRB	16.6	10.46
	RGPP	9.45	49.03
3 LIDs	DDRBIT	9.35	49.57
	DDRBPP	7.63	58.85
	DDPPIT	4.52	75.62
	RBPPIT	7.17	61.33
	RGPPIT	6.12	66.99
	RGDDIT	8.16	55.99
	RGRBIT	11.52	37.86
	RGPPDD	6.54	64.72
	RGPPRB	9.19	50.43

	DDRGRB	12.27	33.82
4 LIDs	DDRBITRG	8.23	55.61
	DDRBPPRG	6.55	64.67
	RBITPPRG	6.19	66.61
	DDITPPRG	3.64	80.37
	DDRBITPP	4.48	75.84
5 LIDS	DDRBPPITRG	3.62	80.47

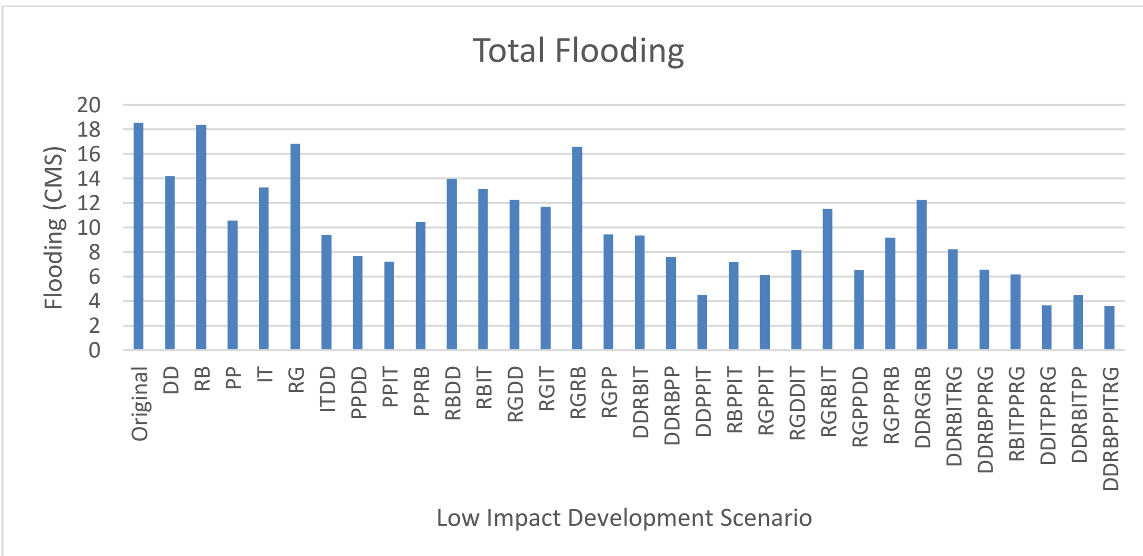


Figure 37- Flooding Analysis

Although it shows that the least reduction is from the rain barrel, the analysis was done using typical sizing for each LID. Therefore, a typical property would have maximum 4 rain barrels and a rain garden would be around $30m^2$. This skews the actual reduction values. The table below shows the percent reduction per unit. These numbers show that the rain barrel does have a large reduction in flooding per barrel, but the major constraint is that there are very few people that can fit 100 rain barrels on their property, which is what is needed to get an equivalent reduction to the other scenarios. The LID that has the highest reduction is the permeable pavement, but it also has the highest cost associated with it. The downspout disconnection has the lowest reduction per square meter of home, but also has the lowest cost associated with it, making it the most cost-effective approach.

The rain garden and infiltration trench are similar in their percent reduction but depending on the way someone installs either LID could vary the costs.

Table 18- Percent Flooding Reduction Per Unit

LID	% Reduction /unit
Rain Garden	0.31 /sqm
Downspout Disconnection	0.16 /sqm
Rain Barrel	0.26 /barrel
Permeable Pavement	0.48 /sqm
Infiltration Trench	0.32 /sqm

The above figure outlines the differences in total flooding for each scenario. Analyzing the graph in figure 37 shows that implementing select combinations of two LIDs could have a larger reduction in total flooding than implementing a select four. From a cost and maintenance stand point, most homeowners would choose the two LID approach.

6.1.5.1 Validation of Results

Outflow data from the August 2017 event was originally intended to validate that the SWMM model output accurately represented the actual real-time outflow data. However, this data was not easily accessible and therefore another route needed to be taken to validate the model outputs. Table 20 compares the total catchment area and the total volume of rain received. The surface areas and depth of infiltration used for these calculations are equivalent to the parameters used on the model. A comparison of Table 18 below and Table 15 above shows similar percent reduction in the model confirming the repeatability (precision) of the model.

Table 19- Validation Analysis

Analysis		
Number of homes in catchment	1106	homes
Total area of model	1.1 million	m^2
Total rain over 12 days	157	mm
Total volume of rain	172700	m^3
Total Volume of rain per home	156.1483	m^3 per home

Table 20- Calculated Percent Reduction

Scenario Calculations	**Storage Volume (m^3)**	**Percent Reduction**
Downspout Disconnection		
150 m^2 home x total rainfall per home	23.55	15%
Rain Barrel		
55-gallon rain barrel x 4 rain barrels	0.832	1%
Rain Garden		
Surface area x depth of berm	13.5	9%
Infiltration Trench		
Surface area x effective porosity x depth of infiltration [50]	43.92	28%
Permeable Pavement		
Surface area x effective porosity x depth of infiltration [50]	47.25	30%

It was also important to prove that if the parameters were kept constant throughout each scenario, the percent flooding reduction remained generally constant. The parameters such as n-perv, and infiltration rates were estimated based on soil properties for this area. As these parameters changed, the table below identifies that the percent reduction between the status-quo and four LIDs remains around seventy-five percent no matter what parameters are chosen. The dstore-perv was estimated at a much higher value than originally estimated and the infiltration rate was estimated at a much lower value. Sensitivity of a system suggests dependence of its properties on parameter variation. The fact that the percent reduction remains constant suggests insensitivity. These results could suggest that the scorecard is more easily adaptable in other municipalities.

Table 21- Parameter Validation

LIDs	SWMM Scenario	Flooding (CMS)	Percent Flooding Reduction
Scenario 1 (dstore-perv)	Original	18.54	0
	DDRBITPP	4.48	75.8
Scenario 2 (infiltration rate)	Original	16.35	0
	DDRBITPP	4	75.5
Scenario 3 (% impervious)	Original	15.16	0
	DDRBITPP	3.99	73.7
Scenario 4 (n-perv)	Original	13.92	0
	DDRBITPP	3.49	74.9

The last validation technique in Table 23 was used to prove that the percent reduction is a linear relationship. The table below displays 4 different scenarios for the infiltration trench low impact development. There is a scenario with 200m^2, 1m^2 and 90m^2 implemented on every property, as well as a 90m^2 area implemented on 50% of the properties in the catchment. The percent reduction is divided by the total area of LID to find the percent reduction per square meter. The percent reduction stays constant at around 0.3 % reduction.

Table 22- Percent Reduction Per Unit Area

Scenario	Flooding (CMS)	Percent Reduction (%)	Percent Reduction per Square-m (%)
Original	18.54	0	0
Infiltration trench 90m2	13.27	28.43	0.32
Infiltration Trench 90m2- 50% homes	15.55	16.13	0.36
Infiltration Trench 1m2	18.48	0.32	0.32
Infiltration Trench 200m2	7.55	59.28	0.3

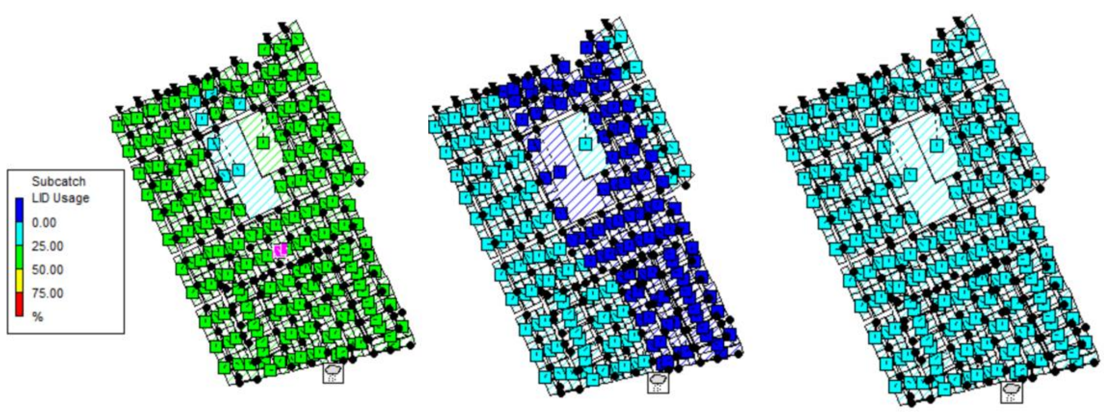


Figure 38- Infiltration Trench LID Usage (200m^2, 90m^2- 50%, 1m^2)

6.2 Risk Assessment

Asset management and the integration of risk provided guidelines to create a typical risk register. This risk assessment process compares the likelihood of an event occurring to the impact of the event. In this case, the impact is based on the amount of flooding occurring on the exterior. Therefore, the impact of a flood depends on the amount of low impact developments on the property. The more LIDs there are, the more there is a reduction in the total flood volume and will reduce the impact from extreme to negligible. On the other hand, the likelihood of a basement flood occurring is based on property level mitigation techniques. For example, a homeowner might take every precaution to implement all the LID's, but they may not check their foundation for cracks, have no sump pump, and never clean their gutter. They may have a minor impact, but a large likelihood. Therefore, they still have a moderate risk of basement flooding.

Basement Flooding Risk					
Likelihood	Impact				
	Negligible	Minor	Moderate	Major	Extreme
Rare					
Unlikely					
Moderate					
Likely					
Very Likely					

Figure 39- Basement Flooding Risk Matrix

Basement Flooding Risk Rating	
	Very High Flood Risk
	High Flood Risk
	Moderate Flood Risk
	Low Flood Risk
	Very Low Flood Risk

Figure 40- Basement Flooding Risk Rating

6.2.1 Risk Impact Assessment

The total impact or consequence of a flood could be reduced by using low impact developments. Using a quantitative SWMM analysis, a percent reduction for each scenario was formed, as seen in table 25. An impact score was given based on the reduction. If there was 0-20% reduction, flooding impact is extreme. Whereas, if there is 80-100% reduction, the impact is negligible. In the final scorecard, a homeowner can edit it based on the amount of surface area of each LID that they would like to implement. This will educate the engineers at a municipality and educate the homeowner about the possible risk reduction. The cost benefit analysis is very important, as 2 LIDs may provide the same reduction in flooding as 3 different LIDs, the only difference is the cost.

Table 23- Risk Impact Matrix

Impact				
Negligible	Minor	Moderate	Major	Extreme
80-100	60-80	40-60	40-20	20-0

Table 24- LID Legend

Legend	
DD	Downspout Disconnection
RG	Rain Garden
RB	Rain Barrel
IT	Infiltration Trench
PP	Permeable Pavement

Table 25- LID Impact Score

LIDs	SWMM Scenario	Percent Flooding Reduction (%)	Impact Score
No LID	Original	0.00	EXTREME
1 LID	DD	23.52	MAJOR
	RB	1.02	EXTREME
	PP	42.93	MODERATE

	IT	28.43	MAJOR
	RG	9.17	EXTREME
2 LIDs	ITDD	49.41	MODERATE
	PPDD	58.58	MODERATE
	PPIT	61.06	MINOR
	PPRB	43.74	MODERATE
	RBDD	24.60	MAJOR
	RBIT	29.07	MAJOR
	RGDD	33.71	MAJOR
	RGIT	36.95	MAJOR
	RGRB	10.46	EXTREME
	RGPP	49.03	MODERATE
3 LIDs	DDRBIT	49.57	MODERATE
	DDRBPP	58.85	MODERATE
	DDPPIT	75.62	MINOR
	RBPPIT	61.33	MINOR
	RGPPIT	66.99	MINOR
	RGDDIT	55.99	MODERATE
	RGRBIT	37.86	MAJOR
	RGPPDD	64.72	MINOR
	RGPPRB	50.43	MODERATE
	DDRGRB	33.82	MAJOR
4 LIDs	DDRBITRG	55.61	MODERATE
	DDRBPPRG	64.67	MINOR
	RBITPPRG	66.61	MINOR
	DDITPPRG	80.37	NEGLIGIBLE
	DDRBITPP	75.84	MINOR
5 LIDS	DDRBPPITRG	80.47	NEGLIGIBLE

The table above included a downspout disconnection for a 150m^2 roof, 4 rain barrels, a 30m^2 rain garden, a 90m^2 infiltration trench, as well as 90m^2 of permeable pavement. Based on a typical expectation, adding more LIDs should decrease the risk. While this statement is true, it also depends on what LIDs are added. This explains why having 3 LIDs in different combinations can vary the impact from minor to major. While a rain barrel does have a similar percent reduction per unit to other LIDs, it has a major constraint based on the size of the property.

6.2.2 Risk Likelihood Assessment

The risk likelihood assessment is more of a qualitative analysis compared to the impact assessment. A literature review was done for all the mitigation techniques a homeowner could add to their property. The likelihood scorecard will be a multi-objective analysis with a weighting system that will add up to 100 points based on the techniques implemented. Based on the research the optimal way to reduce the likelihood of a flood is to manage the exterior first. Properly graded homes and maintained gutters manages water from the exterior. It reduces the risk the most because without this, ponding will occur near the homes foundation, which can increase hydrostatic pressure and cause foundation cracks. If these are not done properly, it will also increase the need for a proper sump pump. This the reason the next important risk reduction technique is a sump pump because it keeps the area under a home dry by pumping the water away from the home.

Whenever there is a sudden downpour, there is also a risk that a basement could experience a sewer backup problem. Installing a backwater valve will help prevent raw sewage from entering the home, especially when a homeowner is connected to a combined sewer and the pipe is overloaded. If all the above were to fail at keeping water away from the home, it is extremely important to check the foundation and window wells for cracks.

Based on the above analysis, a table was created to outline the best risk reduction techniques. If these techniques are used in combination with low impact developments, the chance of a basement flood should be reduced tremendously. The techniques with the most likelihood reduction will be weighted the most and the final score will add up to 100, with a zero score being the most likely to experience a basement flood.

Table 26- Likelihood Reduction

Likelihood Reduction	
Highest Likelihood Reduction	Age of home
	Proper grading
	Gutter maintenance
	Past flooding and no new flooding protection
Medium Likelihood Reduction	Sump pump installed
	Backwater valve
Minor Likelihood Reduction	Checking foundation
	Checking window wells
	Battery Backup
Low Likelihood Reduction	Sump pump age
	Sump pump sizing

Table 27- Likelihood of Flooding Matrix

Likelihood of a Basement Flood	Very Unlikely	80-100
	Unlikely	80-60
	Moderate	60-40
	Likely	40-20
	Very Likely	20-0

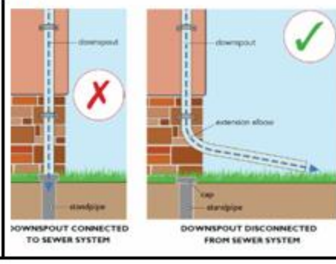
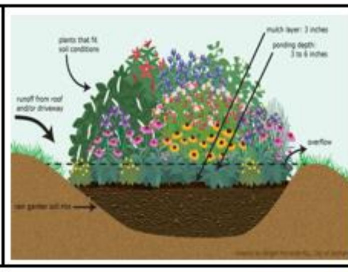
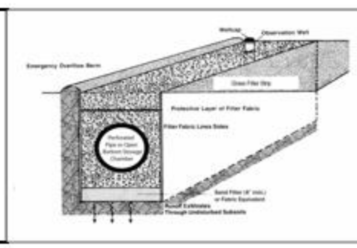
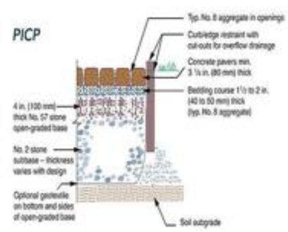
6.3 Risk Scorecard

The risk scorecard is created based on the risk assessment and the SWMM model above. It is a tool for both the homeowner and the engineers at a municipality. This scorecard includes both a risk assessment, as well as a treatment plan. The homeowner can answer questions to find out what their current risk of flooding is. If they see that their risk is extremely high, they can try different combinations of LID's and property level flooding techniques to see what they can do to reduce their chance of flooding. They can also refer to the cost analysis to find the most cost-effective way to reduce their risk. The results of the initial analysis can be sent to the municipality to provide them with up to date data about the current state of the stormwater infrastructure from the private side.

The first step in the scorecard is to communicate what the five possible LIDs are by providing images and the benefits associated. There is information about the LID and includes the costs and benefits associated with it. The next step is the impact analysis. The impact is reduced based on the number of LIDs implemented, as stated above. The homeowner can input what they currently have on their property to educate the engineers and decision makers and can also add different combinations and size of LIDs to find the most cost-effective reduction. The next step is to look at all the possible risk likelihood mitigation techniques for another education session. They will use this education to fill out the next scorecard based on the property level mitigation techniques they have already implemented. The score from both the impact and the likelihood analysis will be put into a matrix to provide the current risk of basement flooding to the homeowner.

Figure 41- Page 1 Scorecard

There are 5 low impact developments to choose from:

LIDs	Image	Benefits
1. Downspout Disconnection		• Diverts water from directly entering system • Adds to the sewer capacity • Reduces basement flooding
2. Rain Barrel		• Water conservation • Lowers water bill by helping most homeowners conserve about 1300 gallons of water per year by using the rain water for watering the garden or filling up the pool • Help garden thrive • Reduce stress on water supply • Preserves water quality
3. Rain Garden		• Natural infiltration of rainwater • Conserves municipal water resources by reducing the need for irrigation • Reduces runoff of chemicals • Improves local water quality • Reduced garden maintenance • Increases garden enjoyment
4. Infiltration Trench		• Infiltration can significantly reduce both runoff rates and volumes • Infiltration provides a significant reduction in the pollutant load discharged to receiving body • Can be incorporated easily into site landscaping and fits well beside roads.
5. Permeable Pavement		• Eliminates runoff • Traps suspended solids and pollutants • Reduces surface temperatures and, therefore, the heat island effect • Eliminates the need for retention basins and water collection areas • In winter conditions, typically requires much less salt or other de-icing products than traditional pavement types • Low life-cycle costs with an equal life expectancy to that of regular concrete: 20 to 40 years when correctly installed

The first page of scorecard provides information about possible LID implementation.

Figure 42- Page 2 Scorecard

IMPACT ANALYSIS

Please enter the quantity you have or plan on having in the yellow box.

Impact				
Negligible	Minor	Moderate	Major	Extreme
80-100	60-80	40-60	40-20	20-0

Downspout Disconnection	0	Sq.m. of home
Rain Barrel	0	# of 55 gallon barrels
Rain Garden	0	Sq.m.
Infiltration Trench	0	Sq.m.
Permeable Pavement	0	Sq.m.

1 LID	RG	DD	RB	PP	IT
% Reduction					
Cost					
Impact Score					

2 LIDS	ITDD	PPDD	PPIT	PPRB	DDRB	ITRB	RGDD	RGIT	RGRB	RGPP
% Reduction										
Cost										
Impact Score										

3LIDS	DDRBIT	DDRBPP	DDPPIT	RBPPIT	RGPPIT	RGDDIT	RGRBIT	RGPPDD	RGPPRB	DDRGRB
% Reduction										
Cost										
Impact Score										

4LIDS	DDRBITPP	DDRBITRG	DDRBPPRG	RBITPPRG	DDITPPRG
% Reduction					
Cost					
Impact Score					

5LIDS	DDRBITPPRG
% Reduction	
Cost	
Impact Score	

IMPACT ANALYSIS

Please enter the quantity you have or plan on having in the yellow box.

Impact				
Negligible	Minor	Moderate	Major	Extreme
80-100	60-80	40-60	40-20	20-0

Downspout Disconnection	0	Sq.m. of home
Rain Barrel	20	# of 55 gallon barrels
Rain Garden	0	Sq.m.
Infiltration Trench	100	Sq.m.
Permeable Pavement	0	Sq.m.

1 LID	RG	DD	RB	PP	IT
% Reduction			5.1		31.6
Cost			$ 2,000.00		$ 2,624.00
Impact Score	EXTREME	EXTREME	EXTREME	EXTREME	MAJOR

2 LIDS	ITDD	PPDD	PPIT	PPRB	DDRB	ITRB	RGDD	RGIT	RGRB	RGPP
% Reduction						36.237				
Cost						$ 4,624.00				
Impact Score						MAJOR				

3LIDS	DDRBIT	DDRBPP	DDPPIT	RBPPIT	RGPPIT	RGDDIT	RGRBIT	RGPPDD	RGPPRB	DDRGRB
% Reduction										
Cost										
Impact Score										

4LIDS	DDRBITPP	DDRBITRG	DDRBPPRG	RBITPPRG	DDITPPRG
% Reduction					
Cost					
Impact Score					

5LIDS	DDRBITPPRG
% Reduction	
Cost	
Impact Score	

IMPACT ANALYSIS

Please enter the quantity you have or plan on having in the yellow box.

Impact				
Negligible	Minor	Moderate	Major	Extreme
80-100	60-80	40-60	40-20	20-0

Downspout Disconnection	150	Sq.m. of home
Rain Barrel	10	# of 55 gallon barrels
Rain Garden	50	Sq.m.
Infiltration Trench	100	Sq.m.
Permeable Pavement	100	Sq.m.

1 LID					
	RG	DD	RB	PP	IT
% Reduction	15.3	23.5	2.6	47.7	31.6
Cost	$ 1,666.50	$ 100.00	$ 1,000.00	$10,300.00	$ 2,624.00
Impact Score	EXTREME	MAJOR	EXTREME	MODERATE	MAJOR

2 LIDS										
	ITDD	PPDD	PPIT	PPRB	DDRB	ITRB	RGDD	RGIT	RGRB	RGPP
% Reduction	52.411	62.781	67.841	50.020	26.136	33.708	40.015	15.019	18.316	59.270
Cost	$ 2,724.00	$ 10,400.00	$ 12,924.00	$11,300.00	$ 1,100.00	$ 3,624.00	$ 1,766.50	$ 4,290.50	$ 2,666.50	$ 11,966.50
Impact Score	MODERATE	MINOR	MINOR	MODERATE	MAJOR	MAJOR	MODERATE	EXTREME	EXTREME	MODERATE

3LIDS										
	DDRBIT	DDRBPP	DDPPIT	RBPPIT	RGPPIT	RGDDIT	RGRBIT	RGPPDD	RGPPRB	DDRGRB
% Reduction	53.963	64.347	81.940	69.347	78.671	64.481	48.461	74.040	59.790	41.493
Cost	$ 3,724.00	$ 11,400.00	$ 13,024.00	$13,924.00	$ 14,590.50	$ 4,390.50	$ 5,290.50	$12,066.50	$ 12,966.50	$ 2,766.50
Impact Score	MODERATE	MINOR	NEGLIGIBLE	MINOR	MINOR	MINOR	MODERATE	MINOR	MODERATE	MODERATE

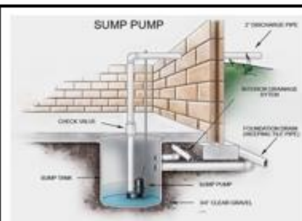
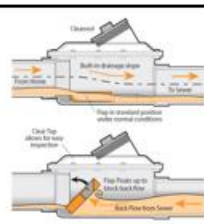
4LIDS					
	DDRBITPP	DDRBITRG	DDRBPPRG	RBITPPRG	DDITPPRG
% Reduction	83.322	65.283	75.151	79.338	74.259
Cost	$ 14,024.00	$ 5,390.50	$ 13,066.50	$ 15,590.50	$ 14,690.50
Impact Score	NEGLIGIBLE	MINOR	MINOR	MINOR	MINOR

5LIDS	
	DDRBITPPRG
% Reduction	92.28289537
Cost	$ 15,690.50
Impact Score	NEGLIGIBLE

The next section of the scorecard is the impact analysis. The three figures show the difference in cost and benefit based on the number of LIDs implemented. The scorecard is automated, and the homeowner inputs the number of LIDs they have currently or would like to implement. The scorecard automatically outputs the impact reduction and the cost associated. This provides the homeowner with information about how much the flooding could be reduced by inputting these low impact developments. It also provides a municipality with up to date information about the current mitigation techniques implemented.

Figure 43- Page 3 Scorecard

Below are the mitigation techniques:

LIDs	Image	Benefits
1. Regrading Lawn		• Reduced foundation shifting • Improved drainage and flood protection
2. Gutter Maintenance		• It protects exterior siding, windows, doors, basements and foundations from significant water damage
3. Sump Pump		• Prevent flooding damage • Reduces threat of mold • Reduces the risk of fire
4. Battery Backup Sump Pump		• Back-up incase the power goes out which is highly likely in flooding situtations
5. Backwater Valve		• Prevents wastewater from entering home • Lowers cost of flood insurance
6. Check foundation and window wells for cracks		• Prevents stormwater from entering home

The third page of the scorecard identifies the homeowner mitigation techniques.

Figure 44- Page 4 Scorecard

Likelihood Analysis

What is the age of your home?
Greater than 40

Is your home properly graded?
Yes

Do you regularly clean your gutters?
Yes-annually

Do you have a sump pump?
No

Is your sump pump appropriately sized to your home?
Yes

Is your sump pump over 10 years old?
No

Do you have a battery back-up in case of power failure?
Yes

Do you have a backwater valve?
Yes

Have you checked your window wells for cracks?
Yes

Have you checked your foundation for any cracks?
Yes

Has your basement flooded in the past?
No

Have you taken any of the above measures to prevent flooding since the flood
Yes

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UNLIKELY

Likelihood of a Basement Flood		
	Extremely Unlikely	80-100
	Unlikely	80-60
	Moderate	60-40
	Likely	40-20
	Very Likely	20-0

Mitigation Techniques	Total Cost	Current Subsidies
Sump Pump	$ 1,150.00	$ 1,500.00
Battery Backup	$ 1,200.00	$ -
Backflow Preventer	$ 1,500.00	$ 1,000.00
Crack Repair	$ 1,000.00	$ -
Regrading Yard	$ 1,500.00	$ -
Gutter Maintenance	$ 200.00	$ -
Cost	$ 6,550.00	$ 2,500.00
Total Cost	**$**	**4,050.00**

The fourth page of the analysis assesses the likelihood of a basement flood. While the low impact developments reduce the impact or consequence by increasing the infiltration and reducing runoff rates, the property level mitigation techniques reduce the likelihood of a flooded home. The homeowner will answer a series of questions and a score will be provided. The score will be based on the amount of mitigation techniques implemented. In the example above, the home is over 40 years old, but the homeowner regularly cleans their gutters, has a backwater valve, has never had a basement flood and has also checked the foundation for cracks. This puts the homeowner at an unlikely chance of flooding.

Figure 45- Page 5 Scorecard

Step 1	Impact				
	Negligible	Minor	Moderate	Major	Extreme
	80-100	60-80	40-60	40-20	20-0

Step 2			
	Likelihood of a Basement Flood	Very Unlikely	80-100
		Unlikely	80-60
		Moderate	60-40
		Likely	40-20
		Very Likely	20-0

Step 3	**Basement Flooding Risk**					
		Impact				
	Likelihood	Negligeable	Minor	Moderate	Major	Extreme
	Rare					
	Unlikely					
	Moderate					
	Likely					
	Very Likely					

Step 4	**Basement Flooding Risk Rating**	
		Very High Flood Risk
		High Flood Risk
		Moderate Flood Risk
		Low Flood Risk
		Very Low Flood Risk

The last step of the analysis is the risk assessment. The homeowner and municipality can use the basement flooding risk matrix with the scores of both the impact and likelihood assessments to determine the final flood risk. For example, if they received a moderate impact score and a low likelihood, the final risk score would be low.

6.3.1 Scorecard Steps

The scorecard approach above can be implemented to other municipal areas by following the steps below. The user would still be cautioned that specific changes would be needed to customize the analysis.

1. Use a 100-year storm event or a typical design storm along with a Stormwater Management Model (SWMM) of the area to find the amount of flooding with no low impact developments.

2. Implement all 5 LIDs in SWMM to find the flooding to compare to the original model. Apply typical LID sizes for a property, therefore a downspout disconnection with a $150m^2$ roof, a $90m^2$ infiltration trench and permeable pavement, a $30m^2$ rain garden and one 55-gallon rain barrel should be implemented.

3. This should be done for all 31 scenarios. The percent reduction in flooding is found by comparing each model to the original model with no LIDs implemented.

4. Copy the percent reductions for each model to the SWMM Analysis excel file. This file is automated and will update the final impact scorecard and therefore tailor it to any town.

5. The likelihood section of the scorecard will remain constant no matter where the scorecard is being used.

6. The change in percent reduction from the new SWMM model may slightly change the final risk score but should remain relatively constant because it is a linear relationship and the final flooding will be proportional to the original model.

7. SUMMARY

It is extremely important to note that the 80% reduction only occurs if every homeowner in the catchment area implements all 5 LIDS. If one person implemented all the LIDs, the reduction would be 0.07%, which would not have any impact on the total flooding. It is through a cumulative effort where significant difference in flooding reduction can be achieved. Therefore, asset management is necessary in attaining infrastructure sustainability. Asset management provided information about:

- The current state of the assets;
- Where the current issues and gaps were;
- Provided risk analysis guidelines and treatment plans, and;
- It helped communicate the importance of cost and level of service objectives.

The scorecard was created as a tool to portray the asset management goals. Its use has multiple possible solutions. The first step is education. For example, there are many homeowners that do not know what an infiltration trench is. This scorecard can be used to educate a homeowner about the possible mitigation techniques. A homeowner can use the scorecard to determine how high their current risk is without any of the mitigation techniques, and therefore potentially shift the current perception about stormwater management. If such a scorecard can communicate the important role that a homeowner can make in helping to control flooding through even simple measures such as gutter cleaning, then that would be significant progress in creating awareness and undertaking actual actions: on a practical level, circumstances have reached the point where no municipality would have the resources to control for extreme events through traditional infrastructure systems alone

The next potential benefit is that this scorecard could be used by the municipality so that engineers and decision makers can evaluate the current state of the flooding mitigation techniques. The last flood cost the City of Windsor over $1,000,000 dollars and the homeowners $500,000,000. The current uptake for free downspout disconnections is only 5-8% and this is likely due to lack of awareness and education on such matters. If the city realizes how much of a reduction could occur from every home having their downspouts disconnected, they could pursue other initiatives such as providing incentives or tax breaks for adding these mitigation techniques.

Does this help promote infrastructure sustainability in stormwater systems? There are three factors that lead to eventual sustainability. The triple bottom line approach looks at environmental, economic and social factors.

Table 28- Triple Bottom Line Benefits

Benefits	
Environmental	Reduction in major environmental disasters
	Reduction in pollutant load discharged
	Water conservation
	Traps suspended solids
	Less sanitary sewer back-ups- increase in water quality
Economic	Less costly main breaks due to overloaded sewers
	Less need to replace the current stormwater system
	Unplanned maintenance is more expensive than planned
	Less expensive than emergency
Social	Less flooding = increased customer satisfaction
	Change in the perception
	More educated about the risks

There have been multiple attempts to incentivize homeowners to implement low impact developments. Some towns have made the implementation of downspout disconnections mandatory, many have started basement flooding subsidy programs where the municipalities pay for the work. The uptake for these free programs is still extremely low and this is because of the lack of knowledge about the risk reduction the mitigation techniques can achieve.

The implementation of the scorecard can be used to educate the homeowner about the advantages of implementing an LID. This would help address the important community and social communication aspects important to modern infrastructure. If a municipality can somehow incentivize every homeowner to apply the scorecard to their home, it may change the perception of who is responsible for flood protection. The city could start implementing tax breaks for those who complete the scorecard, or the insurance companies could raise their premiums for those who have not implemented any LIDs.

Ultimately, the scorecard is an educational tool created using asset management principles to help address a pressing engineering/infrastructure issue by providing and illustrating important information to both the municipalities and the homeowners. Based on the above table, using asset management does help achieve infrastructure sustainability in stormwater systems. Asset management planning provides multiple environmental, economic and social benefits.

8. CONCLUSION AND NEXT STEPS

8.1 Conclusion

The main goal of asset management planning is to reduce risk while increasing the level of service. Based on this research, there is currently a lack of risk management via the homeowner's perspective. The objective of this thesis was to demonstrate that integrating asset management into current design practices will decrease risk, while increasing the level of service, and promote infrastructure sustainability. The asset management plan created in this research for stormwater systems provided the asset age and condition profile of the current stormwater assets; a risk assessment matrix to follow; and demonstrated the significance of cost and increasing the level of service. The assumption used for this research was that most stormwater systems have been engineered to be as effective as realistically possible but cannot handle the increasing storm intensity and durations because of climate change or other factors. Therefore, managing the current assets and reducing the risk is the most optimal way to attain infrastructure sustainability in stormwater systems, and rather than massive, costly re-engineering projects, low impact developments (LIDs) instituted by many homeowners can produce significant benefits.

The initial analysis proved that low impact developments do reduce the consequence of a storm event by increasing infiltration, which will add more sewer capacity; however, low impact developments do not completely remove the likelihood of basement flooding. Actions such as property level flood mitigation techniques for a lawn, along with the use of low impact developments can immensely reduce the risk of a flooded basement.

This research could not have been accomplished without considering asset management. It provided not only the necessary information to achieve the final scorecard, but also a structured approach to assess the critical issues. It further emphasized the importance of risk and cost reduction. It also established that individual property flood risk adaptation measures are critical, as municipalities can only realistically accomplish so much with stormwater infrastructure management. The scorecard can additionally be used as an education tool, to aid in changing the perception of flood protection, and to show what the collective efforts of many homeowners can accomplish when property level flood risk mitigation techniques are used.

Using an asset management approach, the team could provide multiple environmental, economic and social benefits through risk reduction, a cost-benefit analysis, and stressing the importance of level of service and customer satisfaction. The use of engineering asset management will help stormwater systems reach infrastructure sustainability in the future.

8.2 Overall Outcomes

1. Asset management identified the critical flood control techniques and can provide a plan for the engineering community.
2. The project revealed what the collective efforts of the homeowners can accomplish when property level risk mitigation techniques are used.
3. Increased knowledge about the high-risk areas will help decision makers prioritize maintenance and capital projects.
4. May change homeowners' perceptions on who is responsible for flood protection.
5. The project demonstrated that integrating asset management into current design practices will decrease risk, while increasing the level of service to promote infrastructure sustainability.

8.3 Next Steps

A full-scale validation of the approach and resulting outcomes advocated in this research was not possible because of the lack of available data. The following steps would be required to further validate the research, and to further create a scorecard that could be applied to the City of Windsor, the case study, as a whole. This includes:

1. Retrofitting a street in an area with all 5 LIDs and multiple mitigation techniques to obtain experimental observations in the next major flood event.
2. Ensuring there is a means to assess if there is a direct correlation between the reduction in flooding and these mitigation techniques.
3. Receiving observed outflow and flooding data from the 100-year storm event used in this model to validate the model outputs.
4. Implementing the scorecard on a homeowner accessible website in the city and disseminating updated data on the current LID and mitigation techniques being used.
5. Finally, as these LIDs are added onto private properties, it will be important to address maintenance and monitoring issues.

Expanding the application of this research (e.g., assessment and scorecard) to other municipalities would not be difficult. However, it would require some degree of customization by altering specific parameters including infiltration rates due to different soil properties, changing temperatures, and different rain gauge values. This would be necessary to predict the percent reduction in flooding.

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Appendix A

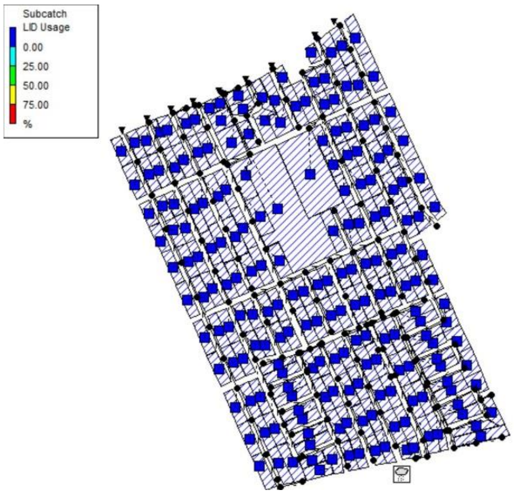


Figure 46- LID Usage- Zero

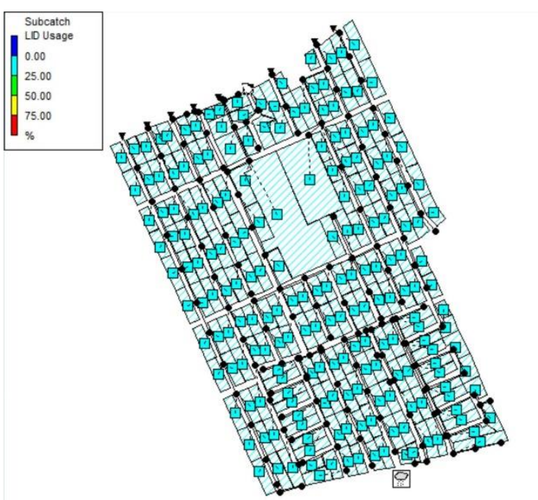


Figure 47- LID USAGE- Rain Barrel

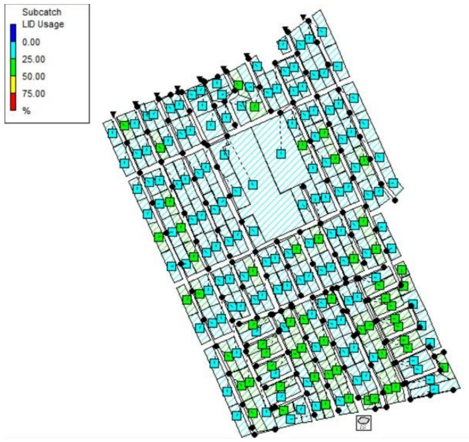


Figure 48- LID Usage- Downspout Disconnection

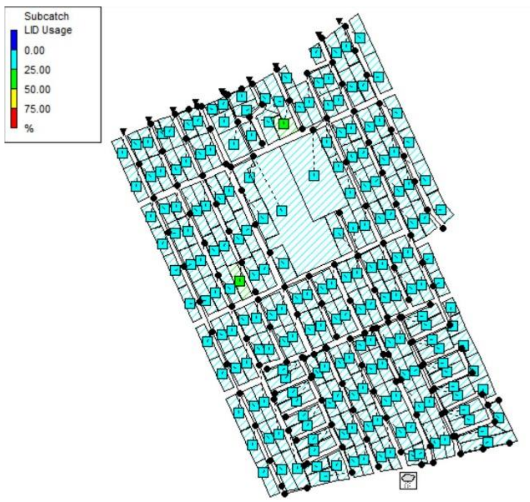


Figure 49- LID Usage - Permeable Pavement

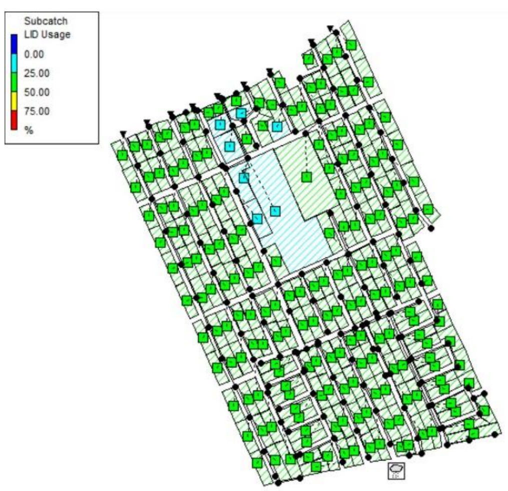


Figure 50- LID Usage- Infiltration Trench

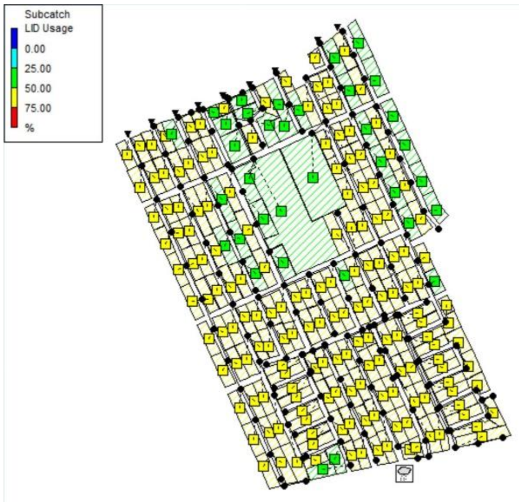


Figure 51- LID Usage- 3LIDs

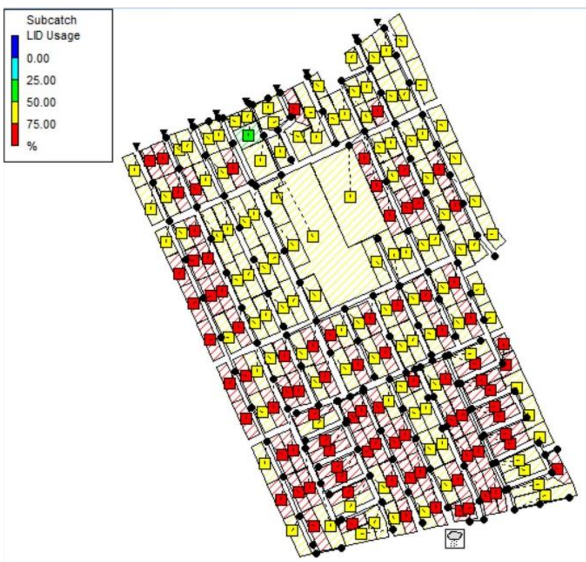


Figure 52- LID Usage- 4 LIDs

Table 29- Flooding Reduction 1 LID Sample

	LID	1 LID					
	Percent Per unit	0	0.153456	0.257872	0.472916	0.311255881	0.300398
	% Reduction	0	23.01846	1.031488	42.56243	28.01302932	9.011944
	Flooding (CMS)	18.42	14.18	18.23	10.58	13.26	16.76
Day	**Hour**	Original	DD	RB	PP	IT	RG
11	0:00:00	0	0	0	0	0	0
11	0:15:00	0	0	0	0	0	0
11	0:30:00	0	0	0	0	0	0
11	0:45:00	0	0	0	0	0	0
11	1:00:00	0	0	0	0	0	0
11	1:15:00	0	0	0	0	0	0
11	1:30:00	0	0	0	0	0	0
11	1:45:00	0	0	0	0	0	0
11	2:00:00	0	0	0	0	0	0
11	2:15:00	0	0	0	0	0	0
11	2:30:00	0	0	0	0	0	0
11	2:45:00	0	0	0	0	0	0
11	3:00:00	0	0	0	0	0	0
11	3:15:00	0	0	0	0	0	0
11	3:30:00	0	0	0	0	0	0
11	3:45:00	0	0	0	0	0	0
11	4:00:00	0	0	0	0	0	0
11	4:15:00	0	0	0	0	0	0
11	4:30:00	0	0	0	0	0	0
11	4:45:00	0	0	0	0	0	0
11	5:00:00	0	0	0	0	0	0
11	5:15:00	0	0	0	0	0	0
11	5:30:00	0	0	0	0	0	0
11	5:45:00	0	0	0	0	0	0
11	6:00:00	0	0	0	0	0	0
11	6:15:00	0	0	0	0	0	0
11	6:30:00	0	0	0	0	0	0
11	6:45:00	0	0	0	0	0	0
11	7:00:00	0	0	0	0	0	0
11	7:15:00	0	0	0	0	0	0
11	7:30:00	0	0	0	0	0	0
11	7:45:00	0	0	0	0	0	0
11	8:00:00	0	0	0	0	0	0
11	8:15:00	0	0	0	0	0	0
11	8:30:00	0	0	0	0	0	0
11	8:45:00	0	0	0	0	0	0

11	9:00:00	0	0	0	0	0	0
11	9:15:00	0	0	0	0	0	0
11	9:30:00	0	0	0	0	0	0
11	9:45:00	0	0	0	0	0	0
11	10:00:00	0	0	0	0	0	0
11	10:15:00	0	0	0	0	0	0
11	10:30:00	0	0	0	0	0	0
11	10:45:00	0	0	0	0	0	0
11	11:00:00	0	0	0	0	0	0
11	11:15:00	0	0	0	0	0	0
11	11:30:00	0	0	0	0	0	0
11	11:45:00	0	0	0	0	0	0
11	12:00:00	0	0	0	0	0	0
11	12:15:00	0	0	0	0	0	0
11	12:30:00	0	0	0	0	0	0
11	12:45:00	0	0	0	0	0	0
11	13:00:00	0	0	0	0	0	0
11	13:15:00	0	0	0	0	0	0
11	13:30:00	0	0	0	0	0	0
11	13:45:00	0	0	0	0	0	0
11	14:00:00	0	0	0	0	0	0
11	14:15:00	0	0	0	0	0	0
11	14:30:00	0	0	0	0	0	0
11	14:45:00	0	0	0	0	0	0
11	15:00:00	0	0	0	0	0	0
11	15:15:00	0	0	0	0	0	0
11	15:30:00	0	0	0	0	0	0
11	15:45:00	0	0	0	0	0	0
11	16:00:00	0	0	0	0	0	0
11	16:15:00	0	0	0	0	0	0
11	16:30:00	0	0	0	0	0	0
11	16:45:00	0	0	0	0	0	0
11	17:00:00	0	0	0	0	0	0
11	17:15:00	0	0	0	0	0	0
11	17:30:00	0	0	0	0	0	0
11	17:45:00	0	0	0	0	0	0
11	18:00:00	0	0	0	0	0	0
11	18:15:00	0	0	0	0	0	0
11	18:30:00	0	0	0	0	0	0
11	18:45:00	0	0	0	0	0	0
11	19:00:00	0	0	0	0	0	0
11	19:15:00	0	0	0	0	0	0
11	19:30:00	0.08	0	0.08	0	0	0.05

11	19:45:00	0	0	0	0	0	0
11	20:00:00	0.08	0.03	0.08	0	0.01	0.05
11	20:15:00	2.85	1.91	2.8	1.45	1.94	2.52
11	20:30:00	6.56	5.73	6.56	4.41	5.39	6.19
11	20:45:00	0.13	0.22	0.13	0.11	0.12	0.13
11	21:00:00	0	0	0	0	0	0
11	21:15:00	0	0	0	0	0	0
11	21:30:00	0	0	0	0	0	0
11	21:45:00	0	0	0	0	0	0
11	22:00:00	0.12	0.09	0.12	0.07	0.08	0.11
11	22:15:00	0	0	0	0	0	0
11	22:30:00	0	0	0	0	0	0
11	22:45:00	0	0	0	0	0	0
11	23:00:00	0	0	0	0	0	0
11	23:15:00	0	0	0	0	0	0
11	23:30:00	0	0	0	0	0	0
11	23:45:00	0	0	0	0	0	0
12	0:00:00	0	0	0	0	0	0
12	0:15:00	0	0	0	0	0	0
12	0:30:00	0	0	0	0	0	0
12	0:45:00	0	0	0	0	0	0
12	1:00:00	0	0	0	0	0	0
12	1:15:00	0	0	0	0	0	0
12	1:30:00	0	0	0	0	0	0
12	1:45:00	0	0	0	0	0	0
12	2:00:00	0	0	0	0	0	0
12	2:15:00	0	0	0	0	0	0
12	2:30:00	0	0	0	0	0	0
12	2:45:00	0	0	0	0	0	0
12	3:00:00	0	0	0	0	0	0
12	3:15:00	0	0	0	0	0	0
12	3:30:00	0	0	0	0	0	0
12	3:45:00	0	0	0	0	0	0
12	4:00:00	0	0	0	0	0	0
12	4:15:00	0	0	0	0	0	0
12	4:30:00	0	0	0	0	0	0
12	4:45:00	0	0	0	0	0	0
12	5:00:00	0	0	0	0	0	0
12	5:15:00	0	0	0	0	0	0
12	5:30:00	0	0	0	0	0	0
12	5:45:00	0	0	0	0	0	0
12	6:00:00	0	0	0	0	0	0
12	6:15:00	0	0	0	0	0	0

12	6:30:00	0	0	0	0	0	0
12	6:45:00	0	0	0	0	0	0
12	7:00:00	0	0	0	0	0	0
12	7:15:00	0	0	0	0	0	0
12	7:30:00	0	0	0	0	0	0
12	7:45:00	0	0	0	0	0	0
12	8:00:00	0	0	0	0	0	0
12	8:15:00	0	0	0	0	0	0
12	8:30:00	0	0	0	0	0	0
12	8:45:00	0	0	0	0	0	0
12	9:00:00	0	0	0	0	0	0
12	9:15:00	0	0	0	0	0	0
12	9:30:00	0	0	0	0	0	0
12	9:45:00	0	0	0	0	0	0
12	10:00:00	0	0	0	0	0	0
12	10:15:00	0	0	0	0	0	0
12	10:30:00	0	0	0	0	0	0
12	10:45:00	0	0	0	0	0	0
12	11:00:00	0	0	0	0	0	0
12	11:15:00	0	0	0	0	0	0
12	11:30:00	0	0	0	0	0	0
12	11:45:00	0	0	0	0	0	0
12	12:00:00	0	0	0	0	0	0
12	12:15:00	0	0	0	0	0	0
12	12:30:00	0	0	0	0	0	0
12	12:45:00	0	0	0	0	0	0
12	13:00:00	0	0	0	0	0	0
12	13:15:00	0	0	0	0	0	0
12	13:30:00	0.17	0.04	0.17	0.04	0.07	0.11
12	13:45:00	0.57	0.14	0.52	0.13	0.18	0.38
12	14:00:00	6.28	4.6	6.22	3.82	4.63	5.71
12	14:15:00	0.18	0.37	0.2	0.14	0.15	0.16
12	14:30:00	0	0.03	0	0	0	0
12	14:45:00	0	0	0	0	0	0
12	15:00:00	0.5	0.27	0.48	0.1	0.15	0.47
12	15:15:00	0.8	0.64	0.78	0.27	0.48	0.79
12	15:30:00	0.1	0.11	0.09	0.04	0.06	0.09
12	15:45:00	0	0	0	0	0	0
12	16:00:00	0	0	0	0	0	0
12	16:15:00	0	0	0	0	0	0
12	16:30:00	0	0	0	0	0	0
12	16:45:00	0	0	0	0	0	0
12	17:00:00	0	0	0	0	0	0

12	17:15:00	0	0	0	0	0	0
12	17:30:00	0	0	0	0	0	0
12	17:45:00	0	0	0	0	0	0
12	18:00:00	0	0	0	0	0	0
12	18:15:00	0	0	0	0	0	0
12	18:30:00	0	0	0	0	0	0
12	18:45:00	0	0	0	0	0	0
12	19:00:00	0	0	0	0	0	0
12	19:15:00	0	0	0	0	0	0
12	19:30:00	0	0	0	0	0	0
12	19:45:00	0	0	0	0	0	0
12	20:00:00	0	0	0	0	0	0
12	20:15:00	0	0	0	0	0	0
12	20:30:00	0	0	0	0	0	0
12	20:45:00	0	0	0	0	0	0
12	21:00:00	0	0	0	0	0	0
12	21:15:00	0	0	0	0	0	0
12	21:30:00	0	0	0	0	0	0
12	21:45:00	0	0	0	0	0	0
12	22:00:00	0	0	0	0	0	0
12	22:15:00	0	0	0	0	0	0
12	22:30:00	0	0	0	0	0	0
12	22:45:00	0	0	0	0	0	0
12	23:00:00	0	0	0	0	0	0

Table 30- Actual vs. Theoretical Percent Reduction

	Rain Garden	30.00	1000.00	9.17	0.01					
	Rain Barrel	4.00	400.00	1.02	0.00					
	Downspout Disconnection	1.00	1000.00	23.52	0.02					
	Infiltration Trench	90.00	2361.60	28.43	0.01					
	Permeable Pavement	90.00	9270.00	42.93	0.00					
		Theoretical	Actual							Benefit/Cost
2LIDS	ITDD	51.94	49.41	0.95	27.04	22.37				
					0.30	0.15				0.01
	PPDD	66.45	58.58	0.88	37.85	20.73				
					0.42	0.14				0.01
	PPIT	71.36	61.06	0.86	36.74	24.32				
					0.41	0.27				0.01
	PPRB	43.96	43.74	1.00	42.72	1.02				
					0.47	0.25				0.00

	DDRB	24.54	24.60	1.00	23.57	1.03				
					0.16	0.26				0.02
	ITRB	29.45	29.07	0.99	28.06	1.01				
					0.31	0.25				0.01
	RGDD	32.69	33.71	1.03	9.46	24.25				
					0.32	0.16				0.02
	RGIT	37.59	36.95	0.98	9.01	27.94				
					0.30	0.31				0.01
	RGRB	10.19	10.46	1.03	9.41	1.05				
					0.31	0.26				0.01
	RGPP	52.10	49.03	0.94	8.63	40.40				
					0.29	0.45				0.00
	DDRBIT	52.97	49.57	0.94	22.01	0.96	26.60			0.01
					0.15	0.24	0.30			
	DDRBPP	67.48	58.85	0.87	20.51	0.89	37.44			0.01
					0.14	0.03	0.42			
	DDPPIT	94.88	75.62	0.80	18.74	34.22	22.66			0.01
					0.12	0.38	0.25			
	RBPPIT	72.38	61.33	0.85	0.87	36.38	24.08			0.01
					0.22	0.40	0.27			
	RGPPIT	80.53	66.99	0.83	7.63	35.72	23.65			0.01
3LIDS					0.25	0.40	0.26			
	RGDDIT	61.11	55.99	0.92	8.40	21.54	26.04			0.01
					0.28	0.14	0.29			
	RGRBIT	38.62	37.86	0.98	8.99	1.00	27.87			0.01
					0.30	0.25	0.31			
	RGPPDD	75.62	64.72	0.86	7.85	36.75	20.13			0.01
					0.26	0.41	0.13			
	RGPPRB	53.13	50.43	0.95	8.70	40.75	0.97			0.00
					0.29	0.45	0.24			
	DDRGRB	33.71	33.82	1.00	23.59	9.20	1.03			0.01

					0.16	0.31	0.26			
	DDRBITPP	95.90	75.84	0.79	18.60	0.81	22.48	33.95		0.01
					0.12	0.20	0.25	0.38		
	DDRBITRG	62.14	55.61	0.89	21.05	0.92	25.44	8.21		0.01
					0.14	0.23	0.28	0.27		
	DDRBPPRG	76.65	64.67	0.84	19.84	0.86	36.23	7.74		0.01
					0.13	0.22	0.40	0.26		
4LIDS										
	RBITPPRG	81.55	66.61	0.82	0.84	23.22	35.07	7.49		0.01
					0.21	0.26	0.39	0.25		
	DDITPPRG	104.05	80.37	0.77	18.16	21.96	33.16	7.08		0.01
					0.12	0.24	0.37	0.24		
	DDRBITPPRG	105.07	80.47	0.77	18.01	0.78	21.77	32.88	7.02	0.01
					0.12	0.20	0.24	0.37	0.23	
5 LIDS										

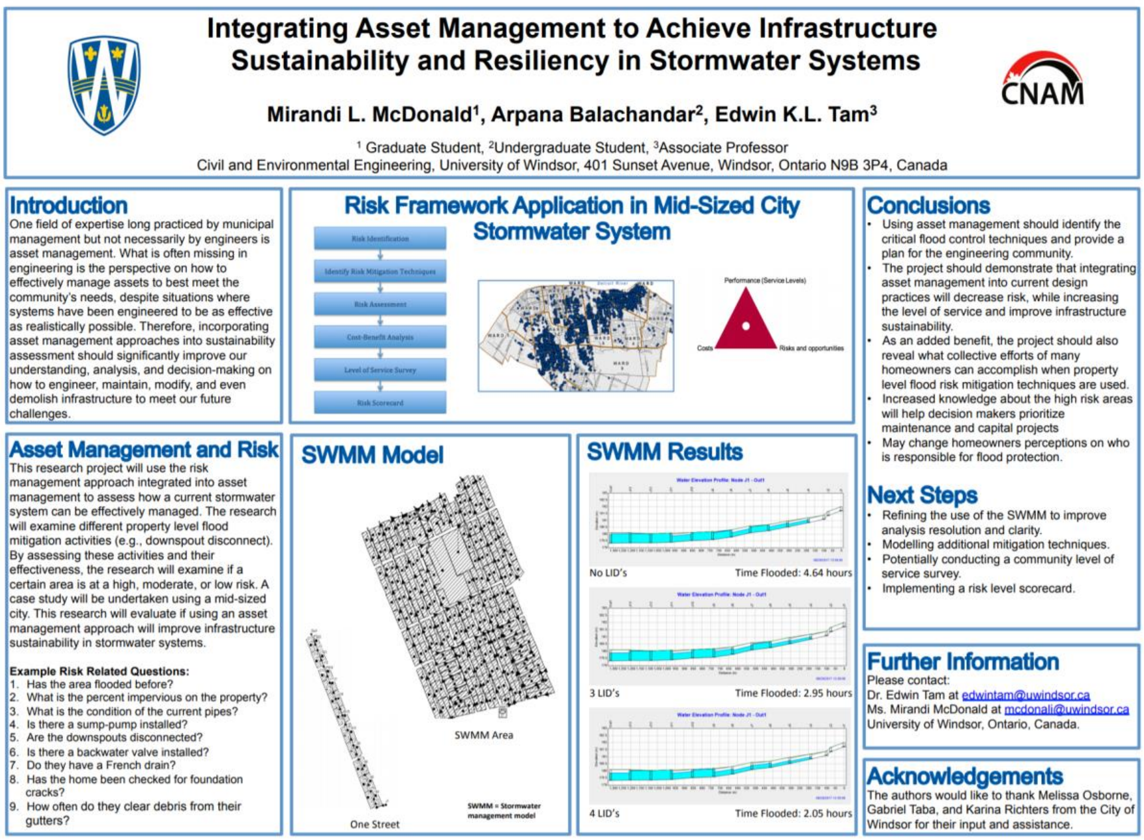
Table 31- Percent Reduction Per Square Meter/Item

		Percent Reduction per Sqm/Item			
1LID	ORIGINAL		0.00		
	RG		0.31		
	DD		0.16	/sqm	
	RB		0.26	/barrel	
	PP		0.48	/sqm	
	IT		0.32	/sqm	
2LIDS	ITDD	IT	0.30		
		DD	0.15		
	PPDD	PP	0.42		
		DD	0.14		
	PPIT	PP	0.41		
		IT	0.27		
	PPRB	PP	0.47		
		RB	0.25		
	DDRB	DD	0.16		
		RB	0.26		
	ITRB	IT	0.31		
		RB	0.25		
	RGDD	RG	0.32		
		DD	0.16		
	RGIT	RG	0.30		
		IT	0.31		
	RGRB	RG	0.31		
		RB	0.26		
	RGPP	RG	0.29		
		PP	0.45		
3LIDS	DDRBIT	DD	0.15		
		RB	0.24		
		IT	0.30		
	DDRBPP	DD	0.14		
		RB	0.03		
		PP	0.42		
	DDPPIT	DD	0.12		
		PP	0.38		
		IT	0.25		
	RBPPIT	RB	0.22		
		PP	0.40		
		IT	0.27		
	RGPPIT	RG	0.25		

		PP	0.40		
		IT	0.26		
	RGDDIT	RG	0.28		
		DD	0.14		
		IT	0.29		
	RGRBIT	RG	0.30		
		RB	0.25		
		IT	0.31		
	RGPPDD	RG	0.26		
		PP	0.41		
		DD	0.13		
	RGPPRB	RG	0.29		
		PP	0.45		
		RB	0.24		
	DDRGRB	DD	0.16		
		RG	0.31		
		RB	0.26		
4LIDS	DDRBITPP	DD	0.12		
		RB	0.20		
		IT	0.25		
		PP	0.38		
	DDRBITRG	DD	0.14		
		RB	0.23		
		IT	0.28		
		RG	0.27		
	DDRBPPRG	DD	0.13		
		RB	0.22		
		PP	0.40		
		RG	0.26		
	RBITPPRG	RB	0.21	20.00	4.19
		IT	0.26	100.00	25.80
		PP	0.39	10.00	3.90
		RG	0.25	10.00	2.50
	DDITPPRG	DD	0.12		
		IT	0.24		
		PP	0.37		
		RG	0.24		

5 LIDS	DDRBITPPRG	DD	0.12	50.00	6.00
		RB	0.20	50.00	9.81
		IT	0.24	50.00	12.10
		PP	0.37	50.00	18.27
		RG	0.23	50.00	11.70
					57.88

Figure 53- Conference Poster



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