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A sustainability assessment framework for infrastructure: Application in stormwater systems

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A SUSTAINABILITY ASSESSMENT FRAMEWORK FOR INFRASTRUCTURE:

APPLICATION IN STORMWATER SYSTEMS

By

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ABSTRACT

This research presents a three-pronged framework focusing on the *functionality-survivability-sustainability* (FSS) aspects for sustainability assessment using stormwater infrastructure as its example, and presents a case study to illustrate how the framework can be used. Existing sustainability assessment tools focus mainly on the functional aspects of environmental, social and economic performance separately with emphasis on reducing resource use, and do not capture the changing demands and issues comprehensively. Infrastructure sustainability is defined as the ability of the system to function well and be able to survive complex and emerging stressors without increasing resource consumption, impacting people's health and well-being, and be able to manage for changing circumstances. A *process based* approach to infrastructure sustainability from *resource, people, and change* perspective (PRPC) was conceptualized. An infrastructure decision making survey was conducted among people involved in management of water. The twenty-five questions in Group A focused on how sustainability is visualized and uncertainties are factored, and how performance of the system is evaluated. Thirteen questions in Group B focused on issues concerning data and information management. The findings of the survey informed the framework development. A set of 34 indicators were developed for the three domains (FSS), based on the following criteria: resource minimization (R), public health (P) and change management (C). A detailed decision process was developed for evaluating non-quantifiable indicators. A multi-criterion method based on weights derived from experts, and related literature was developed to perform the final assessment, and a template was proposed to present the outcome. The case study revealed that despite highest weight assigned on R in both the weighting schemes, the performance of R was insignificant compared to P and C for functionality and survivability. This indicated that there may be some complex interactions going among different indicators. The zero score for R in sustainability indicated that not having enough information on certain aspect of infrastructure may lead the system towards unsustainability in the long term, even though it may be functional presently and may survive some stressors. Applying the framework in additional infrastructure

systems is recommended to test the robustness and wider application of the framework.

DEDICATION

To my loving mother, Mrs. Ahilya Singh, an inspirational teacher and an amazing person from whom I learned all the important life lessons and most of all - “can do” and “keep going no matter what” attitude that truly drove me to start, continue and complete this journey.

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1. INTRODUCTION

1.1. Background

According to 2006 census, almost two-thirds of Canadians lived in metropolitan areas (Statistics Canada 2009). This growing population increases pressure on infrastructure, such as stormwater system. Climate change, aging infrastructure, population growth, public health and sustainability are among the key challenges facing the infrastructure, especially that which manages and distributes water (Buchberger et al. 2008, Grayman 2009). They are more vulnerable to climate change effect due to public health concerns, the large physical network, and the nature of resource itself (Infrastructure Canada, 2006). At a time when stormwater infrastructures are aging, have to serve the growing population with often shrinking funding, coping with frequent urban flooding from climate change (Lemman and Warren 2004, Infrastructure Canada 2006, Cohen and Neale 2006, Clean Air Partnership 2007, Lemman et al. 2008, Engineers Canada 2008, Richardson 2010) is an added challenge. Urban flooding not only creates system failures, but causes socio-economic losses: the loss of personal and public property, associated health and safety issues, and psychological distress. Flooding can interrupt other municipal services such as transportation, electricity, and garbage collection and disposal. The economic loss due to failure in such infrastructure can be immense. Health impacts are also emerging as a major problem in terms of death, injury, communicable illness, water and vector borne illness, chronic disease, and direct or indirect physical and psychological impacts on the residents (CRED 2010). Furthermore, cross contamination and increased wastewater treatment bypasses can result in poor receiving water quality and increasing risk to recreational users from swimming.

Since stormwater infrastructure is a major component of urban design, the function and consequent dysfunction of infrastructure impacts societal health and well-being. Considering the multiple socio economic factors, it is crucial to ensure that the current actions will not detrimentally impact the ability of the infrastructure to function and adapt under future and presumably stressful conditions. In other words sustainability of the stormwater infrastructure is critical. To identify whether the stormwater infrastructure is functioning adequately, is capable of surviving additional stressors, and be sustainable in long term – *assessing the sustainability* of the stormwater infrastructure is essential.

Despite the decades of effort to achieve sustainability, the implementation remains problematic to date. Identifying, assessing, monitoring and evaluating the sustainability of a system are very important to achieve the goal of sustainable development (Lundin et al.1999, Hellstorm et al. 2000). The need for practical tools to assess sustainability of an infrastructure is crucial to policy makers and important to the community if "real" sustainable development is to be achieved (Dasgupta and Tam 2005, Sahely and Kennedy 2005). Most of the previous studies related to sustainable urban water systems focused primarily on water supply and wastewater systems (Murray et al. 2009, Muga and Mehlcic 2008, Sahely 2006, Bagley 2005, Foxon et al. 2002, Balkema et al. 2002, Hellstorm et al. 2000, Lundin et al.1999). A few studies focus on wastewater reuse systems (Upadhyaya and Moore 2012, Kennedy and Tsuchihashi 2005), but rarely on stormwater system (Sundberg et al. 2004). Sundberg et al. (2004) considered stormwater as a core system, and urban water system, society and ecosystem as related systems, and formulated various related indicators under following "basic system criteria": existence, effectiveness, freedom of action security, adaptability and co-existence. By identifying the "related systems", the interconnectedness between the systems is identified. However, existing uncertainties and emerging issues will result in larger, more intense, and even unforeseen stressors in the future: how a system will survive these stressors is not typically addressed. Moreover, the ability of the system to manage for changing circumstances - often referred as *change management* - is not incorporated.

The Canadian Federal Sustainable Development Act 2008 required Environment Canada to establish a federal sustainability strategy, of which monitoring and reporting the progress based on the Canadian environmental sustainability indicators (CESI) is essential (Environment Canada 2011). The CESI indicators report the state of water quality, and water availability in Canada, among other indicators (EC 2011), but do not include the state of any of the urban water systems. The Canadian water sustainability index (CWSI) evaluates a community's water well-being for the indicators of following five components: resource, ecosystem health, infrastructure, human health and well-being, and capacity (Government of Canada 2007). The infrastructure component focus on water and wastewater systems and the impacts of climate change on water resources, but do not specifically target the stormwater systems. The Federation of Canadian Municipalities (FCM) report on water sector (Marbek Resource Consultant 2009) does list challenges, financial implications, opportunities and threats to adapting to the sustainable solutions, but does not assess those solutions, nor is there any specific application to stormwater systems. The Polis Project report *Peeling back the Pavement* (Porter-Bopp et al. 2011) describes the reason and steps to move towards "rain water management" from stormwater management, but only prescribes the solutions, and does not consider how the systems should be assessed.

The current sustainability assessment methods and tools mainly encompass three aspects:

1) Although termed as sustainability assessment tools, most current approaches focus on the functional aspects of a system, or primarily day-to-day operational aspects.
2) The assessment is based on environmental, social and economic performance separately with a reductionist approach, and do not account for the interactions, complexities and vulnerabilities with a system approach.
3) Current methods focus primarily on resource reduction and do not necessarily consider public health or change management concerns.

To ensure the long-term sustainability of a system, first ensuring that the system is functional and can survive the vulnerabilities in crisis situations is important: these are almost pre-requisites to achieving sustainability. Therefore, an overall sustainability assessment method or framework should:

A. Encompass functionality, survivability and sustainability in a well defined comprehensive manner;
B. Consider beyond the conventional environmental, economic and social perspective to address the complexities and vulnerabilities; and

C. Include not only the resource, but also the public health and change management aspect is needed for achieving the real goal of sustainability.

This research intends to fulfill that gap by developing a sustainability assessment framework for infrastructure using stormwater systems as its example. The framework will focus on the resource, health, and change management aspects. The issues of functionality and survivability will be examined in terms of how they contribute to infrastructure sustainability.

1.2. Goal and Objectives

The goal is to develop a comprehensive framework for assessing the sustainability of infrastructure: if the system is fulfilling its intended purpose, is it resilient, and sustainable in the long term? The intent is to capture critical aspects of infrastructure functionality and survivability and how they contribute to sustainability in a comprehensive way. Unlike previous approach towards sustainability- mostly focused on reducing resource consumption only - this research intends to develop a framework that emphasizes critical aspects of public health and change management.
To fulfill these goals, following objectives were identified:

1) Identify and examine various issues in stormwater management, and efforts to address these issues.
2) Examine whether existing approaches to sustainability and performance assessment can be utilized in assessing the sustainability of infrastructures.
3) Develop a comprehensive framework that can encompass broader and long term issues in future as well as current issues.
4) Identify the criteria and indicators for assessing the sustainability of stormwater infrastructure.
5) Apply Multi Criteria Assessment method to come up with a final sustainability score of the system.
6) Propose a method of interpreting the final outcomes of the assessment.
7) Apply the framework to a case study to demonstrate how the sustainability assessment can be carried out.

1.3 Organization of the Dissertation

The dissertation is organized into nine chapters. Chapter 2 examines various approaches towards sustainability, assessment of infrastructure, indicators for sustainability used in stormwater system and relevant application of multi-criteria assessment methods. Chapter 3 presents the review of relevant literature pertaining to stormwater issues and management. Methodology of the research is outlined in Chapter 4. Chapter 5 provides details of the survey done in municipalities across Canada in order to develop the framework. Chapter 6 presents the development of the framework based on the functionality – survivability – sustainability (FSS) model, and development of indicators in each of the FSS domain. Chapter 7 explains the multi criteria style assessment that was selected for the sustainability assessment. The application of the framework to the case study and result of the multi-criteria assessment is presented in Chapter 8. Finally, in Chapter 9 conclusions are drawn and recommendations for further study are made.

2. SUSTAINABILITY ASSESSMENT

Chapter 2 covers various approaches to sustainability assessment, performance assessment practices in Canada, criteria and indicators pertaining to sustainable stormwater systems, and applying multicriteria decision-making in sustainability assessment.

2.1. Background

Sustainability generally does not receive as much attention in the evaluation stage of any engineering system as it does in the planning stage. For example, Strategic Environmental Assessment provides a tool for the decision-maker to choose more sustainable solution among various alternatives in the planning stage of a project (CEAA 2010, Runhaar 2007). The assessment of existing systems and information obtained from such assessment can not only help improve the sustainability of that particular system, but also provide important insight for policy and planning decision-making of a similar system in future.

2.2. Various Approach towards Sustainability

The following approaches are currently used to assess the sustainability of a system: ranking (CK 2009, SustainLane 2008, Kahn 1994); systems using sustainability indicators (FCM 2005); the urban footprint method (Rees and Wackernagel 1996); the metabolism approach (Wolman 1969, Sahely 2006, Zhang et al. 2006, Codoban and Kennedy 2008) and extended metabolism approach (Newman 1999); a combination of footprint and indicators (O'Regan et al. 2009); life cycle assessment; and mathematical models.

2.2.1 Ranking

The ranking approach is widely used by magazines and organizations to rank cities. In general, a multicriteria method is used to assign scores for different criteria, a weighting scheme is employed, and a final score is calculated to determine the overall rank of the city. For example, if a score of 10 is assigned for the most sustainable and 0 for not sustainable in each category, then the city having a highest total score is ranked first. The criteria can be broader or specific, varying from city to city. Some examples of the specific criteria and broad criteria are listed in Table 2-1 below.

Table 2-1: Example of Criteria Used in Ranking Cities

Specific criteria	Broad Criteria
commuting to work, metro transportation, congestion, air quality, tap water quality, green (Leadership in Energy and Environmental Design- LEED) building, local food and agriculture, planning/land use, housing affordability, natural disaster risk, green economy, energy and climate change policy, city innovation, knowledge base/communication and water supply (SustainLane 2008).	ecological integrity, economic security, governance and empowerment, infrastructure and the built environment and social well-being (CK 2009).

Generally, the ranking approach is not specific to infrastructure system. Even in case of city, the weight assigned to each criterion in one city may not be exactly relevant in other cities: the issues and priorities from city to city differ. These differences are not reflected in the ranking system. In some cases ranking is done on the basis of mathematical models (Kahn 1994) where the impacts of many city characteristics and their interrelationship are not reflected in the result. In this regard, the ranking method does not provide a complete picture about a system's sustainability. Climate change policy may be included as a criterion for ranking, but it is typically generic in nature and does not consider specifically how the policy implementation relates to infrastructure sustainability.

2.2.2 Sustainability Indicators

Sustainability indicators are extensively used when assessing the sustainability of a city. Sustainability Indicators (SIs) are one tool to gather information about sustainability of a system. Various studies have been done to develop sustainability indicators for water and wastewater systems (Thorsten 2007, Palme and Chalmers 2007, Sahely 2006, Osborne 2003, Uhlmann 2003, Hellstrom et al. 2000, Bell and Morse 1999, Lundin et al. 1999). Studies to review, compare and identify sustainable treatment technology of wastewater and reclamation has also been used sustainability indicators (Muga and Mihelcic 2008, Juang et al. 2007, Oraon etal. 2006, Lee et al. 2006, Fane 2005, Upadhyaya 2005, Vleuten-Balkema and Juliana van der 2003, Drewer et al. 2003). The Federation of Canadian Municipalities (FCM) used 11 indicators and 72 sub-indicators to examine the quality of life in Canadian cities during 1996 to 2001 (FCM, 2005). Interestingly, in FCM indicators, urban footprint is considered as a sub-indicator under natural environment category. The complexity involved in identifying the urban footprint is in itself a unique approach to sustainability assessment.

Most of the sustainability indicators, although termed “sustainability indicators”, are designed for assessing environmental response and/or physical attributes and do not reflect other aspects of sustainability (e.g., economic and social aspects). It is important to establish what the long-term performance of a system is (Bell and Morse 1999), but most of the current indicators do not reflect a system’s ability to maintain or improve over time (Milman and Short 2009). Milman and Short (2009) considered water provision resiliency (WPR) as sustainability indicator. Bagheri (2006) argues that sustainability is neither a ‘system state’ nor a ‘static goal’ to be achieved and advocates for ‘backcasting’ with the help of indicators. Bell and Morse (1999) and Hellstrom et al. (2000) argue that sustainability of a system should be examined with a system approach.

Indicators in general are a tool to measure criteria, and should be parameters to reflect sustainability, but should not be criteria unto themselves. Using indicators for sustainability without a well-defined framework can be difficult due to the dynamics involved in a system and its qualitative attributes. Multiple biophysical, ecosystem and human interaction may not allow indicators to reflect all aspects of sustainability unless designed within a certain framework. Selecting an indicator based on its function is more suitable than based on the outcomes (Tam 2002), because functional indicators can be more sensitive to the changing conditions. Having a clearly defined framework can categorize indicators based on their attributes and can be used to signal the performance of particular attribute within the given framework.

2.2.3 Urban Footprint

The urban footprint (UF) approach is based on the measurement of the land area required to maintain a population in a city. The UF accounts for land used for infrastructure, agriculture, forests, energy, material and land for waste assimilation in a city (Eaton et al. 2007, Rees and Wackernagel 1996). UF analysis considers the ecological and biophysical aspect of a city and its periphery and interprets the consumption of resources in terms of land area used. Peripheral satellite cities/settlements are often responsible for providing food and materials for the city to sustain its population. In this regard the system boundary of the city is expanded to those outer areas: sustainability of the region rather than the city itself is typically assessed. The footprint for a densely populated small city (area-wise) may be smaller than the one with large area and sparse population; however the city may not necessarily be more sustainable because other parameters (e.g., health, economics) may influence sustainability. The dynamics involved in a city system are not considered in the urban footprint approach; however the system model is conceptually straightforward (inputs and outputs). Quantification is important in footprint analysis and can be useful for small to large size cities. There is generally no explicit consideration of infrastructure, and neither the climate change effect nor its management are explicitly considered.

2.2.4 Metabolism

The metabolism approach generally used at city or neighbourhood scales treats the material flows akin to human metabolism, and material flow analysis (MFA) is utilized. Consuming food, water and energy are considered inflows, while solid waste, wastewater, heat and air emissions are considered outflows (Codoban and Kennedy 2008, Sahely 2005, Wolman, 1969). A life cycle approach is taken in the urban metabolism analysis and usually tangible entities are considered. The metabolism approach can be well suited for engineering systems such as water, energy, transportation and waste which have more tangible inputs and outputs, but it may not capture the intangible or qualitative attributes. Quantification is important in this approach. For this reason, metabolism approach presents only a balance sheet of input and output of resources. No consideration is made for judging the effectiveness of efforts involved in the process of making systems more sustainable, and there is no specific consideration for climate change effects, or the economic and social aspects.

2.2.5 Extended Metabolism

The extended metabolism approach considers livability as a component of metabolism (Newman 1999). Material, food, land, water are considered resource inputs; liveability conditions and waste as outputs; and the dynamics of human settlement are considered in the functional stage. In this sense, the extended metabolism approach improves upon the metabolism approach by including social aspects. The extended metabolism approach can apply to industrial areas, neighbourhoods and individual business, and can also compare cities. The application of this approach requires reducing input and waste output, and improving the livability condition. The livability condition is broadly defined and includes multiple dimensions: health, employment, income, education, housing, accessibility, urban design quality and community. Arguably, livability conditions may be affected by the actions taken to reduce input and waste output in the infrastructure system. The fundamental element of all liveability and social well-being is health, which is greatly affected by environmental causes: by this reasoning, public health should be a part of infrastructure sustainability assessment. The extended metabolism does not include climate change management on the sustainability of a system.

2.2.6 Life Cycle Assessment

Life cycle assessment (LCA) is a method of accounting for the consumption of resource and energy and emissions to the environment, from “cradle to grave” of a product or a service. The resource and energy consumption, and emissions are accounted from raw material extraction, processing, manufacture, distribution, use, repair and maintenance, and end of life stages of a product or service. There are four stages in LCA generally: goal and scope definition, inventory analysis, impact assessment and interpretation of findings. The *functional unit* is defined to reflect the basic function of the system, and all the inputs and outputs calculated on the basis of functional unit. The effectiveness of LCA depends on the system boundary and data availability because all the life cycle stages are interrelated and defining the boundary could be difficult. The quantification of all the resource use and emission cannot generally be done without data.

LCA has been applied to water and wastewater systems to evaluate the energy and chemical usage and environmental emissions in form of GHG and pollutants (Godskesen et al. 2011, Buckley et al. 2011, Racoviceanu and Karney 2010). However, it only accounts for the quantifiable variables, and cannot assess the qualitative aspects, which is a major factor in management of stormwater systems. The GHG emission does take climate change stressor into account, but fails to look into public health related matters or change management aspects. LCAs tend to be more focused on the physical resource aspect.

2.2.7 Combination of Footprint and Indicators

As an example of how approaches can be combined in sustainability assessment, ecological footprint and sustainability indicators are combined to develop a Sustainability Development Index (SDI) to identify the relative sustainability of 79 Irish settlements (O'Regan et al. 2009). The SDI included both tangible and intangible information relating to sustainability. However, this study did not address change management and the broader issue of people's health well-being into the sustainability. The authors noted that such integration resulted in double counting of some of the environmental attributes.

2.2.8 Use of Other Models

Apart from the six approaches of sustainability assessments (ranking, indicators, footprint etc.), engineering practices commonly model individual infrastructure systems sustainability around explanatory and response variables. To simplify the process, the interrelationship of variables is ignored and linear relationship is assumed in many cases. In many cases, computer models are developed to analyze and understand system variability and sensitivity. For example, water supply systems sustainability has been modeled by many researchers as shown in Table 2-2.

Table 2-2: Mathematical model used in water systems

Water system sustainability as a function of:	Reference
Flow of water (Ml/d) and unit cost of process (pound/ Ml/d)	(Foxon, et al. 2000)
Mass of water (m^3/y), quality of water and energy used (MJ/m^3)	(Bagley et al. 2005)
Mass of water, chemicals used and energy used	(Sahely 2006)

Using specific mathematical models alone for assessing sustainability may not be effective because sustainability involves multiple aspects (such as social, economical etc.) and these variables are interdependent. For example, in water systems, quality is very important. Asset management practice and the wastewater management method have significant impact on quality of water supplied and the receiving water quality. Periodic clean up, monitoring, repair and maintenance of the reservoirs and distribution also affect the distribution efficiency as well as quality of the water. Mathematical models may not be able to capture all these variations, but can provide an important tangible tool for decision making, especially for analyzing trade-offs between different scenarios.

However, these models do not provide tool for sustainability assessment. Table 2-3 lists the summary of various approaches and their applicability, advantages and disadvantages.

Table 2-3: Summary of Various Approaches in Sustainability

Approach	Major Details	Implementation	Advantage	Disadvantage	Link to Climate Change Management
Ranking	Based on weighted score for various categories	Infrastructure, cities product, institution	Simple, can be used as pre-screening tool	Do not consider temporal and spatial variability	No

Sustainability Indicators	Based on various categories, may have sub indicators	Infrastructure, cities, product, institution	Can be used as a tool to reflect tangible and intangible aspects	Difficult to choose, sometimes confusion between criteria and indicators unless used within a framework	Some indicators for resiliency
Footprint	Interprets resource consumption in terms of land area used	Cities, product, institution	Affects are indicated in single unit (ha), easy to visualize	Complex, need to consider resources such as food, hard to identify area of improvement	Indirect
Metabolism	Considers system similar to human metabolism and input and output is calculated	Infrastructure, cities	Scientific, simple	Quantification required, hence data availability and data quality can affect the outcome	No
Extended Metabolism	Same as metabolism but considers livability as output	Cities	Scientific, simple	Quantification required, hence data availability and data quality can affect the outcome	No

LCA	Quantifies resources and energy used, and emissions	Infrastructure, products, services	Scientific, simple	Quantification required, hence data availability and data quality can affect the outcome	Indirect, in terms of energy input and carbon emission as output

Multiple infrastructure systems are involved in serving the growing population. Governing and managing infrastructure system requires natural, financial, and human resources. Given the impacts of climate change and the apparent vulnerability of our communities, a paradigm shift is required to address the issues of infrastructure and its possible interaction with public health, with limited resource. Change management strategies for infrastructure systems have to be developed to minimize the risks and maximize the benefit of climate change, and other stressors that are not observed now but may emerge in the future.

2.3. Performance Assessment tools

Assessing and analysing the performance on functional aspect of infrastructure system is in practice. The Report Card for America's Infrastructure (2009) ranked water and wastewater infrastructure as D-, indicating a poor performance in terms of replacing aging infrastructure, complying with existing and future federal water regulations, and repairing leaking pipes (EPA 2009). The assessment is done on the basis of condition and capacity of the infrastructure, and funding versus need. This assessment did not consider the vulnerability of the infrastructure due to natural (and perhaps human induced) causes, such as extreme weather events, which occur with greater frequency. In a survey conducted by Environment Canada over 400 municipal Emergency Management Coordinators in Ontario municipalities, 86% of Ontario municipalities ranked weather and weather-related hazards as priority risks to their communities (Environment Canada 2010). Considering these later factors, it is even more crucial to have infrastructure that can address current as well as future challenges and continue to fulfill people's fundamental need in a safe and secure manner.

In some cases performance assessment has been utilized further to benchmark the performance with respect to a standard or against the performance of other similar systems (NWWBI 2010, FCM and NRC 2003, Ministry of Municipal Affairs and Housing 2001). The Ontario Ministry of Municipal affairs and Housing, under the municipal Performance Measurement Program (MPMP) requires all the municipalities in Ontario to report to the ministry on the performance of various infrastructures since 2000. The main goal of the MPMP is to enable municipalities to make informed decisions relating to service level and optimizing available resources by comparing their performance with other municipalities within same group. Stormwater related indicators are presented in Table 2-4.

Table 2-4: MPMP Indicators for Stormwater

Stormwater Category	Indicators
Urban Stormwater	a) Operating costs for urban storm water management (collection, treatment, disposal) per kilometre of drainage system. b) Total costs for urban storm water management (collection, treatment, disposal) per kilometre of drainage system.*
Rural Stormwater	a) Operating costs for rural storm water management (collection, treatment, disposal) per kilometre of drainage system. b) Total costs for rural storm water management (collection, treatment, disposal) per kilometre of drainage system.*

* Total costs means operating costs as defined by MPMP plus interest on long-term debt and amortization on tangible capital assets as reported in the financial information returns.

The MPMP also encourages municipalities to identify and implement best practices, such as those identified by the Ontario Centre for Municipal Best Practices (OCMBP). The Federation of Canadian Municipalities (FCM) and National Research Council (NRC) prepared and implemented the *Infraguide: The National Guide to Sustainable*

Infrastructure from 2001 to 2007. The main purpose of the *Infraguide* was to collect case studies and best practice reports for sustainable municipal infrastructure based on Canadian experience and knowledge. The Infraguide focused on two aspects: decision making and investment planning issues, and a concise compilation of technical best practices. The FCM and NRC (2003) developed a set of indicators for benchmarking purposes. The indicators were developed to satisfy a number of service objectives that were targeted to provide a decision making support on all levels of decision-making: strategic, tactical and operational. These indicators focused on the effective management of assets to provide cost effective services and prolong the life of the infrastructure. Both the MPMP and FCM & NRC have indicators to measure the performance of water related infrastructure.

The National Water Wastewater Benchmarking Initiative (NWWBI) is targeted to benchmark the performance of water wastewater infrastructures. Since its inception in 1997 as a pilot project, the NWWBI has emphasized an ongoing process of improving quality and performance of water treatment and distribution systems, along with wastewater and stormwater systems, and to compare the results with other similar organizations. Although the benchmarking initiatives described above are effective, two gaps are identified: 1) all the performance assessment are primarily service based and try to optimize the functional attributes such as funding resources; and 2) they do not consider the emerging issues that our water infrastructure has to deal with.

2.4. Infrastructure Vulnerability to Climate Change and PIEVC Protocal

In order to identify the suitable solution to address climate change impacts for an infrastructure system, the vulnerability of the system has to be first understood. Engineers Canada in partnership with Natural Resource Canada has developed a five step *Public Infrastructure Engineering Vulnerability Committee* (PIEVC) protocol to assess the vulnerability of buildings, roads and associated structures, stormwater and wastewater systems, and water resources (PIEVC 2007). The following steps are identified:

Step I - Project Definition

Step II - Data Gathering & Sufficiency

Step III- Risk Assessment

Step IV - Engineering Analysis

Step V - Conclusions & Recommendations

In the project definition stage, the infrastructure to be assessed, time period of study and required climate parameters are established. Relevant data are gathered and in the risk assessment phase relationship between climate loads and the infrastructure capacity are determined. Vulnerability exists if the load exceeds the capacity of the infrastructure. Then a risk assessment is carried out as: $R = P \times S$, where, R is the risk, P is the probability of extreme climate event and S is the severity of the infrastructure component response. Generally, risk assessment is done in a workshop setting involving multiple experts and based on a number of assumptions. A risk matrix is developed and the vulnerability of the infrastructure is validated against the experience of operators and managers. Where potential vulnerability exists further engineering analysis is required. A review and documentation of assumptions, data source and data quality are undertaken. Medium risk items are evaluated, high-risk items move directly to recommendations, and low risk items are eliminated. Recommendations on remedial action, management action, no action or additional study requirement are made for the vulnerable infrastructure components. A follow up study may be done afterwards. Currently the PIEVC is conducting case studies to understand the applicability of the protocol in diverse range of infrastructure component across Canada. A number of case studies can be found on the PIEVC website.

The PIEVC protocol allows the user to identify the nature and severity of risks of climate change, eliminate the need for unnecessary detailed engineering analysis, quickly identify vulnerabilities and ensures consistency with a systematic approach so that proper and effective adaptation options can be formulated. However, the assessment requires a group of expertise from diverse sector ranging from climate scientists to people who have a good grasp of the local situation as well as the infrastructure design, operation, maintenance and management. Putting together a team of such expertise could be beyond the capacity of most of the smaller municipalities in Canada; hence, many municipalities may choose adaptation measures based on limited information and assessment. Due to the lack of a proper assessment of adaptation need in smaller municipalities, some of the adaptation efforts may be ineffective or less effective; they may even have negative impacts in the long term and may compromise the ability of the infrastructure to fulfill its basic function for future. For Northern Canada where most of the settlements are small, rural, and highly vulnerable to climate variations, identifying vulnerability indicators is recommended (Government of Canada 2007). This could be true for other Canadian smaller municipalities who may not have same level of resource and expertise to apply the PIEVC protocol as larger cities can (e.g. Toronto and Edmonton). The PIEVC Protocol allows the user to identify the nature and severity of risks of climate change, but does not necessarily assess the sustainability performance of the system.

In the UK, the central government assesses the service delivery performance of local governments on the basis of Set of National Indicators (NIS). *National Indicators Number 188* for climate change adaptation is formulated for adaptation in various sectors and following “indicator levels” are identified:

Level 0 Getting started

Level 1 Public commitment and impacts assessment

Level 2 Comprehensive risk assessment

Level 3 Comprehensive action plan

Level 4 Implementation, monitoring and continuous review

Local authorities are required to report on which level of preparedness they are in to implement adaptation. In the UK, the recently published *Infrastructure, Engineering and Climate Change Adaptation: Ensuring services in an uncertain future* (The Royal Academy of Engineers 2011) emphasize the need to focus on “…new interdisciplinary methods, new technologies, looking at social services and economic rather than using past engineering solutions and embracing probabilistic methods and flexible solutions”. Understanding the performance and condition of infrastructure in order to understand the resilience of the system is also emphasized.

In Australia five aspects of adaptation science are identified (CSIRO 2010): 1) information and future scenario for decision making, 2) understanding vulnerability and adaptive capacity, 3) technological options, 4) management, planning and design options, and 5) facilitating individual and institutional behaviour. These five aspects build up to the risk management and adaptation pathways which allows decision maker to decide between adaptation options and implement and achieve the adaptation outcomes.

Generally vulnerability assessment, risk assessment and uncertainty assessment are utilized to understand the impact of climate change on infrastructures. Often sensitivity analysis is performed to identify the critical variables of the system which may experience greatest consequences of climate change. However, all these tools fail to capture two things:

1. Qualitative variables.
2. Aspects of sustainability specific to social, economic and public health.

The proposed analytical framework for sustainability assessment developed in this research does include these aspects.

2.5. Criteria and indicators for Stormwater Infrastructure

The US EPA Phase I monitoring program emphasized the quality and quantity of stormwater discharged to receiving water body and in the Phase II monitoring program, evaluation of stormwater management program effectiveness was emphasized, and identification of BMPs based on the achievement of the goals were done (Clock and Bicknell 2002). Stormwater Phase II programs address the following program components (EPA 2008): public education and outreach; public involvement; illicit discharge detection and elimination; construction site runoff control; post-construction runoff control; and pollution prevention/good housekeeping for municipal operations. Stormwater programs concentrate on multiple objectives and program evaluation can focus on a variety of desired outcomes that parallel these objectives. Approaches to evaluating stormwater program effectiveness may therefore fall on a continuum from basic verification of compliance with regulatory requirements, up to assessing changes in knowledge and behaviour to detecting changes in receiving water quality (CASQA 2007) as shown in Figure 2-1.

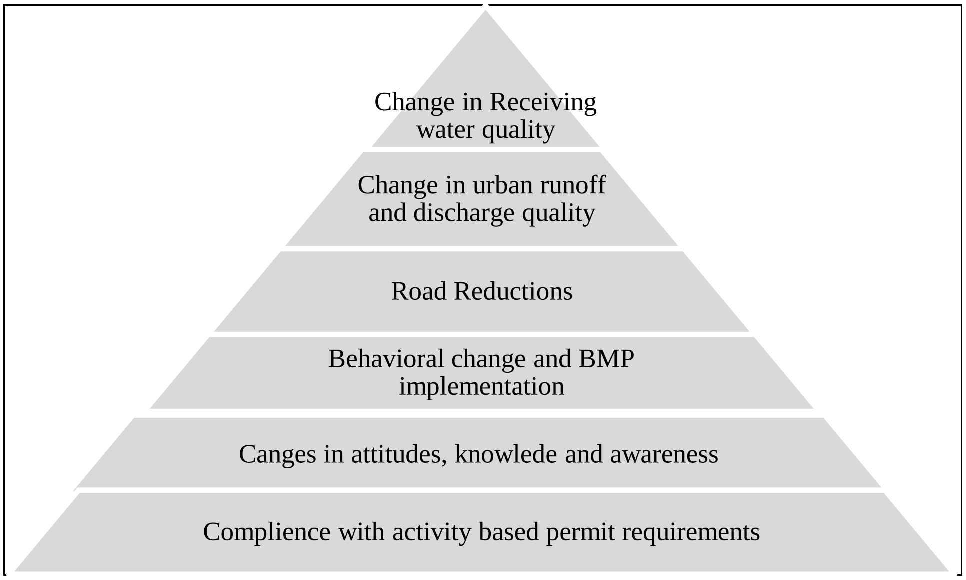


Figure 2-1: Stormwater Program Effectiveness Evaluation Approach (CASQA2007)

The stormwater program evaluation in Baltimore, for example, considers the evaluation approach in three broad categories: operations and activities, social indicators and water quality. The respective indicators are listed in Table 2-5.

Table 2-5: Stormwater Program Evaluation Indicators in Baltimore, Maryland (EPA 2008)

Broad Category	Indicator Category	Indicators
Operations and activities	Track structural BMPs implemented	# and type of BMPs, their specification, location, compliance with permit condition, and ongoing operation and maintenance
	Document and management	Materials collected through street sweeping (one of the programs), # of site inspection, # and type of illicit discharged identified and eliminated, # of training and outreach activity
Social	Effectiveness of public education effort	Attendance at public meeting, # of request for information, # of hits on websites
	Assessing	Change in lawn fertilizer sales in response to

	behavioural change	a campaign, amount of hazardous material turned in at collection event, participation in streambank clean-up, sign-up for environmental action pledges
Water quality	Biological Chemical Physical	E-coli, fish Phosphorous, trace metal Flow, SS, streambank stability

The EPA document –*Evaluating the Effectiveness of Municipal Stormwater Program* - lists other relevant evaluation/ monitoring guidance documents. Many of the indicators identified in these documents are similar.

Clock and Bicknell (2002) tested 20 of the 26 Center for Watershed Protection (CWP) indicators to evaluate the stormwater program in two watersheds in the Santa Carla Valley in California. Table 2-6 lists the CWP indicators.

Table 2-6: Center for Watershed Protection Indicators

CWP Categories	Indicators
Water quality	Water quality pollutant constituent, toxicity testing, non- point source loading, exceedence frequencies of water quality standards, sediment contamination, human health criteria
Physical and Hydrological	Stream widening/ downcutting, physical habitat monitoring, impacted dry weather flows, increased flooding frequency, stream temperature monitoring
Biological	Fish assemblage, Micro- invertebrate assemblage, single species indicator, composite indicators, other biological indicators
Social	Public attitude survey, Indistrial/commercial pollution prevention, public involvement and monitoring, user perception
Programmatic	Number of illicit connections identified/ corrected, permitting and compliance, growth and development

Site related	BMP performance monitoring, industrial site compliance monitoring

Various indicators have been identified for stormwater BMP performance on physical, chemical, biological and biochemical state of the receiving water bodies as well as economic impacts on public (Streaker 2002) as presented in Table 2-7.

Table 2-7: Stormwater BMP indicators

Indicator Category	Indicator
Physical	Dry weather and wet weather flow
Chemical	Pollutant concentration and loading in dry and wet weather, sediment quality
Biological	Introduction of new species
Biochemical	Toxicity testing, BOD/COD/TOC/DO/TS
Economic impact	Loss of economic resource for community, changes in land use mix, long term O& M cost, property taxes and user charges, changes in bond ratings, community debt impacts

The impacts on receiving water bodies and beneficial use are challenging to assess (Strecker 2002) because there are multiple factors affecting these two parameters. However the fact that urbanization affects the quantity and quality of surface runoff and ground water flows is evident because of following factors (Strecker 2002): removal/ reduction in vegetative cover and root systems; removal or compaction of moisture absorbing soils; change in landscape that results in higher surface runoff; creation of impervious surface; and activities and materials on surface area that increase the pollutant concentration in stormwater.

The Canadian Environmental Sustainability Indicators (CESI) is a system of national environmental indicators to provide a baseline of information on air quality, water quality, and GHG emissions (EC, 2011). The water quality indicators for the freshwater constitute physical, chemical and biological characteristics of lakes and rivers (EC 2011). Exceeding guideline values suggests that the aquatic life may be adversely impacted because of the high level of pollutants. Water quality guidelines used in each jurisdiction are available on http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=En&n=5D193531-1&offset=8&toc=show: those used in Ontario is presented in Table 2-8.

Table 2-8: Ontario Water Quality Guidelines' Indicators

Parameter	Form	Guideline description	Unit
Ammonia	Un-ionized	0.019	mg/L
Chloride	Dissolved	150	mg/L
Chromium	Total	2	µg/L
Nickel	Total	e^(0.76*ln[hardness]+1.06)	µg/L
Nitrate	Total(as N)	2.93	mg/L
Phosphorus	Total	0.03	mg/L
Zinc	Total	7.5, for hardness < 90 mg/L; 7.5 + 0.75*(hardness−90), for hardness > 90 mg/L $CaCO_3$	µg/L

The above parameters reflect human-derived water quality stressors such as urban development, agriculture, forestry, mining and other industrial facilities, deposition of atmospheric pollutants, and dams. Climate change and its impact are not identified as stressor; however, many human derived stressors are the primary cause of anthropogenic climate change. The minimum number of sample required for water quality parameters for lakes, rivers and northern rivers for the 2006 – 2008 periods were 6, 12 and 9 respectively. This minimum requirement fails to capture the weather related variations which in the long run can directly be attributed to changing climate.

The water quality indicators are derived from "aquatic life" perspective and do not captures the impact of deteriorating water quality on human health. The resurgence of eutrophication or toxic algal bloom which is caused by high nutrients level is reported in the Great Lakes (IJC 2011). One of the key factors for the rise in eutrophication are impacts from climate change which cause more intense and frequent precipitation and stormwater events (IJC 2010). Apart from the taste and odour problem, the toxic cyanobacteria can have multiple health impacts. Long-term exposure to comparatively low concentrations of the toxins in drinking water supplies is associated with growth of liver and other tumors (Chorus and Bartram 1999). Acute exposure to high doses may cause death from liver haemorrhage or liver failure. Other short-term effects on humans include gastrointestinal and hepatic illnesses. A number of adverse consequences have been documented for swimmers exposed to cyanobacterial blooms (Chorus and Bartram 1999). Due to warmer temperature new species of microorganisms are likely to be evolved which can have direct public health impacts (Patz et al. 2008). In the event of flooding, a larger segment of the population can be affected by the poor water quality of the stormwater runoff and local water bodies.

Assessing adaptation strategies for increased risk of urban flooding in Denmark was done on the basis of social cost benefit analysis (Arnbjerg-Nielsen and Fleischer 2009). There are not any criteria other than economic and structural ones to assess the adaptation of urban stormwater infrastructure to climate change.

The Ontario Ministry of Natural Resources (MNR) regularly reviews the following indicators of potential flooding (OMNR 2008):

1) detailed current weather conditions
2) weather satellites
3) weather radar
4) stream flow and levels
5) soil moisture conditions
6) snowpack information, and
7) ice break-up potential

This is done as a part of emergency management and information is provided to the conservation authority and municipalities to help them better prepare for flood risk. The MPMP indicators as described earlier, focus on the functional aspect and are mostly cost based or percentage based which only gives incremental information about the chosen parameters. In many cases, the current indicators do not represent the intended improvement. For example, the operating cost and total costs do not indicate how many houses have been saved from flooding, how many potential floodings are avoided, or how much loss and damage have been avoided. The municipalities can report their performance based on indicators for many years without considering if the processes they continue, to achieve the target, is optimal and efficient. Therefore a “process based” approach is necessary when uncertainties are inevitable, particularly for example climate change which is considered a “moving target”.

2.6.Multi Criteria Assessment in sustainability and Infrastructure field

Sustainability Assessment is certainly amenable to multi criteria assessment (MCA), which is useful when a single-criteria approach is not feasible, and especially when qualitative and quantitative criteria both are important. Various methods such as Weighted Sum Model (WSM), Weighted Product Model (WPM), Analytical Hierarchy Process (AHP), PROMETHEE, ELECTRE, TOPSIS, CP and MAUT, and multiobjective optimization are commonly used. A well-documented synopsis of these methods is given by Pohekar and Ramachandran (2004). Some other methods are: Entropy Method (EM), CRITIC Method (CM) and Simple Additive Weightings (SAW) (Yilmaz and Harmancioglu 2010). These methods are driven by sound mathematical processes; however, the decision maker’s choice may not solely be driven by objectivity, and subjectivity does play a role (Alvarez-Guerra et al. 2009). In this regard, simpler methods of assigning weight are popular and quite possibly more effective. Out of seventy papers reviewed by Poheker and Ramachandran (2004), the highest number of papers (22) used straightforward multiobjective methods, and WSM was the most commonly used method. A review of papers by Huang et al. (2011) suggests that the recommendations were similar even though different methods of MCA were implemented for same problem.

The main criticism in the application of multi criteria assessment in decision making is the assignment of weight and its influence on the final outcome of the assessment (Alvarez-Guerra et al. 2009, Steele et al. 2008). Generally water management decisions are characterized by multiple objectives and multiple stakeholders, and these objectives are difficult to trade off (Yilmaz and Harmancioglu 2010). Therefore when assigning

weights, a combination of two approaches is frequently suggested in the literature:
1) Assigning weights through expert opinion; and
2) Assigning weights through stakeholders input.
Both these approach utilize experience and understanding of the problems or issues that the system has to deal with. The stakeholders may not be experts on the matter, but their choice is based on the preference and value that they can derive from the system. The value of the outcome or service that the system can provide may vary temporally and spatially. The weighting that a decision maker provides on the individual indicator is crucial in sustainability assessment and it can be affected by temporal and spatial variation, and the stakeholder's vested interest, preference and belief. For example, a person interested in economics would weigh the economical attributes more than environmental and others. Conversely, providing equal weight for all the criteria indicates that the decision maker is neutral, and eliminates the bias from the assessment (Janssen et al. 2005), and changes in preference can be reflected by sensitivity analysis (Alvarez-Guerra et al. 2009). However, assigning equal weightings does not account for the system specific characteristics: ideally, weightings should reflect priorities in the assessment. In other words, equal weightings fail to underline any particular issues the system or the consumers are facing at that time. Ultimately, a decision system should include checks and balances to prevent such bias as much as possible.

Multi Criteria Assessment (MCA) has also been used as a tool in climate change policy decisions (Ebi and Burton 2008, Gough and Shackley 2006). Bruin et al. (2009) utilized MCA to assess best adaptation options in the Netherlands. MCA and cost benefit analysis was performed for qualitative and quantitative assessment respectively. Stakeholders input were also incorporated in selecting adaptation options. Criteria were fixed by expert judgment to evaluate those options, analyzing institutional complexities in implementing the options, and estimating cost and benefits of adaptation options. Weightings were provided by expert judgments in the Netherlands study. Lemmen et al. (2007) identified the limitations in decision-support tools for adaptation actions in Canada. The authors indicated the need for "…expert help and advice regarding the choice of adaptation options...". The report further points towards having a decision support tool to engage stakeholders in considering their adaptation options.

Involving stakeholders in decision making is considered an important element of sustainability. Even though there are some models to involve stakeholders in decision making in general, there are no tested model specifically for infrastructure. Usually the institution or the party responsible for the decision making provides information to the stakeholders, and stakeholders provide their feedback to the party based on their understanding and preference. While critical, this study is not focused on stakeholder involvement issues, and will be not examined further.

2.7.Definitions used in this research

2.7.1 Sustainability

Sustainability, although presented by World Commission on Environment and Development in the Brundtland report, *Our Common Future* (WECD 1987) as a simple concept about 25 years ago as "meeting the current need without compromising the ability of the future generation to meet their need", still lacks a universal definition. There is much uncertainty and disagreement about what constitutes sustainability and how best to attain it. The 1992 Rio Summit defined sustainability as an integration of environmental, social and economic well-being, often referred as triple bottom line (TBL). The sustainability concept then permeated the main stream thinking only after the Rio Summit when 178 countries endorsed the Agenda 21 which was basically a guideline for "what to do" for countries to achieve sustainability. To achieve triple bottom line sustainability, Millennium Development Goals (MDGs) were developed by the UN in 2000 in eight sectors: poverty eradication, primary education, gender equality, child mortality, maternal health, combating diseases, ensuring environmental sustainability, and global partnership for development (UN 2009). The MDG are generally focused on achieving national and international development goals. The recent Rio + 20 summit 2012 focussed on city sustainability.

In general, sustainability is based on environmental, economic and social aspects, not necessarily integrating them. It is often assumed that environment, economy and society are the three “pillars” of sustainability. This concept led to reductionist approach of looking at environmental, economic and social aspects as distinct components of sustainability. The interrelationship and the complex pathways in which various aspects interact were often not addressed.

Current sustainability approaches and definitions are targeted mostly towards minimizing resource consumption. For example, some defined sustainability based on how much land area is used to provide a product or a service to the society (footprint), some defined as how much emission in terms of water, land and air, and energy is consumed in the entire life cycle of a product or service (LCA). The essence of sustainability is meeting human need now while having the ability to fulfill future need. Human fulfills their need by exploiting resources, by implementing economic and technological instruments. The ability of the human beings to function, survive and sustain in long term is the key to sustainability. Sustainability goals are fundamentally targeted towards reducing resource consumption, improving people's health and well-being, and to be able to deal with changing environment. Therefore, it is important to view sustainability beyond the triple bottom line and focus also on other aspects of sustainability such as ability of the system to deal with changing conditions, and public health. Sustainability in this study is defined in a different way, where probably for the first time uncertainties with respect to time and other factors are considered, hence a *process based* approach is argued for, and focus is *on resource, people and change – management*.

2.7.2 Sustainable Infrastructure

Sustainable infrastructure is defined in many ways. Sustainable infrastructure refers to the “designing, building, and operating of *structural elements* of a system in such a way that do not diminish the social, economic and ecological processes required to maintain human equity, diversity and the functionality of natural systems (CRC Research, 2011)”. The design of new or optimization of existing infrastructure should be consistent with the principles of urban sustainability (UofT 2001). The principle of urban sustainability focuses on long term functioning of an urban area based on a sustainable “flow” of required resources (food, water, services etc.), where people can enjoy a good quality of life without stressing the environment. Therefore a sustainable infrastructure contributes to a sustainable society ensuring that the environment and resources are not stressed (NUNU 2011).

Sustainability of infrastructure is about ability of the infrastructure to function in a way that will not compromise the ability of the system to function in future. Given the emerging stressors that a system has to go through, it is crucial for the infrastructure not only to function but be able to survive and be resilient so that it can adjust to the need of the time and be able to serve for a long time. Sustainable infrastructure must embrace the current and future challenges and demands of an evolving society and its needs, both in times of conventional use and extreme conditions. The sustainability of infrastructure depends on variation in the objectives of the system, physical and climatic variations, and factors that are unforeseen and uncertain now but may emerge in future. For an infrastructure system, sustainability can be defined as the ability of the system to maintain its functionality and survivability without increasing resource consumption, impacting people's health and well-being, and be able to manage for changing circumstances. In other words, sustainability of an infrastructure can be measured with respect to *resource usage reduction*, *people's health and well-being*, and effectiveness of the *change management* (RPC).

Sustainability for stormwater infrastructure is therefore defined as the *ability of the system to safely manage stormwater without compromising the ability of the system to do so now and in future without stressing resources and environment, ensuring public health, and being able to adapt to the changing situations as it arise.* Unless a system is functioning well, it is unlikely that it can survive and be resilient, and be sustainable in the long term.

2.8 Stormwater Interactions and System Boundary

A comprehensive urban water system has three components: 1) water supply system; 2) wastewater system; and 3) stormwater system. The stormwater interacts with the other two components as shown in Figure 2-2, and the area indicated in the grey color represents the system boundary for this research.

The stormwater generated from precipitation goes through the collection system either through innovative stormwater management (ISM) structures such as vegetated swales, bio-retention basins, or conventional stormwater collection system which has a series of inlet structure, inline storage and outlet structures. The stormwater may be held in the detention pond or retention basin until required, and then released to the receiving water body, which can be a surface water source for drinking or any other beneficial use for the downstream user. Stormwater can even be collected and used at source for various beneficial purposes such as gardening, car washing etc. which allows to replace the demand for drinking water. The stormwater can also infiltrate into the groundwater at source, or can be collected and purposely used to recharge the groundwater. In some cases, the stormwater is conveyed through a combined sewer system where both stormwater and wastewater are carried together to the wastewater treatment plant.

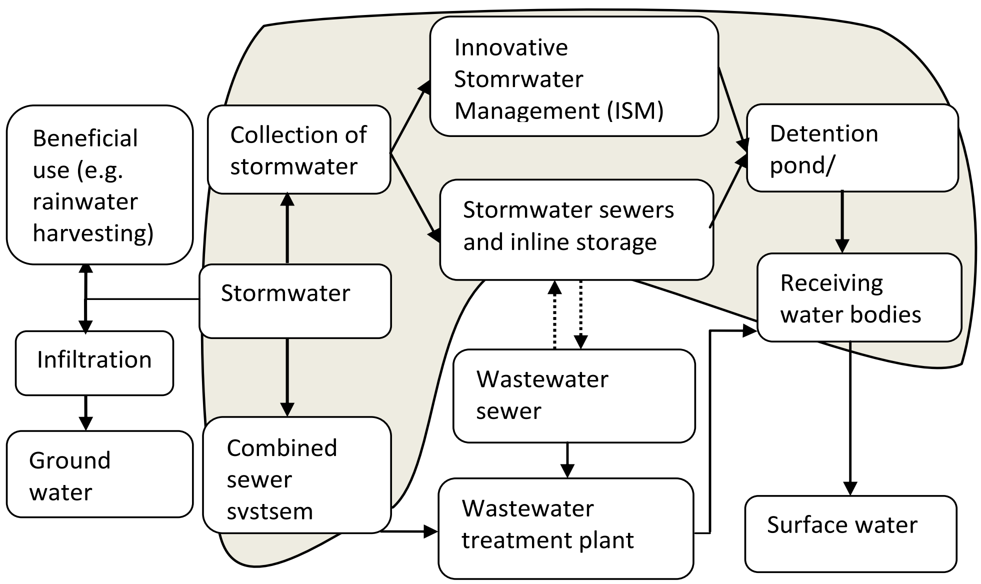


Figure 2-2: Stormwater System Interaction and System Boundary

The flow during dry weather, which only has wastewater, is handled by the wastewater treatment plant while the wet weather flow, which also includes the stormwater, is usually higher in volume. If it exceeds the WWTP capacity, excess volume is discharged directly to the receiving water body. In many cases, inline inflow of stormwater, combined with the infiltration of groundwater (often referred as I&I) into the wastewater sewer is a common conveyance problem of a separate system in which stormwater is conveyed separately from the wastewater. The dotted arrows in the diagram indicate this interface. Because of these complex interactions, understanding the total water system is essential even though the research only focuses on stormwater system as indicated in the grey portion in the diagram. In older cities, combined sewer system still exists. Because of this, certain aspects of the combined system are also covered in this research; for example, the functional aspects such as wet weather and dry weather flow, population, etc. were considered while developing the framework. Basement flooding, an oft-cited concern in municipalities due to an overwhelmed sewer system, is also part of this research. Managing stormwater generated at the lot level depends on awareness and willingness of the consumers to implement sustainable solutions, which they may not unless such measures are mandatory. Therefore only some aspects of residents' participation in source control measures were covered.

2.9 Summary

Various approaches to sustainability assessment, performance assessment practices in Canada, and criteria and indicators pertaining to stormwater systems, and application of mult-criteria assessment were reviewed. Gaps in the current understanding and knowledge about sustainability applied to infrastructure were identified and new definition for infrastructure sustainability was proposed.

Sustainability assessment and evaluation are as important as having a sustainability plan and a "to do" list. Sustainability is dynamic, and as physical, climatic and other circumstances change, so does the sustainability. Therefore, the sustainability of the system should be continuously evaluated. The Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol allows the user to recognize the nature and severity of risks of climate change, but does not necessarily assess the sustainability performance of the system. Existing assessment tools focus mainly on the functional aspects of environmental, social and economic performance separately, and do not capture the overall issues or changing demand. It is necessary to determine whether the stormwater infrastructure is fulfilling its intended purpose, is resilient, and is sustainable in the long term. The current approach to sustainability primarily focuses on minimizing the use of resource but does not necessarily consider public health issues and an effective change management strategy. Another important, missing aspect is that no matter which method of sustainability assessment is chosen, unless there is enough data and information about a system, the assessment may not be complete: the system can be unsustainable but never identified as such. Therefore, it is important to both emphasize the need for data, as well as ways of handling the lack of data.

Chapter 3 summarises the literature review pertaining to issues and management of stormwater systems.

3. ISSUES IN MANAGEMENT OF STORMWATER SYSTEM

This chapter includes the review of literature in following areas: 1) overview of stormwater management methods; 2) current and perceived issues related to stormwater infrastructures; and 3) efforts to address these issues. Issues in terms of climate change impacts on public health and possible interaction with stormwater system are also included, and a general relationship between climate change and sustainability is examined.

3.1 Stormwater Management: Overview

Originally, open channels were used to transport runoff to the nearby water body as quickly as possible to prevent flooding. As the knowledge of pipes and plumbing increased and awareness about the odours and hazards of polluted open channels, combined sewers were designed. Many older cities still have combined sewers in place. As the understanding about water quality problems of receiving water bodies and increased load on wastewater treatment plant was realized, separate stormwater sewers were built (Andoh, et al. 2005).

In Canada, stormwater management is characterized in three phases (Watt et al. 2003):

3.1.1 The Storm Sewer Era (1880-1970)

A network of sewer transported stormwater to the nearest water body. The stormwater drainage network composed of storm drainpipes, curb inlets, manholes, minor channels, roadside ditches and culverts. The design of the sewer was based on the design rainfall for a return period of 2 to 10 years. The peak flow was calculated for duration equal to the time of concentration. The main focus was to size the pipe so that the design peak flow can be conveyed without creating any flooding. However, as urban areas grew significantly, the costs of large collector sewers and erosion control measures increased.

3.1.2 The Stormwater Management Era (1970-1990)

Two additional means of conveyance: a) the stormwater ponds within or at the downstream end of the storm sewer network; and b) provision of the major system to convey flows which exceed the capacity of the minor system (pipes and ponds). For each of the minor and major systems the return periods were typically 2- 10 years, and 100 years respectively. In addition, a restriction that the post- development flow should not exceed the pre-development flow under design storm condition was implemented. Pipes and ponds were sized to convey and store these flows. Local and downstream flooding was minimized, the cost of sewers in many cases was reduced, and waterfront property around the stormwater ponds added economic value. However, long-term costs, including those for pond maintenance and erosion control downstream of the ponds, remained.

3.1.3 The Urban Stormwater Best Management Practices Era (1990 onwards)

As the concern over the residual and water quality problems associated with stormwater management grew, the era of urban stormwater best management practices evolved out of previous efforts. Canadian cities, such as Edmonton, Winnipeg, Hamilton, Toronto, Ottawa, Montréal, and the Greater Vancouver Regional District adopted this approach. In this period the quality as well as quantity aspect of stormwater was recognized. In response a wide range of urban stormwater BMPs such as extended detention ponds, infiltration basins and trenches, porous pavement, sand filters, water quality inlets and use of vegetated swales prevailed. The added benefit of these BMPs is in the form of reduced erosion, and improved water quality, however maintenance cost is increased. Recently risk of stormwater management ponds is an issue for both public health and safety.

Unlike the traditional stormwater management approach, the BMPs adopted since 1990s are innovative ways to manage stormwater. The Innovative Stormwater Management (ISM) often termed as *Low Impact Development, Sustainable Urban Drainage System and Water Sensitive Urban Design*, generally starts by managing the rainwater at household level and progressing to the neighbourhood level and then the watershed level (Marsalek 2009). Taking a multi-barrier approach to stormwater management is important. At property level, the goal for ISM is to minimize the surface runoff. At neighbourhood level, the primary focus is on managing the street and parking lot runoffs in terms of quality as well as quantity. The watershed level stormwater management is more comprehensive and takes into account the water balance of the entire watershed. Some of the ISM approaches for the property, neighbourhood and watershed scale are summarised in Table 3-1.

Table 3-3-1: Innovative Stormwater Management Approaches (Marsalek 2009)

Traditional Approach	Innovative Approach
ISM at property scale	
Roof Runoff directly conveyed to storm sewers	Install green roofs that detain rainfall, allow some evapotranspiration, and reduce and delay storm runoff
Collect roof rainwater and discharge it into Storm sewers	Connect roof water downspouts to a rain barrel or a storage tank and use the water for indoor or outdoor uses
Pave driveways and walkways	Minimize impervious surfaces, use pervious pavements, and infiltrate runoff in swales
Strip top soil, allow soil compaction during house construction and rollout thin turf layer after construction	Prevent soil compaction, or restore sol porosity after construction, and specify atlest 30 cm of topsoil before planting lawn
Use piped drinking water for watering lawns and gardens	Use collected roof water to water lawns and gardens or develop xeriscapes
Remove larg trees because of risk of house damage during storms	Plant and maintain trees property for stormwater generation reduction and carbon credit
ISM at neighbourhood scale	
Pave all roads and sidewalks and direct runoff into storm sewers using a curb and gutter system	Minimize the width of roads, remove all curbs and gutters, and direct runoff into roadside infiltration swales, use previous pavement (as much as possible)
Build a network of storm sewers and direct stormwater	Build stormwater detention ponds and wetlands for large storms to detain runoff and reduce pollutant and

runoff into local streams	sediment loads that enter streams
Build parking lots that are impervious and direct the runoff into storm sewers	Build parking lots with pervious pavement materials or direct runoff away from storm sewers into detention systems, swales and constructed wetlands
Allow contaminants to accumulate on street surface and be washed off by runoff into stormwater conveyance systems	Apply source control by minimizing the use of polluting chemicals, an practicing street sweeping, contaminant retention, and rehabilitation of contaminated areas
ISM at watershed scale	
Stormwater is conveyed through pipes, passes through riparian buffer zones, and is released into local streams	Create wide riparian buffer zones and create constructed wetlands within these zones to store excess stormwater, retain sediments and pollutants, and filter the water. Minimize or eliminate all stormwater outfalls discharging directly into streams
Channelizing urban streams and rivers to increase flow capacity, minimize bank erosion and speedup drainage	Maintain natural river channels to allow lateral flow and storage of stormwater within the riparian zone
Floodplain is designated and flood management (protective) structures are built	Designate areas within the floodplain and the riparian buffer zone to serve for temporal storage of stormwater during flood events
All stormwater systems are connected and their outlets become point source of pollution discharged into local streams	Avoid cumulative effects that increase flow and pollution loads by directing all stormwater drainage to pass through infiltration an detention systems

The ISM is considered effective in reducing the risk of flooding due to climate change effects (Marsalek 2009). However, the implementation is challenging because: 1) the ISM features cannot be built in older cities and already developed areas; and 2) the permeability of soil under intense and frequent rainfall event is poorly understood (Howe et al. 2005). Increased rainfall intensity may reduce infiltration capacity of the bed surface in the ISM structures like swales and may cause stagnant water. While implemented and maintained properly, the ISMs are effective measures for urban flooding: understanding the performance of such ISMs under higher temperatures and rainfall is required.

The conventional stormwater infrastructure was not designed for a higher return period therefore is unable to handle the intense precipitation event. To overcome this situation, designing the sewer network for a higher return period value is recommended (Watt et al. 2003). In order to do this, agencies are considering revising the Intensity - Duration – Frequency curve (IDF) on which designs are generally based on. This solution can only be applied to new areas or areas where the existing sewer system has to be replaced. For existing systems which are within design life and capacity, ensuring that it is functioning at its fullest without putting extra strain on resource and environment is important.

The traditional stormwater infrastructure already has problems such as aging infrastructure, funding issues, cross contamination and so forth, but neither are the newer ISMs free of problems. In recent years, *major system* and *minor system* approaches convey the stormwater. Major system utilizes the overland flow, and road and other open surface to pass the excessive flow that the minor system - the network of pipes - is not capable of handling. This is considered a "last resort" in the management of flooding, and again is only possible to implement in new developments.

3.2 Issues in Stormwater Infrastructure

Two groups of issues are identified: 1) issues derived from social, economic, institutional, technical and related factors; and 2) issues derived from climatic variations.

3.2.1 Issues Derived from Physical Factors

There are six important issues identified regarding stormwater infrastructure and the management of urban flooding:

Economic: The economic impacts from flooding in the form of stormwater management fees on a community and on the institution which manages the water is probably the most direct. Municipalities are forced to maintain and restore infrastructure with a shortage of funding, and expensive but necessary adaptation measures will further put pressure on municipalities. The infrastructure sector is experiencing a funding deficit (AMO 2010) of $60 billion needed over 10 years in Ontario. This deficit in investment requires an estimated $1200/ household/year, to make up that gap. Water, wastewater and stormwater infrastructure will require about $400/household/year to fulfill the investment deficit. The municipal property tax would not sufficiently meet these requirements: additional federal and provincial funds would be needed. Similar scenarios exist in other provinces in Canada. The socioeconomic damage and related cost can be high, and strategies which can reduce the risks of flooding while ensuring minimum economic impact should be adapted (Mailhot and Duchesne, 2010). For example some of the impacts of the July 14-15, 2004 Peterborough flooding were (Ontario center for Climate Impacts and Adaptation Resources 2010, OWWA 2010):

1) The Sewage Treatment Plant recorded a peak flow of 7 million gallons on July 15, 5 times more than its capacity.
2) Approximately 12,500 metric tonnes garbage were placed in the landfill from July 16th to the 27^{th}, about 5 times more than usual.
3) More than six years after the flood in 2010, the true ultimate cost to the City taxpayers is still unknown: estimates range from $50 million to $300 million or even higher.
4) Insurance companies estimate figures as high as $200 million for homeowners only (not infrastructure costs).

Similarly, in 2002 flooding in Stratford, almost $1.3 million in emergency compensation was provided to affected residents immediately after the flood, and a mediated settlement of a lawsuit cost the city about $7.7 million to compensate more than 800 home-owners (City of Stratford 2010).

The economic burden also increases in the form of subsidies or relief funds after a flooding. As a policy measure, many local or maybe provincial governments provide incentives for residents to adopt innovative measures. For example, the City of Toronto used to provide downspout disconnect services at a subsidised rate to the residents. Generally economic risk is spread to the community in form of insurance, for example, fire, theft or motor vehicle insurance. In the UK, although the risk of climate change is spread to communities, most of the insurance companies do not incentivise the retrofits and improvements that homeowners implement to reduce the risk of flooding in their house through reduced premiums (Greater London Authority 2010). Most of the insurance companies do not provide replacement of fittings and fixtures for more flood resilient designs (Greater London Authority 2010) hence even though the insurance arrangement is in place; it fails to improve the resilience of the property at risk from flooding. The price of insurance can encourage people to adapt; therefore, the insurance market could be an effective tool to manage potential risks from climate change. Government policy will be important to enable a flexible market that can help establish a proper pricing mechanism so that behavioural change can happen (Government of Australia 2010). In Norway dual insurance arrangement: private and governmental exists (Næss et al. 2005). Fire and natural hazard insurance is compulsory for private properties and objects. Fire hazard is covered by private insurance agency whereas the flood damages for privately owned objects not covered by fire insurance (such as roads, bridges, and agricultural lands) are covered by the Norwegian National Fund for Natural Damage Assistance.

In Canada homeowners can be covered for sewer overflow but cannot be insured for inland flooding (Sandink et al. 2010). The discussion paper by Sandink et al. (2010) describes issues and actions needed to make flooding insurable in Canada. The discussion paper recommends having a risk based premiums and deductibles to encourage homeowners to reduce the flooding vulnerability by taking adaptation measures for their building and properties. It could be challenging to establish that the cause of the flooding was due to climate change. Other forms of urban flooding - water entering into basement due to overwhelmed drainage system, infiltration from ground, and sump pump overflow - are also not considered.

Although the incentive from government is discouraged in many cases (Sandink et al 2010), incentives from government should be complementary to the insurance premiums. This is especially relevant during large disastrous flooding situation when the damage is high and cost of such damage should be shared by all stakeholders. In such cases, insurance premiums should be lowered to appreciate such retrofitting and avoid double payment for the risks. Therefore a balanced approach to spread the risk over community and government as well as funding provision is necessary.

Health and Safety: Identifying and managing health and safety are key considerations in a flooding event. Generally when flooding occurs in buildings, it can damage personal belongings that could be valuable to the residents on emotional level, and it may not be possible to economically value those assets. Another important factor is the psychological stress on residents as well as on institutions involved in flood management (Næss et al. 2005), as well as illnesses that may arise. Flood water or sewer back-ups can carry contaminated water into basements and can cause waterborne diseases, including diarrhea illnesses. Corrosive cleaning agents and irritants found in leftover sludge from a flooded basement can be a hazard for clean up personnel. Electrical accidents may occur because of water damage and infiltration to electrical systems (City of Toronto 2010). Many innovative stormwater management (ISM) features such as detention pond, swales and so on could be a source of vector borne illnesses in flooding scenarios.

The public health impacts of inadequately managed stormwater system were evident in the form of water borne illness in the US (Gaffield et al. 2003). The health implications are not fully understood yet but studies are being done to assess the health risks due to failure of stormwater features in Canada (TRCA 2011). The combination of higher temperature and impounded water could create suitable habitat for vectors such as mosquito breeding, giving rise to vector borne illnesses (PHO 2008). Cases of West Nile virus (WNV) are already reported (City of Toronto 2008) in Canada, and the main route of human infection is mosquito. There is no specific cause of rise in cases of WNV in Canada, but an indirect relationship with change in rainfall pattern has been reported (TRCA 2011).

Water pollution is also a major concern. Stormwater carries land surface pollution which ends up in receiving water bodies. Higher pollution level can increase algal and bacteriological bloom in the lakes and streams. This pollution can travel a long distance and remain in the environment for a longer period. More energy is required to prevent and control pollution from the water stream releasing more greenhouse gas. Therefore stormwater infrastructure plays a critical role in overall *Total Water Management* (TWM). The percentage of pollution resulting in swimming beach advisory is higher from storm sewer runoff (21%) than CSO (1%), wastewater treatment plant (2%) and septic systems (4%) in the US (EPA 2004). The Great Lakes region generally has the most combined sewer systems in the US (EPA 2004) which can be related to the deteriorating water quality in the great lakes (IJC 2011). The consumers might be affected on health and economic level.

Population growth: Population growth will impact the development and land use pattern in a city. Growth and development require more buildings (commercial, residential or industrial) which in turn leads to more impervious area. Impervious surfaces will result in higher stormwater flow. The recent practise in many places is to accommodate ISM measures in new developments and try to retrofit the existing areas with such measures. How the ISM measure's performance can be optimized can be addressed at policy level. For example, a provision should be made to have every building equipped with ISMs e.g. city of Toronto. Another aspect of population growth is tied with urban form and water quality. Per capita pollutant loadings and runoff decreased markedly with population density for a given population (Jacob and Lopez 2009). On the other hand, densely populated areas may limit the infrastructure that can be retrofitted. The possible impact of urban form – whether densely populated with less area occupied or vice versa, in context of increasing population should not be overlooked.

Institutional: Even though appropriate measures are realized, institutional factors may limit the municipal capacity to carry out appropriate measures. Stormwater infrastructure face a number of challenges in terms of changing precipitation patterns, technology, and funding options. It is important that the organization, in most cases a municipality is well prepared for such changes. The ability (economically, politically and logistically) of a local community to reduce the risk of negative effects from future similar climate induced events may be closely related to the capacity and ability to prepare for climate change in future (Naess et al. 2005). Technical knowledge for adapting to new technology, maintenance and replacement of aging infrastructure with a reduced funding scenario and competing priorities are some of the institutional challenges. Since the system boundary is overlapping in water management - and multiple players are involved such as regional and local municipalities, utility companies, multiple departments within a municipality, as well as provincial and federal governments - obtaining, managing and sharing data and information for problem solving is also a major challenge. This may not be visible during the functional stage but if a system is stressed and needs major changes in terms of resiliency and long-term sustainability, then not having accurate and relevant data and information will impact the decision making significantly.

Ecological: Water quality and flow regime are affected by urbanization (Jacob and Lopez 2009). Impervious surfaces result in greater volume of runoff at a higher rate of flow which can cause channel modification and increased sediment loadings, impacting aquatic habitats. In addition the flowing water carries debris oil, grease, nutrients and CSOs which when discharged to the natural water body; these contaminants can further deteriorate the flora and fauna. Depending upon the time factor and concentration of the contamination, acute and chronic impacts can occur. Various ISM measures can prevent these pollutants from entering into streams but can result into a source of pollution themselves. For example increased phosphorous content in wetlands and ponds, higher sediment deposition can compromise the effectiveness and capacity of the ISM measures to control flood.

Consumer Behaviour: Reluctance to adapt and behavioural change on the consumers' part can occur because of the lack of simplified information of climate science and the severity of impact that can occur. Generally, people are more willing to adapt if there is a direct tangible impact on them. In many cases the impacts of not adapting and benefit of adapting may not be easy to quantify and effectively communicate to the consumers. For example, direct impact due to flooding can be easy to understand on household level where as its impact on infrastructure damage, but land use etc. may not be easy to visualize. Therefore extensive public education and awareness are essential.

3.2.2 Issues Derived from Climatic Variation

Uncertainties in climate projection and data: The rise in global temperature influences the hydrological cycle globally and affects rainfall patterns. For example, the temperature in southern Ontario is predicted to increase by 3 to 8 degree Celsius, and precipitation is estimated to rise up to 40% (Union of Concerned Scientists 2003). The change in temperature and precipitation pattern will affect frequency, magnitude, temporal and spatial availability of both surface and ground water, as well as on extreme events in future. (Cunderlink and Simonovic 2005, 2007; Jyrkama and Sykes 2007). The impact of climate change in terms of extreme weather events is already observed in the form of floods (IPCC 2007, Lemmen et al, 2007, Gleick 2009). The increase in intensity and frequency of extreme rainfall events consequently increase the intensity and frequency of flooding (Mailhot and Duchesne 2010) in many areas including the Great Lake regions (Environment Canada 2011, IJC 2011).

There are limitations in understanding the earth's climatic variations (CSIRO, 2009). The extent of impact of climate change is not fully understood yet and modelling the climate projections to a local level may have some uncertainty associated with it. On the other hand, the water is such a resource whose management significantly involves the user and it is difficult to model human behaviour (CSIRO 2009): it is challenging to precisely specify the adaptation requirement (Pearson and Burton 2009). These uncertainties require a process of continuously assessing the adapted measures, as well as assessing the physical facilities or infrastructures which are subject to adaptations.

Stormwater if not managed properly can result in urban flooding which can be detrimental to property, other infrastructure, and even could be fatal. The frequency, depth and duration of flooding may be impacted by a range of factors such as local back water influences, design standards used by property siting, such as the return period and freeboard above flood level (in the case of coastal areas), extent of flow blockage, prior warning of flood and potential flooding conditions (Howe et al. 2005). As expressed by the MOE (2011):

> Climate change science and modeling currently is not at a level of detail suitable for stormwater management where knowledge of the intensity, duration, frequency of storms and their locations and timing is required. However the economic, health and environmental risks dictate a need to be proactive in the management of stormwater.

Constraints and opportunities identified for water, infrastructure and health sector (IPCC 2007) are listed in Table 3-2.

Table 3-2: Constraints and Opportunities Presented by Climate Change

Sector	Constraint	Opportunity
Water	Financial, human resources, physical barrier	Integrated water resource management (IWRM), synergies with other sector
Infrastructure	Technological, space availability for relocation	Integrated policies and management, synergies for sustainable development
Health	Limit to human tolerance (vulnerable groups), knowledge limitations, financial capacity	Upgraded health service, improved quality of life

3.3 <u>Climate Change and Health: a Pressing Issue</u>

Health can be one of the important determinants of sustainability because the built environment and other elements of development are subsets of the environment, and negative impacts on the environment in turn can negatively impact public health directly or indirectly. Belgium’s Center for Research on the Epidemiology of Disasters (CRED) (2010) identifies the following health impact and health system impacts of stormwater flooding in Europe as listed in Table 3-3.

Table 3-3: Health Impacts of Flooding in Europe (CRED 2010)

Impact	Features
Mortality	Because of drowning, other causes inadequately studied and include heart attacks, hypothermia, trauma, and vehicle-related deaths. Mud and water rushing in also caused some deaths in camping sites.
Injuries	Mainly soft tissue injuries (contusions, lacerations, abrasions, cuts, bruises, sprains, strains, puncture wounds), minor in nature
Communicable diseases	No malaria or dengue, some arbo-virus disease, West Nile virus, leptospirosis. Oro-faecal infections include diarrhoeal diseases and gastroenteritis. General infections include ear, nose, and throat infections; conjunctivitis; skin irritations; skin rashes; and dermatitis. Respiratory symptoms reported include colds, coughs, flu, headaches, acute asthma, allergies to moulds, and pleurisy.
Chronic diseases	Asthma worsening, high blood pressure, cardiac arrest, heart attacks, kidney or other renal infections, joint stiffness, and erratic blood sugar levels
Mental health impacts	Anxiety, panic attacks, increased stress levels, mild/moderate/severe depression, irritability, nightmares, sleeplessness, PTSD, anger, tantrums, mood swings, increased tensions in relationships (e.g., arguing), difficulty in concentration, suicidal thoughts, alcohol dependence, and psychosomatic disorders. Aggression, bedwetting, depression, and PTSD in children ages 11–20 years
Miscellaneous	Carbon monoxide poisoning, toxic fungal spread, insect or animal bites, earache, lethargy, spontaneous abortions mainly due to mental and physical stress
Health systems impacts	Increased referrals more than double in flooded households for the year following the floods; system disruptions such as electricity, lack of standard operating procedures, lack of communication between relief and rescue workers and administrative authorities

Most of the studies in Europe did not consider flash flooding which can have severe impacts in the short term. The findings were based on retrospective studies: no quantitative data was available and trends could not be established.

In Canada, flood related health impacts, and impacts of climate change on health in general are not fully understood (Charron et al 2004). However, waterborne diseases are triggered during high precipitation events (Charron et al. 2004). Excess precipitation, flood, high temperature and drought condition can increase the risk of water borne illness. Cases of giardiasis and cryptosporidiosis are reported in Canada, but the proportion of cases that was waterborne is not known (Health Canada, 2008). Most of the cases involved surface-water sources and frequently occurred in the spring. Snowmelt and heavy spring rainfall may be significant factors. In Ontario, four outbreaks were linked to heavy snowfall, snowmelt, or heavy rainfall along with resulting turbidity (Charron et al. 2004). The International Joint Commission (IJC) 15th Biennial report on the Great Lakes Water Quality identifies the impacts of non-point source pollution on the beach water quality and recommends further research into the indicators of threats to human health (IJC 2011). Human cases of West Nile Virus (WNV), which is one of the main indicators of vector-borne disease in Ontario (PHO 2012), is attributed to warmer temperatures. The number of positive pools of mosquitoes carrying WNV is higher in areas with large number of stormwater catch basins (PHO 2012).

There is not enough scientific evidence to directly factor climate change related impact into health related decision making in Canada (Charron et al. 2004). The conventional approach to assess the health impact of many stressors is insufficient to identify complete array of health impacts due to climate change over a long period of time (Patz et al. 2008). Climate change therefore adds another aspect to un-sustainability, and this is the reason the WHO and many other concerned scientists are pressing to include public health as a key criteria for policy making and planning for climate change.

Since infrastructure systems form the “lifeline” of cities and are the “first line of defense” for public health, climate change and its impacts on public health should be addressed by including public health measures as criteria into infrastructure related decision-making. Public health should be the single most important criteria for social well-being. Governing and managing infrastructure system requires natural, financial, human and other resources. A balance between the natural aspect, social-economic well-being and infrastructural entity is essential, but will be challenging to achieve. Given the impacts of climate change on our infrastructure and on public health, a paradigm shift is required to address the sustainability. Authorities need to develop change management strategies for their infrastructure systems to minimize the risks and maximize the benefit of climate change.

3.4 Efforts to Address the Stormwater Infrastructure Issues

3.4.1 Efforts in Canada

A number of initiatives have been taken on the provincial and local levels in Canada. The Ontario government expert panel provided a range of recommendations for Ontario in the panel's report - ***Adapting to Climate Change in Ontario*** (2009). Recommendations 10 to 15 are directed towards infrastructure on a policy level. Some of the highlights of the recommendations relevant for stormwater infrastructure are:

1) Support the development of tools to help homeowners and professionals identify retrofit measures that will *increase the resilience* of existing buildings to climate change, especially extreme weather events.
2) Complete a comprehensive review of stormwater management throughout the province by the end of 2011 to ensure that provision has or is being made to *take climate change risks into account.*
3) Update the Stormwater Management Design Manual to encourage adoption of *innovative, multi-barrier stormwater management practices* by municipalities.

Ontario recently announced the Ontario Regional Adaptation Collaborative (Ontario RAC), a series of projects to help communities adapt to climate change (MOE, 2011). More information on current provincial level adaptation initiatives in Ontario is available on the MOE website.

On a local level, many municipalities such as Toronto, Edmonton, Peel Region and others are implementing various measures for stormwater management. All these municipalities have taken similar approach towards source control, conveyance control and end of pipe solution. The details of their efforts can be found on the respective websites. The efforts in Toronto and Edmonton are described here as examples:

> The City of Toronto implemented a Wet Weather Flow Master Plan in 2003, which was based on the hierarchical solution of source control, conveyance improvement and end of pipe solution. Recently, Toronto started a *Chronic Basement Flooding* program for which solutions are identified based on the 2003 Master plan. Downspout disconnection is taken as a source control measure; flow balancing, sewer separation, in-line and off-line storage, pipe upgrades for conveyance, and a tunnel for storm water trunk sewer are considered conveyance control measures. Combined Sewer Overflow (CSO) tanks and additional storage is considered as an end-of-pipe solution.
>
> The City of Edmonton has adopted a holistic "Flood Proofing Program" after the severe rainstorm of July 2004 which caused flooding on streets, roadways and in more than 4,000 homes throughout Edmonton (City of Edmonton 2011). The main goal of the program is to reduce the risk of the basement flooding due to sewer backup and to reduce the wet weather flows in the sanitary sewer system. To achieve these goals, the City of Edmonton established two separate complaint procedures for reporting the basement flooding related to the sanitary sewer backup within two weeks and after two weeks of the rainfall event. The city has taken four measures: downspout extension, outward grading of lots, flood – proofing devices such as sump pump and back water valve, and installation and regular monitoring of plumbing fixtures by qualified plumbers. To successfully implement these measures, the city has established three strategies to educate the public: flood prevention check-up program to identify and resolve drainage deficit, advertising and promotion campaign to increase awareness, and

neighbourhood education initiatives targeted to at-risk communities.

3.4.2 International Efforts

The following section examines some of the measures taken internationally.

King County, Washington approaches stormwater management in three ways through the: 1) built environment, 2) natural environment, and 3) human health, and adopted following measures to reduce the flooding impacts. They reduced current and projected flood risk by repairing levees and revetments, acquiring at-risk floodplain properties and improving flood warning and prediction capacity.

In New York City, following options are identified to reduce basement, street and sewer flooding (New York City, 2008) by:

Augmenting the collection system by increasing sewer cleaning, building high level storm sewers, implementing stormwater controls at the source, retaining stormwater using rooftop or off-line storage and reusing it for ecologically productive purposes, pumping stormwater, increasing wet weather capacity, and building larger sewers.

Revising drainage design criteria.

Enhancing natural landscape and drainage features for runoff control.

Managing flooding unconventionally (e.g., plan for controlled flooding in designated areas during storms).

In Chicago, Green Urban Design (GUD) is adopted for urban flooding which is composed of various ISM measures for source control such as green roofs and porous paving in alleys (City of Chicago 2008). These measures capture the rainfall at source to minimize the stormwater flow so that functionality of the existing stormwater infrastructure can be prolonged. The synergistic effect of these measures is realized in terms of reduced pumping cost and energy usage thus minimizing the resource usage and mitigating the GHG emissions. The interrelationship between the natural environment, built environment and people is identified in order to improve quality of life and health well-being to make Chicago more resilient city. Individuals, community based organizations and business are also engaged in the process.

In London, UK, Sustainable Urban Drainage Systems (SUDs) are considered for preventing flooding (Greater London Authority 2005) which includes rainwater harvesting, green roofs, water butts, filter strips and swales, infiltration device such as soakaways, stormwater tanks, permeable and porous pavements, basins, storms water ponds, and reed beds. The primary function of these structures is to properly convey stormwater without impacting the natural habitat. Prevention, preparation, response and recovery are identified as part of a comprehensive flood management strategy (Greater London Authority 2010), and the following recommendations were made as shown in Table 3-4.

Table 3-4: Greater London, UK Climate Change Adaptation Plan-Recommendations

Strategy	Action
Prevention	Spatial planning to avoid flooding, improving flood defence and drainage system by long term investment strategy in improving flood defence, reviewing the standard for flood protection, standardization of services provided by network
Preparation	Identifying important assets for flood risk and improving resilience, managing flood risk by coordination among local authorities and environmental agency to prepare emergency plan, and reporting to central government, preparing surface water management plan, and identifying critical infrastructures such as WTP and electric sub-stations and improving the resilience of such infrastructures. On a community level, taking insurance coverage for flooding, keeping the valuable possessions in a safe place, signing up to the Enviornmental Agency’s flood warning system, and having a flood plan and emergency kit in home
Response	Local and regional level coordination to response to an event, provision for escalating a local level response to a regional level response, mutual aid agreement for emergency, For residents, retrofitting their homes with flood resilient or resistant measures. Setting up grant for covering up the cost of retrofits

Recovery	Provision of humanitarian assistance, housing for displaced residents, facilitate the insurance claim process, helping business after damage, after event waste management, long term social impact management, and volunteer agency's support.

All the above efforts to curb flooding can be summarised in four major groups:

1) Allow the safe passage of runoff- by revising design criteria for stormwater infrastructure.
2) Control the runoff by adopting source control, reusing stormwater, and improving and changing the land use pattern.
3) Find ways to increase the resiliency of the infrastructure; for example by allowing the conveyance of runoff via major system (overland flow path) to flood a depressed area downstream and reduce the load on the minor system (sewer system).
4) Accept the flooding by encouraging the community to be "better equipped" for the consequences of overwhelmed stormwater system (flooding).

No single solution will likely be enough, and a mixed approach is essential to deal with the problems of stormwater infrastructure.

Various other measures are undertaken on institutional level and community level to address the stormwater management issues, which can be summarised into five broad categories:

1) *Upgrading the combined sewer infrastructure* in conventional ways such as larger pipe size, structures, pumps, etc. or replacing the combined sewer with separate sewers, and in case of separate sewers, flooding a local area used for recreational purpose such as a park (Ambjerg-Nielsen et al 2009).
2) *Decentralized design considerations* such as constructing a wetland in a lower area, pro-active retrofitting at the property level such as down spout disconnects (Zevenbergen et al 2008), reducing runoff by tapping water for urban use on household level or city level such as rain water harvesting, green roofs, water

reuse, increasing the pervious surface by planting trees and vegetative covers (Lwasa 2010).

3) *Dual adaptation*. The Stormwater Management and Road Tunnel (SMART) project is successfully operating in Kuala Lampur since 2007 (Royal Academy of Engineering 2011). The tunnel is designed to pass 1 in 100 years storm at the time of flooding whereas on occasions of extreme traffic congestion, it is used as a traffic tunnel.
4) *Preparing at the community level*. Being prepared for any flooding by building on higher plinth level, using appropriate building materials such as wooden floors, raising the height of the furniture, building temporary ramp to access the flooded floors, funding arrangement for cleanup, recovery and rebuilding, proper storage of belongings- specially food, and a support network of family friends and other stakeholders (Jabeen et al 2010) are some of the measures taken in Bangladesh.
5) *Engaging in proper land use and choosing appropriate building design* and materials are also emphasized in the climate change plan for King County, Washington which is considered as a national leader in reducing GHG emission and in planning to improve community resiliency (Saavedra and Budd 2008).

These various adaptation steps basically identify the risks, solutions to lower the risks, and issues behind implementing the solutions. The final decision on which solution to implement can come down to a cost-benefit trade-offs analysis. However, we need to assess whether the chosen solution is able to address the prior issues involved, maintain future adaptive capacity, and be sustainable in the long term.

3.5 Sustainability and Climate Change

Climate change and sustainability are interrelated (Munasinghe 2003, IPCC 2007). Climate change vulnerability, impacts and adaptation affect sustainability, and in turn, unconventional development paths influence emission levels that affect future climate change (Munasinghe 2003). Changes in emission levels would have important implications for mitigation strategies as well.

Adapting to climate change should not be done at the cost of other sustainability aspects.

This is especially true for water management because water management not only involves technical aspects but also has strong social aspects attached to it. Climate change also impacts public health directly or indirectly, and health is one of the most important reasons for climate change related studies (WHO 2000). The public health impact of climate change further diminishes the life supporting capacities and further deteriorates the environment. From social and economic aspects, a city's sustainability largely depends on the health and well-being of its citizens. Therefore, water related adaptation should bring about synergies between technical and social adaptations. Hence, solutions "destabilising the resilience or adaptability of ecosystems, social systems or individuals might bring about benefits in the short term but are likely to have long-term negative outcomes" (Parish 2007, Gagnon et al. 2008). On the other hand policies and plans may not be sustainable in the long term if climatic variability and its impact are not considered in development. Hence understanding the connection between climate change actions and sustainability goals will facilitate municipalities to prioritise the use of resources in a way to achieve more sustainable outcome in future (Richardson 2010): managing climate change and climate change adaptation must involve sustainability in cities (Government of Australia 2010). An integrated effort to reduce GHG emission, protecting against climate change, and creating more sustainable communities should be developed (City of Toronto 2008). In this regard then, mitigation and adaptation to climate change is considered a subset of sustainability as shown in Figure 3-1.

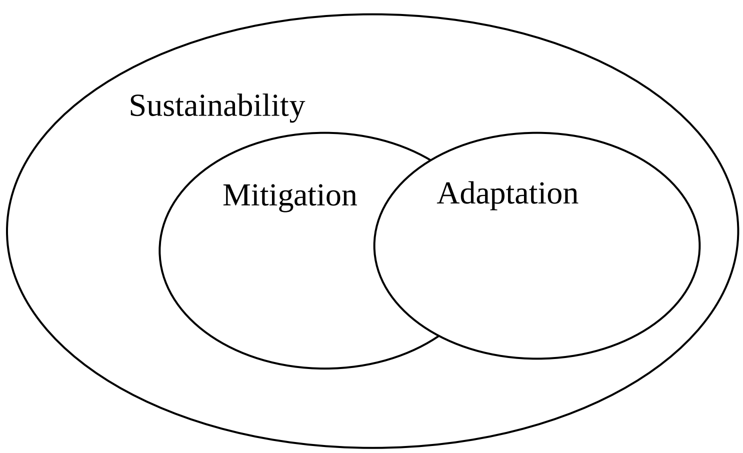


Figure 3-1: Relationship between mitigation, adaptation and sustainability (City of Toronto 2008)

In other words, sustainability and climate change are tied together because:
Sustainability and efforts to deal with climate change share common goals.
Climate change is an additional stressor to sustainability.
Adaptations to the impacts from climate change are based on sustainability criteria.

Since adaptation and mitigation should be consistent with the sustainability goals, the sustainability assessment of infrastructure is even more important than ever. There is a gap in existing knowledge pertaining to sustainability of stormwater system with respect to various stressors.

Considering all the challenges, it is important to ensure that the measures taken to improve the stormwater management reduce the impacts from climatic variations rather than multiplying the problem into the future. While economic benefits of adaptation are obvious at a community level and an institutional level (e.g., preventing flooding), some issues can hinder the effective implementation of selected measures, and their future adaptive capacity while maintaining the functionality, resiliency and sustainability of the related infrastructure in the long term. In this regard assessing the performance of the stormwater management measures and infrastructure is important. Assessing and analyzing the performance of infrastructure system is important decision making tool for management. Therefore a process-based, adaptive and long-term approach is necessary.

3.6 Summary

General stormwater management methods, current and perceived issues related to stormwater management infrastructures, efforts to address the issues, stressors such as climate change and interaction with sustainability was reviewed. The literature review was focused mainly on two aspects: issues related to stormwater system, and sustainability. Two groups of issues were identified: 1) issues derived from social, economic, institutional, technical and related factors; and 2) issues derived from climatic variations. The first group of issues - economic, population growth, health and safety, institutional, ecological and consumer’s behavior - are known and with some degree of certainty, while the second group of issues are uncertain, such as climatic variation related information and data, and other impacts of climate change which can directly or indirectly impact stormwater system. Urban flooding is an issue; and climate change is exacerbating the problem. Municipalities have developed solutions to deal with many issues, but assessing whether these solutions are sustainable or not - and whether a stormwater system as a whole is sustainable or not - has not attracted as much attention as it deserves. The current indicators or approach for assessing the conventional as well as the innovative stormwater management structures (ISMs) do not particularly address urban flooding and its management in context of climate change. Usually, the management of conventional stormwater infrastructure and the ISMs (commonly referred as BMPs) are viewed separately, and the existing performance measures (e.g., Infraguide, MPMP, etc.) do not include the ISM related indicators or evaluation of the infrastructure. However the BMPs constitute part of the overall urban stormwater management infrastructure system and it is important to consider these as an integrated system. The emerging public health issues and its implications in terms of stormwater system are currently not considered. The causal link between infrastructure and health is not clearly established but the issues are currently under study.

4. METHODOLOGY

The main goal of this research is to develop a comprehensive framework for sustainability assessment that can encompass broader, long-term, and changing issues, and stormwater infrastructure system is used as an example. The following objectives were identified to achieve that goal:

1) Identify and examine various issues in stormwater management, and efforts to address these issues.
2) Examine whether existing approaches to sustainability and performance assessment can be utilized in assessing the sustainability of infrastructures.
3) Develop a new framework that can encompass broader and long term issues in future as well as current issues.
4) Identify the criteria and indicators for stormwater infrastructure.
5) Apply Multi Criteria Assessment method to come up with a final sustainability level of the system.
6) Propose a method to interpret the findings of the assessment.
7) Apply the framework to a case study to demonstrate how the sustainability assessment can be carried out.

The methodology adopted for this study built on multiple levels: a sound and comprehensive literature review provided an understanding of the existing state of knowledge and gaps. The understanding of the stormwater system, and water system as a whole, was important to obtain because familiarity of the system is critical in sustainability assessment. Therefore, a comprehensive approach to develop the methodology has been taken.

4.1 Research Pathways

Figure 4-1 shows the methodology adopted for this study, and the following sections describes it in brief. The steps were not necessarily taken linearly, and simultaneous and overlapping steps for the research methodology were adopted. A unique approach was established which can encompass the resource, people's health and change management (RPC) as a foundation for sustainability and, later formed the criteria for sustainability assessment. A framework was developed for example stormwater system with the functionality, survivability and sustainability (FSS) as its main components.

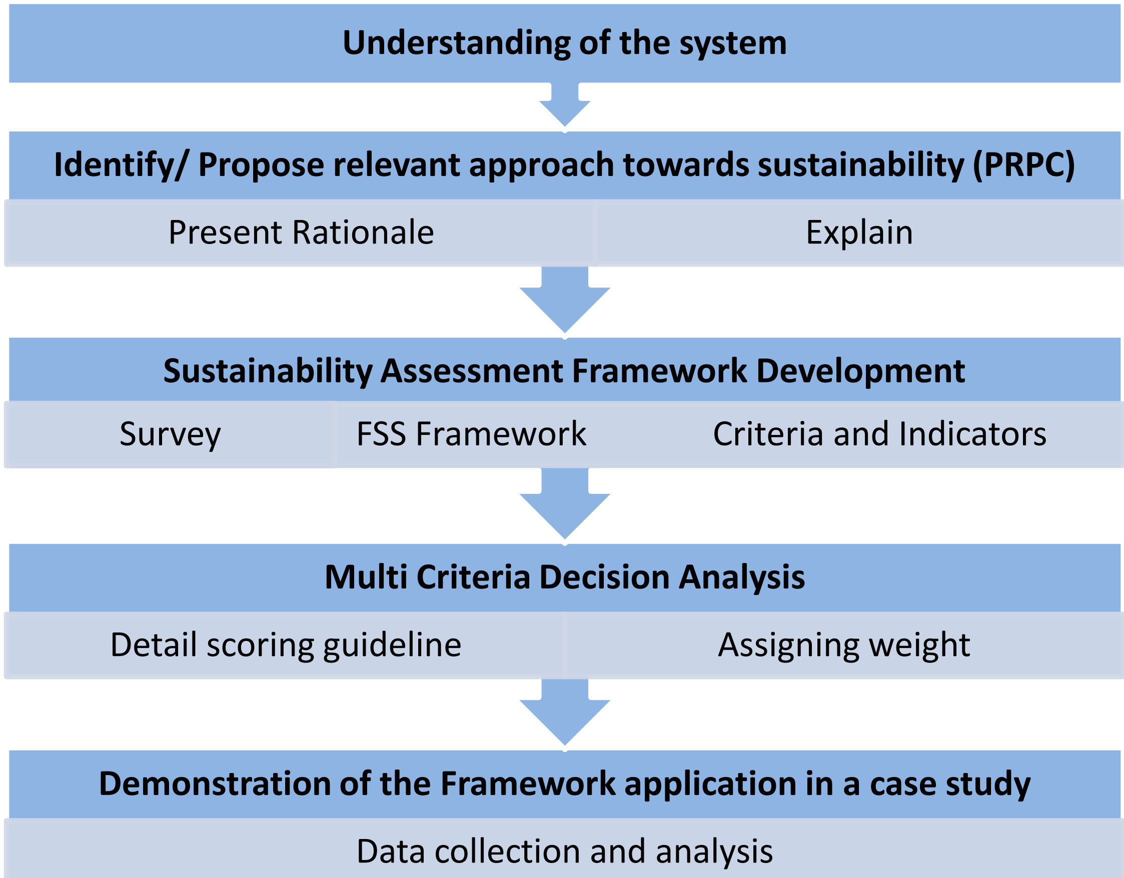


Figure 4-1: Research Pathway

4.2 Understanding of the System

Understanding the stormwater system and its interaction with other components of water systems are important for sustainability. Personal communications were established with experts in the field (Wastewater - Manjon 2010 - 2011; Infrastructure operations - Hicks 2010 - 2011; Water supply - Rossi 2010 - 2011; Stormwater infrastructure - Kellershohn 2011). Meetings with the experts and their teams were conducted, site visits were done, and past personal experiences were also collected and assessed to build a comprehensive idea about the system. The input from the experts also informed the questionnaire development which is described later. The infrastructure decision-making survey also helped understand the issues related to the water systems.

4.3 The PRPC Approach towards Sustainability

There are many sustainability approaches previously developed that can provide guidelines for planning, implementation and management of water infrastructure such as urban footprint, metabolism and extended metabolism, as summarized in Chapter 3. No single approach used so far to improve sustainability will be entirely adequate when new issues are emerging with varying degrees of uncertainty. The current methods are mostly focused on resource aspect and do not necessarily capture the complex implications and vulnerabilities. Current approaches to sustainability do not explicitly factor human health and the changing circumstances that influence system performance into the decision making. Moreover, all the approaches to date do not consider the importance of system dynamics of the system, and the fact that sustainability itself is also dynamic. This study proposes instead a *process based* approach to infrastructure sustainability from *resource, people, and change* perspective (PRPC) towards sustainability. Public health, resource minimization, and proactive management of perceived or unperceived vulnerabilities (termed as *change management*) are fundamental to the long-term sustainability of water related infrastructure. Although sustainability should be a guiding principle in managing infrastructure - particularly in the light of large scale issues such as climate change - it is difficult to incorporate into decision making. The PRPC approach is broken down into operational concepts. The PRPC approach emphasizes the process based approach as opposed to the individual outcome based approach. Details are given in Chapter 6.

4.4 Sustainability Assessment Framework Development

Two aspects have been considered while formulating the sustainability assessment framework:

1) The dynamicity of the sustainability itself and inclusion of resource, people, and change management aspect.
2) The balance between “present” and “future” by taking functionality, survivability and sustainability into account.

The framework is founded by amalgamating various approaches studied and discussed in literature review earlier. The framework development comprise of three main tasks: 1) developing the infrastructure decision making survey; 2) developing the functionality – survivability – sustainability (FSS) structure; and 3) developing indicators for assessment.

The *Infrastructure Decision Making Survey* was developed and applied as a tool to gain insight about decision processes in water related infrastructure. A characterization domain was established based on the issues related to functionality, survivability and long term sustainability of the stormwater infrastructure. The outcomes of the survey of water infrastructure professionals also guided the development of the FSS framework. The findings of the survey informed the indicator development for the stormwater system. Figure 4-2 represents the framework development process and a brief introduction of the survey and the FSS framework is given in next sections. Detailed descriptions are given in following chapters.

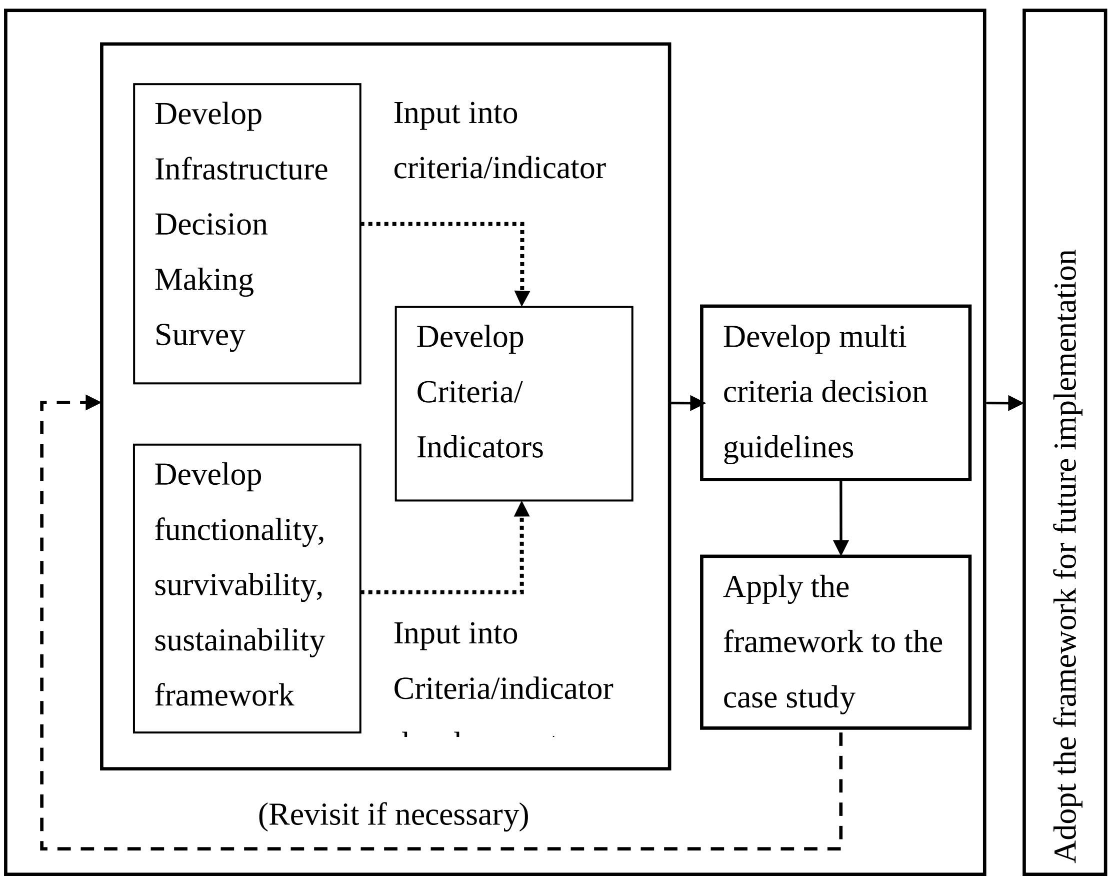


Figure 4-2: FSS Framework

The aim of this research was to develop an innovative framework based on the functionality – survivability – sustainability (FSS) concept for assessing the sustainability of stormwater infrastructure as an example, for other systems additional modifications would be required. Some of the indicators were identified as general indicators that can be applied to other systems with modifications. Details are described in section 6.4.5.

4.5 Infrastructure Decision Making Survey

The *Infrastructure Decision Making Survey* was developed to gain insight about the issues, challenges, decision-making process, data and information availability and management arrangement of water infrastructure in Canada. The survey was completed by professionals working in the water sector in general, and was not limited to only stormwater sector. Because all the water, wastewater and stormwater systems are interrelated, many times all three are handled collectively and can share common sustainability issues.

A significant portion of the survey questionnaire was dedicated to data availability or the lack of data availability and its impact on decisions related to the system, because not having information about a specific aspect or component of a system can detract significantly from achieving sustainability. The survey development and results are described in Chapter 5.

4.6 Functionality – Survivability – Sustainability Framework

Infrastructure cannot be sustainable unless they are functioning at its best, and can survive the impacts of various stressors both current and in the future. A characterization domain was established which provided the structure of the Sustainability Assessment Framework. The details are described in Chapter 6.

4.7 Indicator Development

This was done primarily through the study of existing indicators for stormwater management, infrastructure performance, and current effort and policy towards urban stormwater management. Issues associated with urban stormwater management were also considered while developing the criteria and indicators. The following general criteria were considered: 1) resource minimization (or optimization); 2) public health improvement; and 3) management of changing conditions. As much as possible, quantifiable, reliable and meaningful indicators were selected. New indicators were also proposed wherever necessary. It should be noted that the indicators vary depending upon temporal and spatial variability, therefore monitoring for some indicators is proposed to capture the dynamics of the system.

The indicators were then grouped in R, P and C, according to how closely the indicators fit for one of the RPC designations. Some of the indicators can fit into more than two categories, but were grouped based on whichever category they matched the most closely. The FSS framework and indicator development are discussed in Chapter 6.

4.8 Multi-Criteria Assessment

Sustainability assessment lends itself to a multi objective style approach for analysis and decision-making. The objective in this case was to evaluate the system performance based on indicators in functionality, survivability and sustainability category on the basis of resource (R), public health (P) and change management (C). The first step is then for decision makers to score the indicators. For quantitative indicators generally linear increments are considered. Qualitative indicators employed a scale of 0 to 5: "0" being not sustainable to "5" being the most sustainable. Many indicators require some degree of subjective analysis therefore a step-by-step procedure guided the decision process. The weight for the criteria was determined by two ways:
1) Asking a follow – up question to the invitees of the *Infrastructure Decision Making Survey* to assign weight (out of 100%) to the R, P and C criteria for stormwater infrastructure management; and 2) Based on weightings available in literature. The process is described in detail in Chapter 7.

4.9 Data Collection and Analysis

Sustainability assessment is a comprehensive process and collecting all the necessary information was a highly challenging task because of one or more of the following reasons:

1) Data were once recorded, but no longer available in records.
2) Data are not recorded because the need for doing so was not identified.
3) Inability to share data because of lack of man power; and
4) Unwillingness to share data.

After identifying these challenges, a significant portion of the survey was devoted to understand and unravel some of the issues surrounding data and information management. In decision making, emphasis is often given on those aspects for which data and information are available. By doing so, issues that lack data - even important ones, or those that are not obvious or understood yet - are already ignored. Hence, in this study not only did the analysis depend on both qualitative and quantitative data and information, but monitoring for emerging indicators are also proposed.

Multiple avenues were identified and followed to collect data, such as: retrieving direct data, already synthesized reports, personal communication, and site visits. Data were taken from authentic sources which rely on the standard methods of data collection; for example, water quality data. Because of the widely varying nature of the issues and therefore data involved in this research, it was challenging to collect all the data for indicators that were applicable to the system in the case study: estimates were made based on some assumptions. The assumptions are outlined in the case study description in Chapter 8.

4.10 Case Study

A case study is a widely used method in sustainability research. A case study approach is suitable because there is limited control over the system variables and multiple issues are at play, rendering a controlled study approach difficult. An example case study of "area X" in city "A" is presented, and to the greatest extent possible, the case study is based on realistic, actual circumstances. The purpose of the case study was to demonstrate how the framework can be implemented in real situation, not to actually assess the performance of the system.

Issues were reviewed and sustainability assessment based on the indicators under RPC category for the three characterization levels, functionality, survivability, and sustainability was done. The details are given in Chapter 8.

4.11 Evaluation

The system was analysed for each indicator and based on the decision guide for qualitative indicators, and in some cases for quantitative indicators, a score was assigned. Two sets of weighting were used: one assigned by the experts, and another derived from the literature. Weights were determined and normalized against the minimum value weight among the RPC, and this normalized weight was then proportioned among all indicators within a category. Each indicator was then evaluated by averaging the proportioned weight fraction times the indicator score, and then the average of all these gave a value for each of the category RPC. Therefore a category score was derived for R, P, and C. Then the category score was averaged to obtain the functionality score. This entire evaluation process was repeated for survivability and sustainability. The methodology for this research was built up on small but significant steps, and these were not always taken in a linear fashion. The details are given in Chapter 8.

4.12 Future Application of Framework

After developing multiple indicators under R, P and C for FSS, a number of common indicators that can be applied in other infrastructure were identified and presented in Chapter 6.

The next chapter describes the *Infrastructure Decision Making Survey* development and resulting analysis.

5. INFRASTRUCTURE DECISION MAKING SURVEY DEVELOPMENT AND FINDINGS

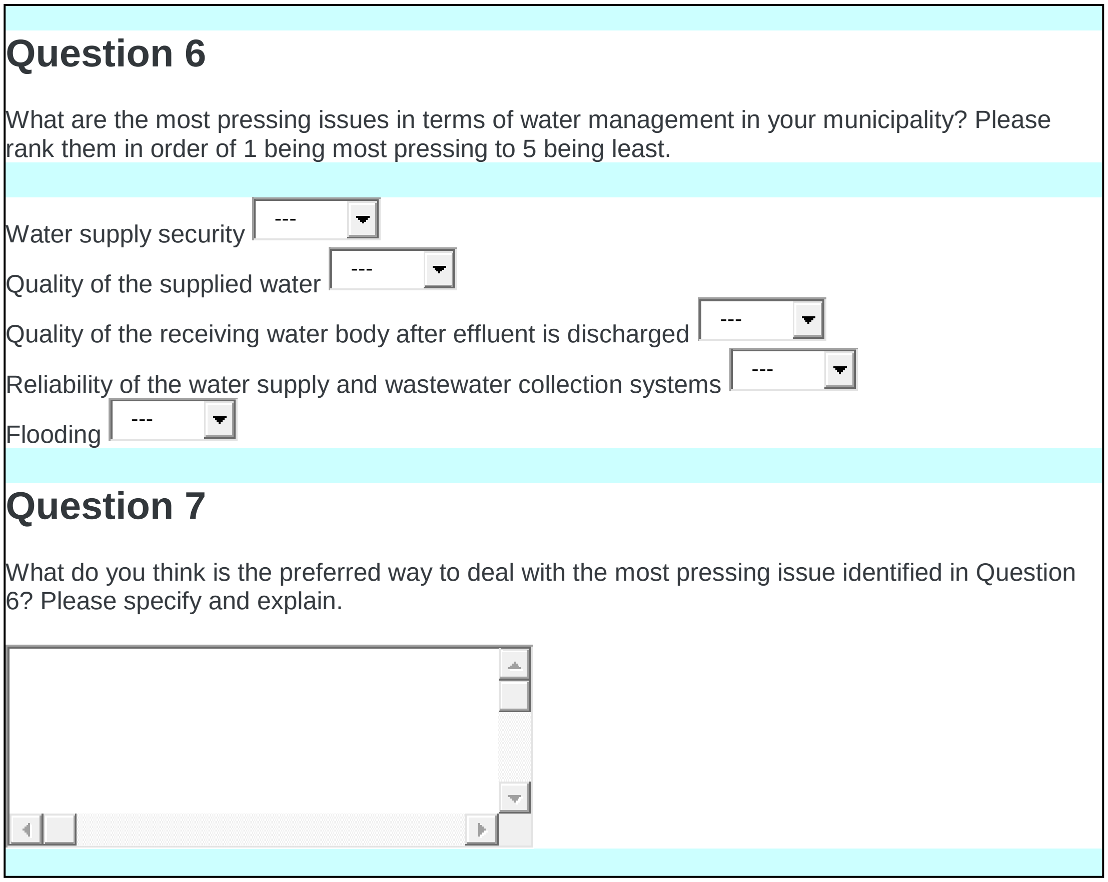
An online survey was developed and used as a first step to develop the sustainability assessment framework. The survey development process included using a design of survey instrument, obtaining research ethics approval, developing questionnaires, developing the online survey, identifying and recruiting survey participants, analyzing the survey, and interpreting the survey outcomes. The main goal of the survey was to gain insight about the overall water infrastructure issues and management practices. Sample size was not significant to conduct statistical hypothesis testing.

5.1 Design of Survey Instrument

The design of the survey instrument required knowledge of survey basics, ethics approval, maintaining confidentiality of the participants, and quality control for validity of the survey. The survey basics included how to prepare questionnaire, what should be the objectives of the questions, the appropriate phraseologies, and so forth. Several references and peer-reviewed journal papers that have many similarities with this survey were studied (Marlow et al. 2010, ECO Canada 2010, Franceschini et al. 2010, ULSF 2009, Rice et al. 2009, Brown and Farelli 2009, Marlow 2008, GEMI 2007, Robson 2002). One of the experts in survey methodology, Dr. Charlene Senn (2010), reviewed the questionnaire and her advice was incorporated.

Ethics clearance from the University of Windsor Ethics Committee was obtained. This survey did not involve any direct human subject, therefore the risk factor was low, and implied consent from the participant was sufficient.

A separate online survey was created which asked for the respondents' contact information so that a token of appreciation could be sent to them. The second survey was linked to the original survey such that upon completion and submission of the first survey, the respondents would automatically be redirected to the second survey. This was done to ensure that the contact information of the respondent was not tied back to the actual response, and anonymity of the participants was maintained. Personal information was not collected and only information related to their work experience was asked. All the participants were adults. The survey instrument is included in Appendix A, and an example question is given in Figure 5-1.



Question 6

What are the most pressing issues in terms of water management in your municipality? Please rank them in order of 1 being most pressing to 5 being least.

Water supply security ---

Quality of the supplied water ---

Quality of the receiving water body after effluent is discharged ---

Reliability of the water supply and wastewater collection systems ---

Flooding ---

Question 7

What do you think is the preferred way to deal with the most pressing issue identified in Question 6? Please specify and explain.

Figure 5-1: Sample Survey Question

5.2 Quality Control (QA/QC)

Like any other data collection method, special attention was paid to the QA/QC aspect for the survey, including:

1) How to prevent multiple responses by the same subject?
2) How to screen invalid responses, such as respondents not answering one-third or more questions, or choosing the 1st answer all the time?

A number of methods were investigated, and it was found that an online survey instrument is capable of addressing these QA/QC problems. The online survey instrument

Fluidesurvey was implemented, and the details about this online tool can be found on its website: www.fluidesurvey.ca.

Although statistically representative sample size was not collected for the survey, a significant effort was made to collect information from municipalities spanning all of Canada. Initially 47 municipalities across Canada representing a population range of less than 10,000 to more than 1 million from small, medium and large municipalities were selected . Municipalities were selected on a proportional basis from 10 provinces and 3 territories in Canada. Larger numbers of cities were contacted from the provinces having the larger number of municipalities. In an ideal case, the statistically significant sample size would have been calculated based on the statistical power of the survey. Time and resource limitation presented a constraint in this case. For future attempt to conduct similar survey, it is recommended to calculate the statistically significant sample size. Email or telephone contact was made in those municipalities to take the survey. Contacts in some provinces such as Prince Edward Island and Newfoundland and Labrador could not be made even after multiple attempts.

5.3 Questionnaire Development

The survey was divided into two groups of questions. Twenty five questions in Group A focused on who are involved in the decision making process, what is the management arrangement, what are the key factors to influence the decisions, how they visualize sustainability of infrastructure, how they address a pressing issue, how uncertainties and risks are factored, and how performance of the system is evaluated. Thirteen questions in Group B mainly focused on issues concerning data availability and information management for decision making, how data and information is utilized to make a decision, and how gaps in data and information management can influence some of the decisions. The lack of data, or even “good quality” data, can indicate a lack of sustainability given that there would be no information to carry out an assessment.

Questions were formulated so that participants could choose the answer from the given options, as well as write their own opinion on a matter. Please refer to the questionnaire in the Appendix A for details.

5.4 Recruitment

People working in the municipal water-wastewater sector - for example people involved in operation, maintenance, engineers, mid-level and senior managers, etc.- were invited to the survey. The participant's contact information was not publicly available in many cases. Therefore, a telephone call was made or email was sent out to the "contact us" address of the municipality's website. A brief description of the reason for the call was given to the call recipient, and then asked for related manager's email address/ phone number. Upon receiving the contact information of the related person, an email was sent out to the manager. In some cases, contact information of some professionals was already available, and a direct contact was established. The managers were invited to the survey, and asked to circulate the survey among their colleagues who work in stormwater, wastewater and water supply sector. They were briefed about the objective of the survey, estimated time to complete the survey, any risks involved, importance of their participation, and remuneration. Some of the invitees did not respond to the email, some provided another contact information and some agreed to take the survey. A reminder was sent out in couple of months to increase the participation rate.

5.5 Participation Rate

Twenty-one municipalities out of the 47 (44.6 %) that were initially contacted responded as either they were willing to participate or they provided another contact. Attempts to contact the other source were not successful. The 21 responses resulted in 42.6 % survey participation (9 responses). The survey completion rate was 77.77 % (7 out of 9). 54% of the respondents were managers and 46% were engineers.

Although the participation rate was small, the survey gave important indication about how water is managed, and what some of the challenges are for the system to be sustainable. In the literature related to water sector surveys, the participation rates were generally not very high either. However, although the number of participants is small, the information that was obtained by such a comprehensive survey from professionals in the field is what matters the most, because these responses do represent a water management scenario in the given city. Therefore, the importance of this survey should not be viewed for the understanding and insight that was gathered about the water management in Canada.

5.6 Limitation

The number of participants being less than 20 limits the statistical power of the survey hence this can be considered as a limitation. However, the information about stormwater system and water system in general obtained by this survey is important.

5.7 Outcome of the Survey

The outcome of the survey and its analysis are given for the group A and group B questions below. The question, and the response from the survey is given below the questions either in a tabular, box or text form, followed by a brief analysis as appropriate.

Question 1

Which municipality is served by the water infrastructure system of which you are an employee? Please specify.

The 9 responses to this question ranged in the following population bands as shown in Table 5-1.

Table 5-1: Population Range of Participant Municipalities.

# of Response	Population Range	Province
1	500, 000 - 1 million	Alberta
5 1	100, 000- 500, 000, < 10, 000	Ontario
2	10, 000- 100, 000	British Columbia, Northwest Territory

Out of nine responses, one was from British Columbia, one from Alberta, one from Northwest Territory and remaining from Ontario. There were no participation from Quebec, Manitoba, New Brunswick, Saskatchewan, Yukon and Nunavut. Language barriers might have played a role as the survey instrument was designed in English only. It was useful to know how issues and challenges of smaller municipalities vary from the larger ones.

Question 2

In which category would you identify yourself? You can select more than one category. The following responses were obtained as shown in Table5-2.

Table 5-2: Respondents Employment Level

Employment level	Percentage	Count
Senior management.	56%	5
Mid level management.	44%	4
Engineer.	44%	4
Technical and operational.	0%	0
Other, please specify.	0%	0

There was no response from the technical and operational people, possibly because the initial contacts were either made to one of the three above represented groups. The contacts made through the general contact information available on the municipal website were most likely be forwarded to the related section head or branch managers who in most cases are engineers or managers. From the table, 44% of the respondents were engineers and were involved in management.

Question 3

What is the average age of water related infrastructure such as pipe lines, pumps, treatment plants etc. in your municipality? You may provide a range, e.g. 20-40 years.

There were 9 responses to this question which indicated that the average age of water infrastructure is between 20 to 60 years old. One respondent could not specify the infrastructure age. This indicates that water infrastructure in Canada are aging and would require significant repair, maintenance and replacement. The aging infrastructure may compromise delivery of services, and result in significant leaks and losses leading to the wastage of water resources as well as energy. The aging infrastructure could also compromise the resiliency of the infrastructure.

Question 4

What is the management arrangement for water/wastewater/stormwater systems in your municipality? The responses are indicated in the Table 5-3.

Table 5-3: Management arrangement in water sector

Response	Percentage	Count
All the water, wastewater, stormwater systems are managed by general engineering/infrastructure division within the municipality.	11%	1
All the water, wastewater, stormwater systems are managed by general environmental division within the municipality.	0%	0
All the water, wastewater, stormwater systems including treatment and distribution are managed under one umbrella within the municipality.	44%	4
We have separate body responsible for water. Wastewater and stormwater are under one separate group within the municipality.	0%	0
Water system (conveyance, treatment and distribution) is privately operated while wastewater and stormwater are within municipality.	0%	0
More than one private party is involved in water, wastewater, and stormwater management.	0%	0
Any other arrangement, please specify.	44%	4

The responses specified as “others” are given below.

1. Regional municipality manages water, wastewater treatment. Municipality manages water distribution and WW collection
2. Regional municipality manages/operates water and wastewater treatment. Stormwater,water treatment for one system,wastewater collection and water distribution are operated by one division within the local municipality
3. Operation and maintenance of water, wastewater and storm water is under one division; capital programming for renewal and infrastructure planning for

	additional capacity is undertaken in a separate division
4.	Water and Wastewater are managed by specific dedicated groups. Stormwater is co-managed by two departments. Engineering (Planning, design and construction) and Operations (maintenance)

A significant (44%) proportion indicated that multiple players are involved in managing water, ranging from regional municipalities to various divisions within the municipality. This kind of arrangement may not operate on the basis of Total Water Managaement (TWM) philosophy and could fail to account for the urban catchment and its water balance which are crucial to the sustainability of water systems.

Question 5

In your opinion, which of the following groups has the most effect through their actions on decisions related to municipal infrastructure (e.g., planning, costs, implementation, maintenance, etc.)? Indicate up to the two most important groups. Table 5-4 lists the responses.

Table 5-4: Influential stakeholders in municipal infrastructure related decisions

Influencial Group	Percentage	Count
Senior management.	62%	5
Mid level management.	0%	0
Engineers.	50%	4
Technical and operational staff.	62%	5
Consumers (Residents) through their elected representatives.	12%	1
Other, please specify.	0%	0

The results emphasize the importance of involving various levels of staff into decision making, including technical and operational staff, engineers and managers. However, none of the survey respondents were from technical and operational staff group.

Question 6

What are the most pressing issues in terms of water management in your municipality? Please rank them in order of 1 being most pressing to 5 being least. Table 5-5 provides the responses.

Table 5-5: Ranking of the Water Management Issues

Issues ↓ / Ranks →	5	4	3	2	1
Water supply security	1 (12%)	3 (38%)	1 (12%)	2 (25%)	1 (12%)
Quality of the supplied water	2 (25%)	1 (12%)	2 (25%)	0 (0%)	3 (38%)
Issues related to aging infrastructure	0 (0%)	3 (38%)	1 (12%)	2 (25%)	2 (25%)
Funding deficit	0 (0%)	3 (38%)	1 (12%)	1 (12%)	3 (38%)
Hazard associated with natural incidents e.g. flooding	4 (50%)	1 (12%)	2 (25%)	0 (0%)	1 (12%)

50% of the respondents ranked flooding related hazards as 5, while funding deficit, aging infrastructure and water supply security was ranked 4 by 3% of respondents. The respondents have put highest priority on public health in terms of hazard associated with flooding, and water quality. Aging infrastructure and funding can be termed as a resource issue. The water supply security can be seen as an indicator of change management because it is associated with vulnerability of the system and service interruption. Hazards associated with natural incidents can be related to both public health and resource, and the impacts are only possible to adapt to, therefore it can be termed as a matter of change management.

Question 7

What do you think is the preferred way to deal with the most pressing issue identified in Question 6? Please specify and explain. Table 5-6 indicates the responses. The significant aspects are highlighted in bold.

Table 5-6: Ways of Dealing with Water Systems' Issues

	Response
1.	**Understanding the risks** and ensuring that they are dealt with as a normal part of asset management.
2.	Strong **communication** between region, municipality and provider of water.
3.	Ensuring **operators are well trained** and facilities are adequate to treat and supply water
4.	Asset management plans based on **accurate reliable data**, that rely on risk assessment to drive the **priority of undertaking renewal work**. **Funding** to implement the capital planning is also required.
5.	**Water quality** is the most important issue and is incorporated into the daily management of the system. The City I believe has a good handle on this aspect by meeting the various provincial requirements. The **Source Protection Plans** to be developed over the next couple of years will work to address the long term sustainability of the system. There are obviously costs to maintain this high level of service. **Renewal of infrastructure** will also have a big effect on this. We are in the process of developing a more complex method to address infrastructure renewal
6.	Developing an asset management plan which will allow the municipality to project the funding requirements needed to close the infrastructure gap and **establish borrowing and taxation policies to address the shortfall in funding**.
7.	**Strategic planning** and associated **education of the value and importance** of the critical infrastructure, to staff, council and tax payers.

Based on the above responses, understanding risk, having accurate and reliable data, ensuring sources of funding, provision for professional development of staff, providing education and awareness of consumers, and engaging in long term strategic planning are essential. Interestingly, the responses cover a wide range of possible actions that could be undertaken; at this point, it is difficult to ascertain if one is more critical than the others.

Question 8

What are some of the issues related to aging water infrastructure e.g. under capacity, breaks and leaks? Please specify.

The seven responses are listed in Table 5-7, and important points are highlighted in bold.

Table 5-7: Issues with Aging Infrastructure

	Response
1.	**Land use planning** (how will our infrastructure serve the needs of a City that is moving from suburban expansion to redevelopment and inner city densification), **climate proofing (how will our infrastructure perform under the uncertainties of climate change and uncertain impacts).**
2.	Aging infrastructure is not a significant issue as much of the community is newly built. In the older areas of the community, **water main breaks** may present as an issue.
3.	The **cost** of water main replacement
4.	**Breaks** - primarily in cast iron pipe; under capacity (some locals mains are 19 mm, or 38 mm) resulting in extremely low water pressure and fire flow issues; a challenge is matching up the water renewal needs with the rest of the infrastructure so we enter a right of way only once.
5.	In our case the issues tend to be more **breaks and leaks** and therefore the **operational costs** are high to address these.
6.	Mostly **breaks**.
7.	breaks, leaks, infiltration, timing and importance of these need to again be explained to the staff, council and tax payers.

The ability to manage for climate induced effects, such as by land use planning is highlighted, in addition to the expected concerns about breaks and leaks and source of funding to replace the infrastructure.

Question 9

Response to a natural hazard is done in three phases: pre incident planning, emergency response right after incident (within hours and days), and post incident recovery activity (within days, weeks and months). How does your organization respond to a natural incident over the long term (i.e., not an emergency response) that can affect the water related infrastructure (e.g., pipes, pumps etc.)? The responses are listed in Table 5-8.

Table 5-8: Response to a Natural Incidence in Long Term

Response	Percentage	Count
We usually just react to the situations as they arise but do not follow through with any further analysis.	0%	0
We try to determine the reasons for the issue so that we can improve our response should a similar situation arise in the future but we limit our analysis to only the situation specifics.	14%	1
We undertake a systematic review of current processes to determine how to proactively handle future, similar scenarios from a comprehensive viewpoint by considering also elements outside of the situation specifics.	86%	6
We wait for the province or other regulatory authority to provide us guidelines and frameworks to handle any emerging issues.	0%	0
Other, please specify.	0%	0

The majority (86%) of respondents indicated that they respond in a comprehensive solution for a situation arising from climatic variations.

Question 10

How frequently is the performance of the water system monitored and measured? The responses are given in Table 5-9.

Table 5-9: Performance Monitoring Frequency

Response	Percentage	Count
Once every month or more frequently.	43%	3
Once a year.	29%	2
Once every five years.	0%	0
Whenever provice requires us to undertake such activities.	0%	0

We do not measure the performance of our system.	0%	0
Other, please specify.	29%	2

(“Other” response)

#	Response
1.	Not sure what specifically is meant by "performance"
2.	Unsure of specifically what you mean by measure and monitor. Quality is complete regularly (multiple times per month) on various components

The 43% response indicating that system’s performance is evaluated once a month or even more frequently seems to be actually addressing a particular component of the system; the “once a year” response is likely more realistic. Interestingly, the “other” response indicates that engineers and managers do not seem to have a consistent or actual understanding about performance assessment on a system. This strongly suggests that the emphasis in current water management approaches focuses on the “to do” aspects, rather than on evaluating and assessing the overall system.

Question 11 of the survey has three parts.

Question 11A

Generally quality, cost and time are the fundamental criteria for engineering decision making. In your opinion what was the priority during initial decisions (planning/design)? Please rank the initial priority as 1 being the highest and 3 being the lowest. Table 5-10 indicates the responses.

Table 5-10: Fundamental Criteria for Engineering Decision Making

	3	2	1	Total
Quality	1 (14%)	2 (29%)	4 (57%)	7
Cost	0 (0%)	4 (57%)	3 (43%)	7
Time	5 (71%)	1 (14%)	1 (14%)	7

Question 11B

How have these priorities changed over the time? Please rank the current priority of the following criteria against the initial priority as 1 being the highest and 3 being the lowest. If the priority has not changed, please move to Question 12. Responses are listed in Table 5-11.

Table 5-11: Changed Priority for Engineering Decision Making

	3	2	1	Total
Quality	0 (0%)	1 (50%)	1 (50%)	2
Cost	0 (0%)	1 (50%)	1 (50%)	2
Time	2 (100%)	0 (0%)	0 (0%)	2

Question 11C

Why do you think the weighting and priority has been changed over time? You can choose up to three answers. Table 5-12 lists the responses.

Table 5-12: Reasons for Changed Priority in Engineering Decision Making

Response	Percentage	Count
Due to economic instability.	0%	0
Due to aging infrastructure.	33%	1
Due to consumers increased demand for improved services.	0%	0
Due to regulatory requirements.	33%	1
No change.	67%	2
Any other reason, please specify.	0%	0

Quality ranked highest, followed by cost and time in initial decision making. Interestingly, when asked to rank the priority in current decision making, two respondents indicated that quality and cost both ranked equal. The reason for this changed priority was regulatory requirement for water quality, and aging infrastructure. Because of the public health concern, water quality requirements are becoming much more stringent.

Question 12

If you are required to report the performance of your water systems to your province, what do you think about the parameters used to report to the province about the performance of the water system? You can choose more than one. The answers are listed in Table 5-13.

Table 5-13: Parameters Chosen for Performance Reporting

Response	Percentage	Count
They truly represent the overall system performance.	29%	2
They mostly give information on what outcomes were achieved.	43%	3
They are mostly focused on financial performance.	14%	1
They do not tell us whether the processes that we implemented to achieve the results were good.	0%	0
They do not tell us whether we are going to be more sustainable or less.	71%	5

The majority of the respondents agreed that the current performance assessment of water related infrastructure system do not reveal any substantive information about the sustainability status of a system, and mostly list the achievements made in a particular time frame, focusing on financial performance. Twenty nine percent of the respondents thought that the current practice represents the system performance overall.

Question 13 in the survey has three parts.

Question 13A

Does your organization consider sustainability in the infrastructure related decision making?

Five out of seven respondents said that they do have a sustainability plan, but only in the early stage of implementation, and two respondents indicated that they do have a plan and they are in the process of implementing it.

Question 13B

At what stage of decision making do you think sustainability is or should be implemented in the water sector in your municipality? Table 5-14 indicates the responses.

Table 5-14: Sustainability Implementation Stage

Response	Percentage	Count
In long term policy formulation only.	0%	0
Annual programs and goal settings.	14%	1
Conceptualization of any program or project.	57%	4
Design phase of any new or improvement project.	14%	1
Ongoing operation and maintenance (O&M).	14%	1
Other, please specify.	0%	0

Question 13C

Do you think implementing sustainability will be helpful to deal with pressing issues such as natural hazards associated with climate change? Answers are given in Table 5-15.

Table 5-15: Benefits of Implementing Sustainability

Response	Percentage	Count
No, because sustainability and climate change are not tied together.	0%	0
To some degree, because sustainability and climate change are somewhat tied.	71%	5
This relationship between climate change and sustainability has not really been considered by many organization.	0%	0
I do not know.	0%	0
Other, please explain.	29%	2

The two other responses are given in the box below.

#	Response
1.	Yes, sustainability principles assist in adaptation and managing risk from climate change
2.	To some degree, because if you are following a plan that is sustainable, then you should be better equipped to deal with emergencies

Sustainability is still very much in its infancy in terms of actively playing a role in municipal decision making for water related systems. It is doubtful if municipalities truly know if and by how much their system is moving towards sustainability, therefore it is very important to have a plan for *assessing* sustainability, not only just the sustainability plan for infrastructure.

Question 14

What indicators would be most effective for measuring sustainability of water systems? Please rank your choices as 1 being most effective to 5 being least effective. The rankings are given in table 5-16.

Table 5-16: Ranking Sustainability Indicators

Indicators	5	4	3	2	1	Total
Indicators reflecting the resource conservation	1 (14%)	0 (0%)	3 (43%)	2 (29%)	1 (14%)	7
Indicators reflecting emissions or waste reduction	1 (14%)	4 (57%)	1 (14%)	0 (0%)	1 (14%)	7
Indicators reflecting public health and ecosystem health	0 (0%)	1 (14%)	0 (0%)	2 (29%)	4 (57%)	7
Indicators reflecting the cost reduction for treatment, operation and maintenance	0 (0%)	1 (14%)	1 (14%)	1 (14%)	4 (57%)	7
Indicators reflecting ability of the system to manage any uncertainties associated with the system e.g. comprehensiveness of the approach to prepare for potential flooding.	3 (43%)	2 (29%)	0 (0%)	1 (14%)	1 (14%)	7

The respondents ranked public health and cost reduction the highest, followed equally by resource conservation, waste reduction and change management.

Questions 15 and 16 in the survey have two parts.

Question 15A

How does your municipality approach resource usage and its conservation and efficiency for water system?

All the respondents answered that they have a policy and program to improve resource usage, and through monitoring, that they have a “good” grasp on its effectiveness.

Question 15B

What are the main issues that interfere with your efforts to implement water resource management practices? Please rank your choices as 1 being most challenging to 5 being least challenging. Table 5-17 displays the rankings.

Table 5-17: Ranking Issues Interfering with Water Resource Management Practices

Issues	5	4	3	2	1	Total
Lack of data and information readily available to make an informed choice	3 (43%)	2 (29%)	1 (14%)	0 (0%)	1 (14%)	7
Lack of funds	1 (14%)	0 (0%)	2 (29%)	1 (14%)	3 (43%)	7
Lack of mandatory requirement by law to enforce any initiative	1 (14%)	0 (0%)	1 (14%)	2 (29%)	3 (43%)	7
Lack of staffing and manpower	2 (29%)	1 (14%)	1 (14%)	2 (29%)	1 (14%)	7
Lack of awareness among consumers	2 (29%)	3 (43%)	0 (0%)	1 (14%)	1 (14%)	7

Lack of funding, and the mandatory requirement by law to enforce any initiative were considered most challenging, followed equally by lack of data and information readily available to make an informed choice, staffing and manpower, and awareness among consumers.

Question 16A

Has your municipality identified or implemented policies/ processes/ programs in relation to water system to improve upon public health?

Four out of nine respondents said that they have a policy and program to improve public health and through monitoring, they have a “good” grasp on its effectiveness. Out of the two “other” answers, one said that such issues are dealt with by regional municipality.

Question 16B

What are the main issues that interfere with your efforts to implement public health improvement practices? Please rank your choices as 1 being most challenging to 5 being least challenging. Table 5-18 shows the answers.

Table 5-18: Ranking of Issues Interfering with Public Health Management Practices

Issues	5	4	3	2	1	Total
Lack of data and information readily available to make an informed choice.	2 (33%)	1 (17%)	2 (33%)	0 (0%)	1 (17%)	6
Lack of funds.	0 (0%)	1 (17%)	0 (0%)	2 (33%)	3 (50%)	6
Lack of mandatory requirement by law to enforce any initiative.	1 (17%)	1 (17%)	1 (17%)	2 (33%)	1 (17%)	6
Lack of staffing and manpower.	0 (0%)	2 (33%)	1 (17%)	1 (17%)	2 (33%)	6
Lack of awareness among consumers.	0 (0%)	2 (33%)	1 (17%)	1 (17%)	2 (33%)	6

Fifty percent of the respondents ranked lack of funding as the main challenge, followed by lack of manpower, and consumer education (33% each). Lack of data and information, and mandatory requirement each ranked as main challenge by 17% of the respondents.

Question 17

What does the term “change management” mean to you in an infrastructure context? The responses are given in Table 5-19.

Table 5-19: Meaning of Change Management

Response	Percentage	Count
a) Managing physical changes in infrastructure to at least maintain the current level of service, but not necessarily to improve it.	14%	1
b) Managing infrastructure to improve level of service provided.	29%	2
c) Strategic change in policy to reduce future risk.	14%	1
If you selected 17 (c), What should be done? Please specify.	43%	3
# Response to 17 (c): 1. Understand risk and incorporate into long term life cycle renewal plans 2. Raise awareness with decision makers on the extent of the risks and options to mitigate risks. 3. Aasset management planning that encompasses engineering/technical requirements as well as financial sustainability		

Fifty seven percent of the respondents (four out of seven) answered that change management means strategic change in policy to manage future risks, and three elaborated on what should be done as given in the above table. They emphasized long term planning, risk awareness and understanding, and focusing on technical and financial sustainability. Twenty nine percent said that managing infrastructure to improve “level of service” is termed as change management, while 14% indicated that at least maintaining the current service would be considered change management. Clearly the emphasis was more on reducing the risk, making the infrastructure more resilient, and improving the survivability of the system.

Question 18

System approach is the process of understanding how things influence one another within a whole. Do you approach infrastructure management from a systems perspective?

57% (4 out of 7) indicated that they are implementing (or will be in the near future) a systems approach, and 43% said that they have already been using a systems approach for some time now and continue to do so.

Questions 19 to 21 in the survey have two parts.

Question 19A

For a system to be sustainable, it is important for it to be functional (to be able to fulfill its purpose) and be able to survive any perceived or unforeseen hazards (e.g. extreme natural event). Unless a system is functioning well, it is unlikely that it can survive an incident, and be sustainable in the long term. Therefore an interrelationship can be implied between all the three elements. Do you think this relationship is important for decision makers to understand in order for your system to be sustainable over long term? Please explain. The 6 responses to this question are given in Table 5-20.

Table 5-20: Importance of Understanding the Relationship between FSS

	Response
1.	Yes but this is more important that the engineers understand the relationship more than the decision makers (politicians)
2.	Decisions makers must understand the necessity to provide sufficient redundancy and safe guards in a system to effectively provide safe and adequate water, even in adverse conditions.
3.	Yes - decision makers will only allocate sufficient funds and other resources, as well as support new ways of doing things, if they see the multiple benefits that can be achieved, and the risks if they don't
4.	The functionality and sustainability are tied closer than being able to survive an extreme natural event. I do not see the system being vulnerable to individual natural events.

5.	Yes and the best way to deal with specific events is to determine what hazard will have the most impact and ensure measures and redundancies are put in place to help mitigate these hazards.
6.	Yes, I agree.

Five out of 9 respondents agreed that the interrelationship between functionality, survivability and sustainability is important and should be understood by decision makers and one respondent who identified himself/herself as engineer said that it is more important for engineers to understand the interrelationship than the decision makers who are often politicians. One respondent said that functionality and sustainability are more closely tied than with survivability.

Question 19B

Do you think performance assessment of your water system should reflect the functionality, survivability and sustainability of your water system, as described above? Please explain. The 6 responses to this question are given in Table 5-21.

Table 5-21: Opinion on Inclusion of FSS in Performance Assessment

#	Response
1.	Don't understand what you mean by survivability. Performance assessment should be linked to sustainability only. The others don't have any relevance in my opinion.
2.	Ongoing assessments must always incorporate these items so that the weakest link in the system can be addressed and improved upon.
3.	Yes.
4.	To a certain extent noting the rationale above.
5.	Absolutely how else can to determine if you are doing a good job and indentify areas of weakness so that you can improve.
6.	Yes, I agree.

Almost all the respondents agreed that performance assessment should reflect all the aspects – functionality, survivability and sustainability. One respondent did not seem to understand the survivability concept, as indicated in response #1 above.

Question 20A

Functionality is defined as the ability of the system to fulfill its purpose. What factors do you think affect functionality of your water system e.g. population dynamics, aging infrastructure, funding, water pricing etc.? Please specify. The answers are listed in Table 5-22.

Table 5-22: Factors Affecting Functionality of Water System

#	Response
1.	Usage demand and the ability to meet the demand without service interruptions.
2.	Increasing demands due to population growth, cost of infrastructure replacement and the funding to provide for all of this
3.	Age of infrastructure, investment in renewal of existing infrastructure and ability to manage growth of system
4.	Age is a major component. Suitable planning to ensure the infrastructure is sized properly to function for its entire lifecycle is prudent too.
5.	Design parameters, funding available for capital improvement projects, ensure utility rates are appropriate to cover the cost of operations and provide reserve funds
6.	Everything is tied 100%

Cost, aging infrastructure, funding source and pricing structure, infrastructure capacity in terms of adequate size, and design parameters are considered the factors affecting functionality of the water related infrastructure.

Question 20B

What should be the main indicators for assessing the functionality of your water infrastructure? Please specify and explain. Table 5-23 lists the responses.

Table 5-23: Main Indicators for Functionality

#	Response
1.	Demand -ICI sector, Residential Peak demand, # and length of time of service interruptions

2.	Water quality, water quantity, infrastructure replacement scheduling
3.	Adequate water treatment; out of service time (eg. response time to breaks and issues); investment in rehabilitation; investment in replacement
4.	Ability to supply required flows at a reasonable and sustainable cost
5.	Operational costs vs. performance
6.	Cost, timing, need, health,

Some of the above responses seem to be specific towards the water supply system, but service interruption, infrastructure rehabilitation and operational cost, and health related matters are all important issues for stormwater and wastewater systems as well.

Question 21A

Survivability is the ability of a system to continue to function during and after a natural or man- made incident, e.g. flood event. What factors do you think affect survivability of your water system? Please specify and explain. Answers are shown in Table 5-24.

Table 5-24: Factors Affecting Survivability of Water System

#	Response
1.	Water quality, water quantity, residual chlorine levels.
2.	Age of some of the pipe in the ground.
3.	Redundancy; how well it was constructed; quality of data and ability to use the data to fix the system (to respond).
4.	Good design. Our system is design with multiple redundancies.
5.	Given our location, power outages during the winter months pose a significant threat to our system in terms of freeze-ups.
6.	Planning is extremely critical and emergency preparedness is key.

The above responses indicate that having a good design, redundancy plan, water quality, age of infrastructure, good planning and having emergency preparedness are some of the factors affecting survivability of the system. Response # 5 indicates that how various infrastructure systems are related and that one should think beyond their own system boundary when thinking about survivability of their system. Another important aspect noted was the importance of having good quality data and its use in decision making to fix the system in case there is a challenge to the survivability or resiliency of the system.

Question 21B

What should be the main indicators for assessing the survivability of your water infrastructure? Please specify and explain.

Table 5-25 lists the answers.

Table 5-25: Main Indicators for Survivability of Water System

	Response
1.	See above.
2.	Age; condition.
3.	Past operational incidents. Review of designs based on new design criteria.
4.	How well we deal with the potential threats.
5.	How to safely server the tax payer?

Water quality, condition, past incidents, new design criteria, ability to deal with potential threat, and service to the tax payer were identified as main indicators for survivability. Many of these indicators are indicators of functionality. Infrastructure will be able to deal with potential threats more effectively if its functioning well.

Question 22

Climate change is linked to the increased vulnerability of infrastructure to the extreme weather events. Is there a climate change management plan in your municipality? The answers are given in Table 5-26.

Table 5-26: Climate Change Management Plan

Response	Percentage	Count
No, we do not consider climate change at present nor is it an outstanding issue.	14%	1
No, but are developing a climate change management plan.	14%	1
Yes, we have a plan, but it is only in the early stages of implementation.	14%	1
Yes, we are implementing a plan that has been previously	14%	1

developed.		
Others, please specify.	43%	3
Response to " others"		
# Response 1. Don't know 2. Some components such as increase storm intensities used for storm design 3. Not consider yet?		

Only one respondent answered that they are implementing a climate change management plan, and one said that they are considering design aspects for climate change. Clearly more needs to be done.

Question 23

If you have a climate change management plan, which aspects of water management are addressed in the plan? Table 5-27 lists the answers.

Table 5-27: Aspects Addressed in Climate Change Management Plan

Response	Percentage	Count
Water supply security.	17%	1
Distribution system management.	17%	1
Treatment process management.	17%	1
Flood management.	17%	1
All the above.	0%	0
Other. Please specify.	17%	1
Not applicable.	50%	3
Response to the "other". 1. We are undertaking risk assessments on all of our water related infrastructure		

The responses probably reflect what type of system the respondents were responsible for at the time of this survey. One municipality was considering risk assessment on all the systems, while half of the respondents said that this was not applicable to them because the issue of climate change was not considered yet by them or their organization.

Question 24A

Which of the following systems is most vulnerable to climate change? Table 5-28 lists the responses.

Table 5-28: Most Vulnerable Water System

Response	Percentage	Count
Water supply system.	57%	4
Wastewater system.	0%	0
Stormwater system.	14%	1
All the above.	14%	1
Any other system. Please specify.	14%	1
Response to "other" 1. all of the above and transportation network		

Interestingly, four of the seven respondents considered water supply system as the most vulnerable system, while one considered all the water related systems as vulnerable and even included the transportation network. Despite some of the municipalities are dealing with urban flooding and stormwater related issues- the respondents considered water supply system as most vulnerable system. Probably they focused on supply security in the long term.

Question 24B

Please comment on why you think the system you chose above is most vulnerable for your municipality? The 5-29 responses are below in Table 41.

Table 5-29: Reasons for the System being Selected as Most Vulnerable

#	Response
1.	Water availability is already limited in this region and we have high growth rates. Water availability will also be impacted by climate change.
2.	Water supply in smaller communities.
3.	Water supply comes from a distance, most expensive to upgrade. Wastewater mostly flows by gravity to lagoon system that is easy to maintain
4.	The systems are linked - we are a water front community and so have many

	creeks and flooding is a major concern. The creeks are often parallel to sanitary trunks, and culverts are often used to enclose creeks near the sanitary treatment plan and water mains; failure of storms systems would negatively impact all assets within the right of way - roads would collapse impacting water mains and sanitary sewers; especially in older areas where infrastructure is in poor condition and storm capacity issues are frequent
5.	More recently we have seen more intense storms more often and this is predicted to continue.
6.	Climate change poses little threat to any of our systems but well into the future (100 yrs +) our water supply system may become vulnerable to climate change.
7.	Water is the key to life and without it we would not be able to function as humans. We could take everything else in our present lives away and we would be okay except for water?

The responses emphasize the water system, stormwater system, and their interconnectedness, location, population growth, resources of the municipality, and time scale in future.

Question 25A

Which of the following systems poses greatest risk to the people because of effects from climate change within the municipality?

57% of the seven respondents said that water supply system poses greatest risk to the people while 43% indicated that it was stormwater system.

Question 25B

Please comment on why you think the system you chose above poses greatest risk to the people within the municipality? The responses are given in Table 5-30.

Table 5-30: Reasons of System being Most Risky to the Community

	Response
1.	Same reason as in 24
2.	Stormwater systems are more vulnerable due to increased number of weather events occuring as a result of climate change. These systems lack an adequate level of contingency plans.

3.	Water supply comes from a distance, most expensive to upgrade. Wastewater mostly flows by gravity to lagoon system that is easy to maintain
4.	Because of its impact on the other systems.
5.	Potential for increased flooding.
6.	Only well into the future our new treatment plant will be able to deal with any natural issues that may arise and given that our emergency water source is the 9th largest fresh water reserve on the planet vs. our project population of 50,000 the city of Yellowknife should be able to handle any climate change issues.
7.	Water is the key to life and without it we would not be able to function as humans. We could take everything else in our present lives away and we would be okay except for water?

The above explanation indicated that water system was considered vulnerable because it is directly related to human sustenance, while stormwater systems are vulnerable because of flooding events and the lack of an adequate contingency plan, as well as its impact on the other infrastructures. Two of the seven respondents had same response to this question as the earlier question suggesting that those system that are more vulnerable, poses greater risk.

Group B Information and Data Management

Question 26

Is there a data/information management system in your organization? The answers are summarized in Table 5-31.

Table 5-31: Data and Information Management System

Response	Percentage	Count
No, we do not have a data/information management system at present.	0%	0
No, but are developing a data/information management system.	14%	1
Yes, we have a data/information management system, but it is only in the early stages of implementation.	29%	2

Yes, we have a data/information management system that has been implemented for decision making.	57%	4
Other. Please specify.	0%	0

57% of the seven respondents said that their municipality does have a data management system which is used in decision making, while 29% indicated that it is only in the early stage of implementation, and 14% said that they were developing one.

Question 27

If you have a data/ information management system, how effective it is in helping you or other decision makers to make a infrastructure related decision?

The four responses to this question are in Table 5-32.

Table 5-32: Effectiveness of Data and Information System

#	Response
1.	The system is fairly new so for the most part decisions are based on older information and methods
2.	Our data, and ability to analyze it is improving constantly. It allows us to prioritize capital works based on risk of failure - we can compare watermains in one part of the city with sanitary sewers in another part of the city. we can communicate this information to senior management and council and they can use this to make decisions about investment
3.	It is in the early stages. We generally have a inventory to meet PSAB requirements but the next steps in building on the data and utilizing the data better in progress.
4.	It is early stages but I find it very intrigate to my overall planning.

All the answers indicate that their data management systems are in the early stage of implementation except #2.

Question 28

What is the most important piece of information to assist you or other decision makers in making a long-term water infrastructure related decisions in your municipality?

Answers are given in Table 5-33.

Table 5-33: Most Important Information

Response	Percentage	Count
Data and information kept within data/information management system of the municipality.	43%	3
Budget availability.	0%	0
Provincial government policy.	0%	0
Regulatory requirement.	57%	4
Residents outcry.	0%	0
Others, please specify.	0%	0

In most cases decisions were made based on the regulatory requirements rather than the specifics of the particular system.

Question 29 in the survey has two parts.

Question 29A

What time step data are usually used when a long term water infrastructure related decision is made in your municipality? Table 5-34 compiled the answers.

Table 5-34: Time Steps of data Used in Decision Making

Response	Percentage	Count
a) Five year data.	14%	1
b) Annual data.	29%	2
c) Monthly data.	29%	2
d) Daily data.	14%	1
e) Other, please specify.	14%	1
The "other" response Data is continually being updated, and we use the most current data available.		

Question 29B

If you selected 29 A (a) or 29 A (b), do you think a more frequent time step data should be used for decision making?

Responses are given in table 5-35.

Table 5-35: Importance of More Frequent Time Step data

Response	Percentage	Count
Yes, because it can capture any seasonal variation.	20%	1
Yes, because it can capture any patterns in terms of time.	0%	0
No, because it would be cumbersome to work with.	20%	1
No, because our system is already designed for higher capacity, we do not need to consider smaller time steps.	20%	1
It would not make any difference.	0%	0
Not applicable.	40%	2
Please specify a time step that would be preferred	0%	0

One respondent said that increasing the data frequency was important to capture the seasonal variations; another said that it would be cumbersome, and one other indicated that the system is designed for higher capacity so small time steps do not matter.

Question 30

Do you think that the future decisions made in absence of data can influence the water system's ability to deal with uncertainty? Table 5-36 lists the answers.

Table 5-36: Impact of Lack of Data

Response	Percentage	Count
Yes, because it can increase the vulnerability of the system.	43%	3
No, because our system is robust enough to deal with vulnerability.	43%	3
No, our system is newly built and safe.	0%	0
Do not know, we have not considered uncertainty.	0%	0
Other, please specify	14%	1
"Other" Response Yes, because decisions are not reflective of the actual conditions in the field, or of other asset classes		

Fifty seven percent of the respondents agreed that future decisions made in absence of data can influence the water system's ability to deal with uncertainty.

Question 31

What type of data and information do you think are most effective for sustainability assessment? Table 5-37 gives the responses.

Table 5-37: Most Effective Type of Data for Sustainability

Response	Percentage	Count
Data reflecting the resource usage.	0%	0
Data reflecting the public health measures (e.g. Boil Water Advisory).	0%	0
Data reflecting financial issues.	0%	0
All the above.	86%	6
Other parameters - please specify.	14%	1
"Other" Response age, condition and material of assets		

Eighty six percent of the respondents indicated that data reflecting resource use, public health, financial resource are most effective, and fourteen percent said that the condition of the infrastructure are the most effective in sustainability assessment.

Questions 32 and 33 are focused on water consumption. While less relevant to the stormwater system, conservation is key to any water infrastructure sustainability.

Question 32A

In your opinion what is the preferred indicator of measuring the consumption of water? Responses are shown in table 5-38.

Table 5-38: Indicators for Water Consumption

Response	Percentage	Count
Total water taken from the source.	29%	2
Total water distributed.	0%	0
Total water billed.	29%	2

Other, please specify.	43%	3

"Other"	Response
1.	We have four indicators; water withdrawals from the river, per capita consumption, peak day demand and number of flat rate accounts left in the system
2.	Don't know
3.	Both from source and billed

Question 32B

In your opinion what is the preferred indicator for interpreting how to minimize water consumption? Table 5-39 lists the responses to this question.

Table 5-39: Indicators for Water Consumption Minimization

Response	Percentage	Count
Water taken from source/ person	0%	0
Water distributed/ person	14%	1
Water used/ person	14%	1
Water used/ category e.g. for industrial, commerial, institutional etc.	29%	2
Other, please specify.	43%	3

"Other"	Response
1.	Don't know
2.	As mentioned above from source and billed because you need to flush more if water consumption goes down too much
3.	all of the above

Additional explanations were provided by two respondents as below.

1. Calgary has a mix of metered accounts and flat rate accounts. We cannot separate the demand of flat rate customers from metered customers (only an estimate). We measure water pumped into the system and divide by population.
2. Not involved in consumption discussions

The responses indicated that having a solid understanding of the consumer's demographic (type and number of customers), water lost in the system (water distributed vs. used), and per capita consumption were considered important. One respondent interestingly noted that withdrawal from source should always be more than billed water because if water consumption goes down too much, more water has to be wasted meaning wasting energy and resources used in the withdrawal. In other words, reducing withdrawal of water from the source was important.

Question 33

In your opinion what should be the key indicators for public health related to water supply? Table 5-40 lists the responses.

Table 5-40: Indicators of Public Health

Response	Percentage	Count
Number of cases of water borne illnesses.	17%	1
Number of Boil Water Advisory issued.	33%	2
Number of swimming advisory issued downstream of the wastewater treatment plant efluent discharge point.	0%	0
Number of beach closure issued downstream of the wastewater treatment plant effluent discharge point.	0%	0
Number of times the wastewater treatment plant has to be bypassed.	0%	0
All the above.	33%	2
Other indicator, please specify.	33%	2
Other indicators: Meeting regulatory limits Number of times water doesn't meet provincial guidelines		

Illness, precautionary advisories, and functional aspects such as how many times a TP was bypassed and regulatory guidelines were considered main indicators of public health.

Question 34

In your opinion what kind of data are important to record and monitor for water infrastructure functionality? Please specify. The responses are given in Table 5-41.

Table 5-41: Data Monitoring Requirement for Functionality

#	Response
1.	Flow, chemical analysis and other water quality parameters, system capacity, distribution mapping and areas of deficiency - not looped, dead-ends, lack of fire hydrants, inadequate mainline size for fire flows, reservoir capacity and treatment capacity
2.	Size, material, location, age, break history, to determine capital investment; treatment levels, operational funds required to maintain
3.	Production flows and costs as well as water billed
4.	Number of breaks
5.	More guidelines

Water flow, cost, condition of infrastructure, service (number of breaks) and level of treatment on the water were considered the main factors for functionality.

Question 35A

In your opinion what kind of data are important to record and monitor for water infrastructure survivability (ability of a system to continue to function during and after a natural or man- made incident, e.g. flood event) in the short term? Please specify. Responses are given in table 5-42.

Table 5-42: Data Monitoring Requirement for Survivability in Short Term

	Response
1.	Auxiliary power capabilities, distribution mapping, chemical stores, spare parts for critical systems
2.	Age, material, location, area being serviced - these records and data will allow efforts to repair the system to focus in the right areas, and will also provide information as to areas at greatest risk
3.	Water quality
4.	Number of times water system isn't operating
5.	Function to deliver safe drinking water

Question 35B

In your opinion what kind of data are important to record and monitor for water infrastructure survivability (ability of a system to continue to function during and after a natural or man- made incident, e.g. flood event) in long term? Please specify.

The responses are given in Table 5-43.

Table 5-43: Data Monitoring Requirement for Survivability in Long Term

	Response
1.	accurate distribution system mapping, functional auxiliary power supply and ability to access other alternatives, chemical stocks, repair parts, potential flood elevations and engineering to survive
2.	same as above
3.	water quality
4.	Number of times water plant is by-passed
5.	function to deliver safe drinking water

The responses did not vary much between data monitoring requirements for short term and long term which can be interpreted that all the data should be kept for a longer period of time, rather than destroying them after a certain period of time because it is not mandated by law (Manzon 2010).

Question 36

In your opinion what challenges exists in the data management in your organization?

The responses are given in Table 5-44.

Table 5-44: Challenges in Data Monitoring

Response	Percentage	Count
Lack of knowledge sharing within organization.	29%	2
Not knowing the exact importance of data and information.	29%	2
Lack of people and resources to record, manage and assess data.	43%	3
Lack of support from higher management.	0%	0

Lack of clear directives from province.	43%	3
All the above.	0%	0
Others, please specify.	0%	0

Lack of clear directive from the provincial authorities, and the lack of man-power were considered by 43% of the respondents as the main challenge, followed by lack of awareness and knowledge sharing policy within the organization, as indicated by 29% of the respondents.

Question 37

How do you think the barrier to data availability and management can be addressed? Responses are given in Table 5-45.

Table 5-45: Addressing Barrier to Data Availability and Management

Response	Percentage	Count
By having more research to identify the data gap and finding a method to address it.	14%	1
By having a central repository of all the municipal infrastructure data.	43%	3
By making data management and sharing a mandatory requirement.	29%	2
By increasing inter and intra organizational cooperation.	57%	4
All the above.	0%	0
Other, please specify.	0%	0

Increasing organizational cooperation was considered the main solution to the data availability, followed by having a central data repository system, mandated data sharing policy, and identifying the data gaps and finding solutions to them.

Question 38

Is there anything we have not asked you about that you think is important for us to know?

Response
Water is the most valuable resource we have and yet is the least expensive liquid any one in Canada can purchase. People need to learn that now not 10 years from now,

they need to understand??????????

This response reflects a common sentiment of the overall situation regarding sustainability and its relationship to water infrastructure very well.

5.8 Summary

Based on the response to the group A questions, the respondents of the survey have put highest priority on water quality (public health) and funding deficit (resource). Aging infrastructure and funding are related to resources. Water quality is related to public health. Hazards associated with natural incidents can be related to both public health and resource, and the impacts are only possible to adapt to, therefore it can be termed as a matter of change management. Although specific to the water supply, supply security can be seen as an indicator of change management because it is associated with the vulnerability of the system and service interruptions.

Twenty nine percent of the respondents considered that sustainability principles assist in adaptation, risk management, and dealing with emergencies. 71% believed that sustainability and climate change are tied and therefore would want to deal with the impacts of climate change. A specific follow up issue is assigning the weights of the R, P and C for multi criteria style of assessment, which is discussed in chapter VII.

Group B questions were centered on lack of data and information and its management. The majority of the respondents indicated that not having a proper data hampers their decision making, and having a transparent data sharing policy, mandated data keeping requirements and creating a central repository system for water related data and information will be the best way to deal with the issues.
Information obtained from the survey was factored in the sustainability assessment framework development, which is described in Chapter 6.

6. FRAMEWORK DEVELOPMENT

The sustainability assessment framework required main three tasks: 1) developing a survey to gain understanding of the broader water infrastructure related issues; 2) developing a framework to encompass the functionalility – survivability – sustainability aspects; and 3) developing indicators for stormwater infrastructure to fit into the FSS framework an address the climate change issues in the sustainability assessment. Chapter 5 detailed the survey development: this chapter focuses on the framework and indicator development.

6.1 Framework Development: Background

Maintaining a safe and sustainable stormwater infrastructure throughout its life cycle is a common challenge many water authorities are facing worldwide. Aging infrastructure, population growth, public health, sustainability and climate change are among the key challenges facing the infrastructure that manages water (Grayman 2009, Buchberger et al. 200). The Critical Infrastructure Partnership Advisory Council CIPAC (2009) identifies flood, extreme wind, lightning, water loss/drought, hurricane, tornado, severe weather (ice/snow storm) fire/wildfire, power/ communication failure, weapons of mass destruction, cyber attack, infrastructure failure, hazard material release, vandalism/ sabotism/ terrorism, economic disruption, supply chain disruption, pandemic flu, and perceived incidents as common hazards to water sector. These threats can cause service interruption, water contamination, power failure, communication system failure, and supervisory control and data acquisition system (SCADA) failure immediately, and sound emergency response would be required to overcome the situation within hours and days. However, such incidents can impact the normal functioning of the system for a long time and a sound recovery strategy is needed. In Peterborough, Ontario, the flooding incident in 2004 is an example where service has been restored but the city is still unable to assess the level of damage, let alone restore the full recovery of the system to the pre-event functionality (OWWA, 2010). The ability of the water system to survive such impacts is important for long term sustainability, and reflects that *change management* is required: this is aligned with the PRPC approach.

6.2 Characterization of Infrastructure

There are three characterization domains for infrastructure: functionality, survivability, and sustainability. Stormwater related infrastructure systems are created to manage urban surface water: this is its basic function. Survivability of a stormwater infrastructure is defined as the ability of the system to continue to function during and after an extreme event. Staying with the precepts of the basic definition, sustainability for stormwater infrastructure can be defined as the ability of the system to safely manage stormwater without compromising the ability of the system to do so now and in future without stressing resources and environment, ensuring public health, and being able to adapt to the changing situations as it arise. Unless a system is functioning well, it is unlikely that it can survive an incident, and be sustainable in the long term.

Survivability requires additional explanation because it is the “middle tier” performance of infrastructure. It is defined as the capability of a system to withstand a man-made hostile environment without suffering an abortive impairment of its ability to accomplish its designated mission (McGraw-Hill Dictionary of Scientific & Technical Terms 2003). Survivability of a stormwater infrastructure can be defined as the ability of the system to continue to function during and after a natural (or man-made) extreme event such as flooding. The interrelationship between these three elements is shown in Figure 6-1.

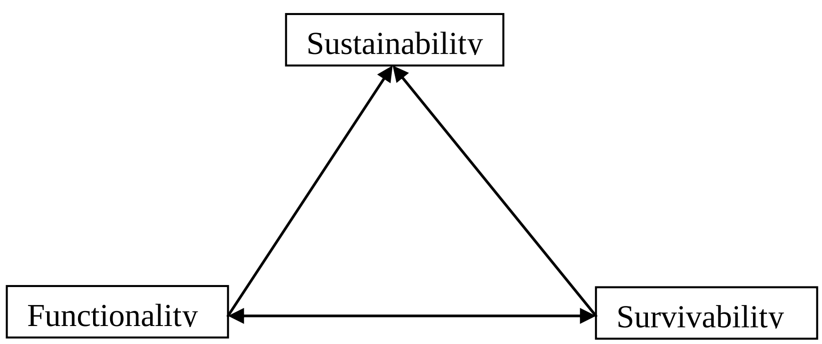


Figure 6-1: Characterization Domains Leading to Infrastructure Sustainability

Based on above relationship between functionality, survivability and sustainability, three levels of performance assessment will be done as shown in Figure 6-2.

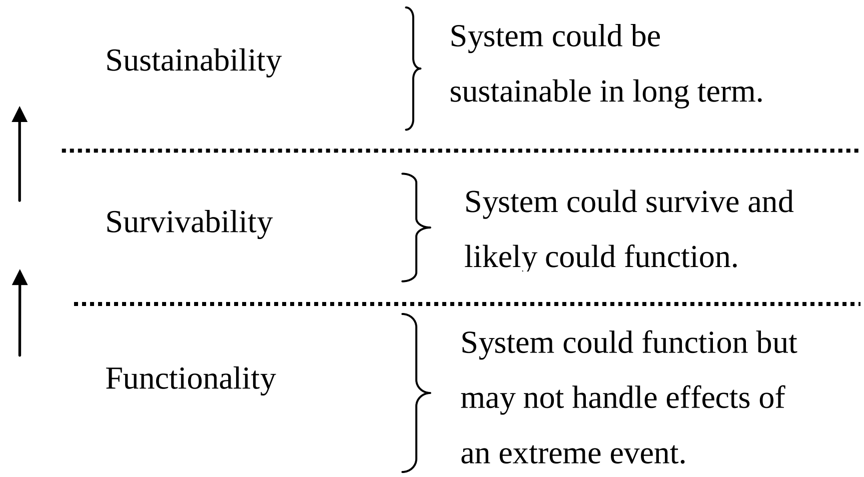


Figure 6-2: Performance Description for Characterization Domain

The above diagram may give an impression that these three characterization domains are linearly related, but in reality they are all interrelated and do not necessarily connect in a linear manner. This research advocates that survivability and functionality both are subsets within sustainability as indicated in Figure 6-3, which is similar to an earlier diagram.

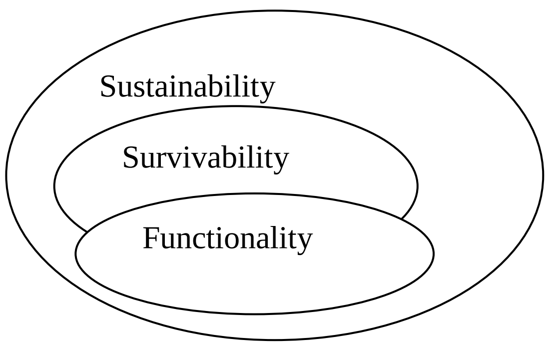


Figure 6-3: Interrelationship between FSS

This framework is unique because it gives decision makers the opportunity to assess the performance of infrastructure on multiple levels: functionality, survivability and sustainability. Depending on the need, preference and requirement, utilities can conduct the infrastructure performance assessment in the three stages consecutively or independently at different times. Functionality and survivability can be assessed separately; however, the sustainability assessment is not possible without encompassing the earlier two aspects. The common, existing notion of sustainability seems to focus on functional aspects emphasizing resource reduction as in, for example, the *Infraguide* and the *footprint* approaches.

Two aspects have been considered while formulating the sustainability assessment framework: 1) the dynamics of sustainability itself, and 2) including resource, people, and change management aspects. In this regard a *process based* approach to infrastructure sustainability from *resource, people, and change* perspective (PRPC) towards sustainability is proposed as a concept.

6.3 PRPC approach

A new approach was conceptualized to include resource reduction, public health and change management aspects for sustainability, but which also apply to functionality and survivability because of the interrelationship. Figure 6-4 depicts the concept of the PRPC approach for the sustainability domain.

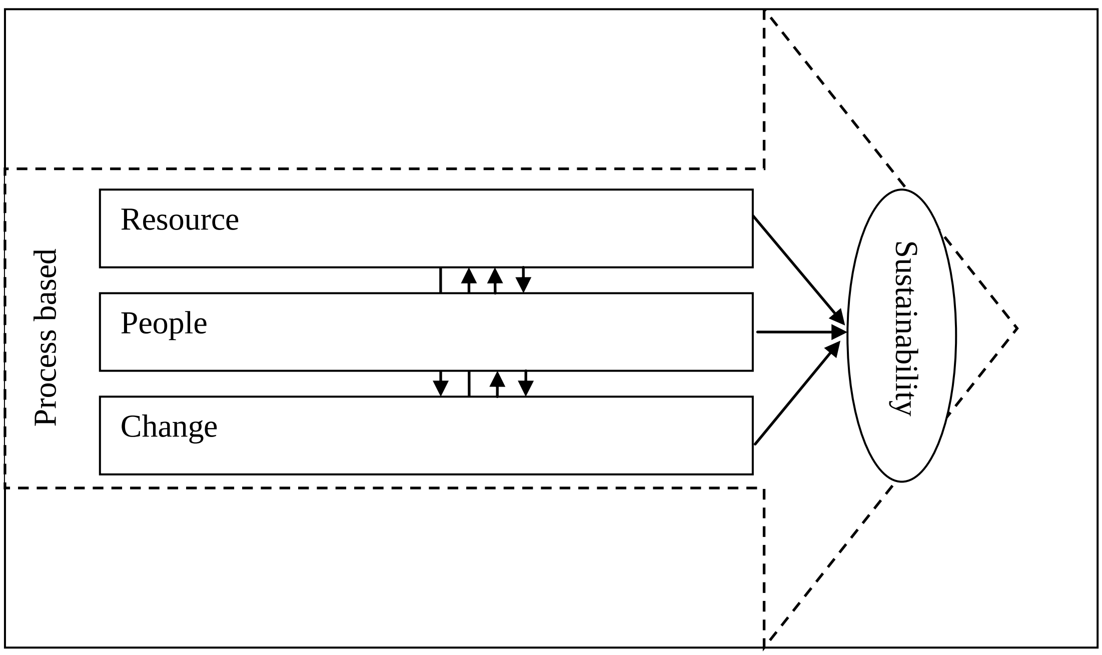


Figure 6-4: The PRPC Approach

The arrow headed dashed rectangular box represents the "process based" approach; the three rectangular blocks in the middle represent the three aspects of resource, people and change management. In Figure 6-4, the final outcome of the entire process is the state of sustainability achieved. The arrows in the middle represent the complex interaction between the R, P and C. The first two arrows indicating the interaction between R and C are partially hidden in the diagram. The *process based* approach means to capture dynamic elements, and any change in the system will likely change the functionality, survivability and sustainability in the long term. Ultimately, the last domain of sustainability is not a final goal, but rather a progression in the state of the infrastructure in relation to resources, health and well-being of the people and the ability of the system to manage changing circumstances.

Resource(s): In terms of infrastructure, resources such as natural, monetary, human resources implemented in infrastructure systems would be optimized and minimized. This will save money and also reduce emissions. Less emissions means improved public health and less expenditure means the funds can be utilized in managing for change. The process evaluation and feedback should be incorporated in future decisions.

People: As we understand it now, health reflects the "combined impacts of climate change on the physical environment, ecosystems, the economic environment, and society…" (WHO 2000). Therefore, considering the public health aspect in infrastructure sustainability is important. Implementing change management would improve the Environment, reduce emissions and thus improve people's health. On a philosophical level, healthy populations in general are more content, more creative, and participate in the social and economic well-being of the society as a whole. Indirectly, having a healthy and content population could save on the resources required to provide physical and psychological health care for the people.

Change: Managing for change is necessary to make our infrastructures more sustainable especially when the "moving target" is the challenge. Putting effort into infrastructure adaptation should increase the useful life of the system components, and will save money and other resources. Adaptation would further reduce the public health risks. As an example, for combined sewers, the effects of climate change on combined sewer overflows (CSO) can be seen in many places. Retrofitting storm water drains or sewer mining means replacing fewer existing sewers with higher capacity ones. The change management effort put into this system will benefit the resources and people, and bring about change. Change management should be considered with a system approach so that a better understanding can be achieved in terms of what we need to do, how we can do it, who is responsible for doing it, and what are the effects on the system. Various criteria and indicators were developed for these parameters and are described in the following sections.

6.4 Criteria and Indicator Development

The assessment criteria and indicators were developed within the functionality-survivability-sustainability characterization domains. Because data is so critical in assessing sustainability, the indicators used should be manageable, relevant, meaningful, quantifiable, well defined and aligned with the objective (FCM and NRC, 2003). As much as possible, existing indicators were selected, because they have already been tested and have been implemented. However, not all the existing indicators represent necessarily the performance measures that we intend to measure. In such cases, new indicators have been proposed. Each indicator was set on the basis of review of available information. Stormwater infrastructure, or at least some of its major aspects, may not have been assessed for survivability before; therefore indicators were proposed based on literature reviewed in similar areas such as emergency management and hazard management. All the indicators were based on resource minimization, public health, and change management aspects. The outcome of the survey had also been utilized to support the selection of criteria and indicators. The following descriptions explain the rationale for choosing the indicators for functionality, survivability and sustainability.

6.4.1 Functionality

The functionality of infrastructure is affected by changes in population, land use, aging infrastructure, funding, service, water quality, conservation and capacity of the employee. Indicators are developed in relation to these factors.

Population: Population growth impacts the stormwater management in cases where combined sewer systems are in place because population growth can increase the dry weather flow. Increased flow requires larger conveyance pipe size. Even if the surface runoff entering the combined sewer remains the same over a period of time, the sanitary sewer flow can increase because of increasing population. This situation will require higher capacity sewers. If possible, eliminating combined sewers is preferred; if not conveyance capacity should be increased. This latter option may not always be possible because of funding and physical limitations in built-up areas. Therefore reducing the dry weather flow is important. Therefore *dry weather flow/per unit length of pipe* and *wet weather flow/per unit length of pipe* is a good indicator in case of combined sewer system.

For a separate stormwater system, the per capita stormwater flow may not play a significant role in surface flooding because the rate of increase in stormwater runoff may not necessarily match the population growth rate. The runoff is more of a function of land use type and imperviousness of the surface apart from soil type, rainfall intensity and duration. However, noting changes in runoff and population pattern would still be prudent. Monitoring the population in terms of type and number of customer is important for a city in order to maintain its revenue base for long term. For example, if the population of the city is increasing but if large industrial, commercial and institutional (ICI) customers are moving out of the city due to economic factors, the revenue base will drop significantly: typically half of the largest users of water are ICI customers in many cities. Revenues from large ICI customers will influence the regular operation and maintenance of the city's water-wastewater-stormwater systems. In addition, the demographic pattern and its influence on stormwater management should be monitored because public education and awareness is important especially for source control, and demographic characteristics such as age and education may play a role. Therefore, *monitoring of the demographic pattern* is another indicator.

<u>Peak flow:</u> Another important aspect in stormwater management is the peak flow. Generally stormwater sewers are designed for the peak flow which is a function of intensity of rainfall (I), duration (D) and frequency (F) of the rainfall event. Due to climate change effects intensity of rainfall is increasing, consequently increasing the peak flow. The sewers are no more able to handle the stormwater peak flow and increased surface flooding is observed. Uncertainties associated with climate variation should be addressed by providing an appropriate safety factor, hence higher design values are

required. Because stormwater infrastructure is cost intensive, careful design consideration is required to avoid overdesign. Finding the right balance is crucial. Newer systems are designed to take increased peak flow into account by deliberately allowing flow overland through natural ground slopes, roads, swales etc. However, older systems may not have such provision and sewers are the only means of conveying the stormwater. Therefore monitoring the peak flow for new observed or projected frequency and intensity of rainfall should be done. In the past the sewers were generally designed for 1 in 2 or 1 in 5 year storm events. It should be checked if the sewers are still capable of handling the current peak flow. Therefore *peak flow generated in the catchment/ high rainfall event* could be an important indicator. Monitoring of outfall for peak flow, although challenging, can be done in case of conventional sewer system, whereas for the combination of major and minor systems with overland flow, a hydrograph can be utilized.

<u>Land Use</u>: The main purpose of the stormwater management is maintaining the hydrologic cycle, protection of water quality, and preventing increased erosion and flooding (MOE 2003). Urbanization increases the impervious area which changes the local water balance, with potential alteration of the subsurface groundwater level and flow (MOE 2011). Stormwater runoff is a function of land use pattern; it is important to have an indicator for *percent increase or decrease in impervious area*. Even if the impervious area is increased, it is likely that the runoff can be managed by the source control measures such as rain barrels; in such a case, the source control related indicator will likely account for the effectiveness of such alternatives.

<u>Aging Infrastructure</u>: Water related infrastructure is aging, and leaking pipe networks lose energy and money. In Canada, about 28% of the water related infrastructure are over 80 years old and only 41% is less than 40 years old (Rehman 2007). Seventy nine percent of the useful service life of infrastructure has been used and conditions have been degrading. About 55% of the stormwater infrastructure needs repair or are not in "acceptable" condition (Rehman 2007). Therefore, the *percentage* of *storm sewer replacement* is an indicator. If a given section of infrastructure has exceeded its design

life or capacity, it is desirable to have it completely replaced. However there are multiple factors to consider, notably the age distribution, funding deficit and other physical constraints.

Funding: Storm water infrastructure like any other municipal infrastructure needs financial resources for maintaining the services and for capital improvement projects. For example, as the infrastructure reaches its end of life, more investment is needed to rehabilitate, replace and maintain the infrastructure. In Ontario, the infrastructure sector is experiencing a funding deficit (AMO, 2010) of $60 billion needed over 10 years. This deficit in investment requires an estimated $1200/household/year, to make up that gap. Water, wastewater and stormwater infrastructure will require about $400/ household/year to fulfill the investment deficit. Generally municipal stormwater management programs (or infrastructure) are largely funded by property taxes. Property tax would not suffice to meet the growing and competing requirements of many assets: a sustainable financing system is also needed. Recent studies indicate that the following funding options are mostly applicable to municipalities (Gregory et al. 2010):

- Property taxes: primary source of funding.
- Development related charges: common funding sources for SWM programs in Canada and the USA.
- Stormwater Rate: a user fee based on a flat rate to residential and area-based rate to ICI sector.

The amount of property tax is based on the property value which depends on zoning, building type and taxing status (Gregary et al. 2010) and does not necessarily account for the services provided by the municipality to the property. A portion of the property tax is assigned for water related services. Even if the service provision is changed, the amount of property tax may remain unchanged. This is not a sustainable practice because it does not charge the user for the actual stormwater management services and also does not provide incentive to reduce runoff.

The development related charges can be applied by municipalities through a by-law and can only be allowed for development needs. For example, the development charge is fixed for an area having a stormwater system in place. If the land use changes and stormwater service has to be increased, the area cannot be subject to increased charges. Hence this method of revenue generation is limited, and only accounts for the initial land development.

The Stormwater Rate is the most sustainable option of all the three because it accounts for the imperviousness of the area within a property and hence encourages the owners to reduce the impervious surface and reduce the runoff load to the stormwater system. This reduces volume of the runoff, and cost of stormwater management associated with the conveyance and end of pipe solutions. In other words, this is a conservation oriented pricing structure. Therefore, the *type of pricing structure* should be an indicator of funding resources.

Sometimes municipalities can utilize special funds available from federal and provincial government through specific policy and program, such as the *Infrastructure Stimulus Fund*. How effectively such external resources are sought and then utilized are important. Overall to reduce the investment need, having a cost saving approach for both capital works and services is necessary. Cost savings should include the downstream benefits in terms of (Belanger 200):

- Reduced flooding damages, treatment costs, increased property values, etc.
- Land released back to the developer for additional returns.
- Reduced needs for infrastructure project bonding.
- Higher property values (increased sales, higher sale/resale prices, shorter on market time).
- Increased tax revenue.
- Increased tourism and recreation.

Sometimes, the current cost incurred in an infrastructure can avoid costs in future, for example, installing inline storage can avoid immediate upgrading costs for larger size sewer, and extend the useful life. Based on the above, the following indicators are identified: *Future cost savings on capital infrastructure project* = difference between actual cost and estimated cost:((estimated cost)- (actual cost))/estimated cost)*100% (adjusted to a future worth of present value for the life cycle of the infrastructure), and *savings on O&M of the infrastructure/ year* (adjusted to a future worth of present value for the life cycle of the infrastructure).

Service: Service to the public in terms of a flood-free state is of prime concern. In this regard, customer satisfaction should be of utmost priority for a municipality. Therefore, *reduction in flooding complaint by property owners/rainfall event of similar magnitude that resulted in flooding in previous years* is an indicator. Similarly *number of stormwater related complaints/ thousand population/ year* could be important indicator. Note that flooding obviously depends on rainfall events, and the details in Chapter 7 on this indicator provide additional guidance on assessing service.

Conventionally, operations and maintenance (O& M) cost is considered an indicator; however, how effective an O&M activity is in terms of service the infrastructure is set to provide should be the key. Therefore, *increase or decrease in O&M activity with respect to intended service per year* is considered an indicator. The service goal for a stormwater system is consistent, but O&M activity might slightly change depending on land use and other physical parameters. Generally hazardous spill response, water-course inspection, and catch basin clean-up are considered operation and maintenance (O&M) activities. Storm sewer length, stormwater connections, number/size of stormwater ponds, and open channel (km) are considered service level indicators because although they represents the physical aspects, the intent is to provide service to consumers.

Water Quality: The water quality guidelines in the stormwater design manual (MOE 2003) is primarily based on the settling of sediments, and water quality of runoff entering the specific innovative stormwater management (ISM) feature is not considered. Urban stormwater carries debris and contaminants from roads, parking lots, sidewalks, rooftops, lawns, and other surfaces. Stormwater can contain suspended solids, nutrients, bacteria, oil and grease, trace metals, and organic contaminants such as pesticides, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) (EC 2005). Different ISMs can have different impacts on urban stormwater runoff depending on soil and vegetation type, landscape practices, street surface clean ups and point source pollutions. Therefore each ISM facility should be able to deliver the water quality as per the specific guidelines.

The end of pipe facilitates such as detention pond, retention basin, dry and wet ponds for example, accumulate persistent contaminants in sediment and during flooding event. These sediments can spill over and may cause health risk. It is important to have an ISM structure-specific, water quality criteria. Such criteria can vary depending on characteristics of the catchment and receiving water body. The local conservation authority or municipal government should establish ISMs specific water quality guidelines. Therefore*, meeting each ISMs specific water quality criteria* is considered an indicator. This study did not intend to develop such guidelines and it is therefore a subject of separate research.

<u>Public health:</u> Public health can be viewed from disease outbreak and water quality perspective. Three categories of diseases can result from flooding: waterborne diseases; mosquito-borne diseases; and infections caused by exposure to water such as fungal skin diseases, eye infections and respiratory illnesses (SDWF, 200). Waterborne diseases are associated with ingestion of contaminated water or exposure to it. A study by Health Canada reported that 4200 cases of giardiasis and 1600 cases of cryptosporidiosis were reported in 2001, although how many of them were waterborne was not clear (Health Canada 2002). Giardia cysts have been reported in raw surface water (Wallis et al. 1996), which may worsen due to changes in future weather patterns, changes in pollutants characteristics, and so forth. The risk of exposure to such microbes are increasing due to increasing urban flooding events, aging infrastructure which may lead to cross contamination of treated water through leaks, infiltration and inflow.

Combined sewer systems are particularly a problem because as the urban flooding is increasing due to change in weather pattern, more and more wastewater treatment plant-bypass events can contaminate the surface water sources. For rural communities this could be a concern because the drinking water from surface source may not be adequately treated in these communities. The Walkerton incident is an example of stormwater contaminating the source water (IJC 2011). Waterborne illness may sound more appropriate indicator for monitoring drinking water, but stormwater infrastructure or systems are directly or indirectly part of the problem. Although extremely difficult to establish a causal relationship, monitoring for waterborne illness and their relationship with stormwaters system is important and *cases of waterborne illness/ 100, 000 population/ year* is considered an indicator. It is recommended to further examine this relationship.

Although most of the cases of vector borne diseases are associated with travel to other countries, some cases of West Nile virus (WNV) have been reported in Canada and the numbers are rising. Across Canada in 2003, a total of 1,300 clinical cases were reported. 1,130 cases met the definition of WN Fever and 16 cases met the definition of WN neurological manifestations. Fourteen deaths were reported in 2011 (City of Toronto, 2011). Generally these infections cause disease like encephalitis/ meningitis, and the mosquito is the primary carrier of such virus from animal to human. Stormwater infrastructure such as catch basins, dry and wet ponds, and constructed wetlands can be breeding grounds for mosquitoes (MOE 2008). Changes in weather pattern can influence the rise or fall in vector population, on the top reduced functional capacity of the SWM can worsen the situation. For example, stagnant water in ponds and wetlands for a long period of time may increase the WNV population in a given area. Therefore monitoring for WNV is important and *cases of WNV reported/ 100, 000 population/ year* is considered as an indicator.

Many stormwater outlets discharge into water bodies which are sometimes used for recreational activities. In such situations, the health of the people using these water bodies should not be compromised. Therefore, the *percentage of total samples tested* *downstream of the stormwater catchment/year that resulted in a swimming advisory* and the *percentage of total samples tested downstream of the stormwater catchment/year that resulted in a beach closure advisory* are important indicators.

These two indicators can also be used as sustainability indicators depending on the temporal and spatial variability. Hence long term monitoring of their trends can represent more than just the functionality of the system.

<u>Conservation</u>: The much touted general abundance of water in Canada is deceptive. During 1994 to 1999, about 26% of municipalities experienced water shortage due to drought, seasonal shortage, infrastructure problem, and increased consumption (Environment Canada 2004). Municipalities serviced by ground water sources experienced more water shortage than those depending on surface water source (Environment Canada 2002). Since stormwater is a major component of hydrological cycle, conserving stormwater will help reduce the demand for water from other sources. Therefore conservation is important and stormwater should be used as a resource rather than waste. Reuse of roof runoff and green roofs are examples of stormwater being used for beneficial purposes. The *volume of stormwater replacing the demand of treated water (through demand management effort)* should be an indicator**.**

<u>Capacity building:</u> Stormwater infrastructure faces a number of challenges in terms of changing environment, technology, and funding options. It is important to assess whether the organization is well prepared for such changes. Obtaining and generating new knowledge is often achieved by research and innovation. Therefore what effort has been done in this area is important. *Research and innovation activities/ year* and *having data sharing policy* are considered an indicator.

Beside career development and refreshing the existing skills, professionals are required to obtain continuous professional development (CPD) to acquire new knowledge and gain more skills to keep up with the developments and changes in related field. In Canada, such a requirement is not mandated, but in many other countries (e.g., Australia) such professional development is mandatory, and has been considered as an indicator for reuse systems sustainability (Upadhyaya and Moore 2012). Therefore, *CPD of engineers and staff in terms of hrs/ year* as designated by the respective professional regulatory body is an important indicator.

6.4.2 Survivability or Resiliency

For functionality, the assessment uses mostly physical parameters. For survivability, the scenario is different: an assessment of vulnerability should be done in order to make the infrastructure more resilient. In this regard, constructing a future scenario may be necessary. This can be done either by simulating the future scenario based on hypothetical conditions or observing the past extreme events and predicting the future conditions.

Responses to natural hazards are done in three phases: 1) pre incident planning; 2) emergency response right after incident (within hours and days); and 3) post incident recovery activity (within days, weeks and months) (CIPAC 2009). Disaster risk reduction is no longer optional but rather a "strategic and technical tool to help local and national governments fulfill their responsibilities" (UN 2010). How municipalities plan for and respond to a natural incident over the long term (i.e., not an emergency response) can affect the stormwater related infrastructure and is crucial for long term sustainability. Having a good emergency management plan is crucial to minimize the negative impact of the event within a short amount of time. Post event survivability effort is mainly focused on restoring the infrastructure system's functioning as soon as possible. If the infrastructure is not functioning as per the standard or to its fullest, then bringing back the infrastructure to fully functional state after an incident would be more challenging. If infrastructure is not properly maintained, it is more likely that the system will have greater risk of failure during an event and would require more resources to recover. For example, poorly maintained stormwater ponds cannot hold extra runoff during higher rainfall events for the designed duration to attenuate the peakflow, and may result in flooding. Most of the poorly maintained infrastructure would have to be totally replaced, as opposed to having repaired had the infrastructure been properly maintained because they can no longer withstand the additional load. This is highly relevant for water infrastructure in Canada where most are towards their end-of-life. This situation makes the water infrastructure more vulnerable to damage in case of a flooding incident even if probability of occurrence is minimal. Therefore, maximizing the functionality of a system should be taken as prerequisite for better survivability. Peck et al. (2010) considered loss of function, loss of equipment and loss of structure for assessing flooding risks associated with climate change in various municipal infrastructures in London, Ontario. The Government of Canada (2011) has issued a *Flood – What to Do?* guideline for residents to follow in a flooding event with following three steps: 1) know the risks and get prepared 2) make an emergency plan, and 3) get an emergency kit.

The focus of this research is on long-term issues, and not specifically the emergency response immediately after an incident, nor the recovery. In other words, this research is mainly focused on improving the resiliency of the infrastructure, or the ability of a system to adapt itself to the consequences of a catastrophic failure caused by an event. Resilient systems for municipal stormwater management are systems that strengthen the treatment train approach already established in the SWM Manual by building in resiliency to climate change (MOE 2011).

Understanding the vulnerabilities, minimizing system impact, emergency response, and adequate financial resources, are all considered as main criteria for resiliency.

<u>Understanding vulnerability</u>: Having a vulnerability assessment plan is the first step towards resiliency. Vulnerability assessment for the existing conventional stormwater management systems is necessary to assist in adaptation decisions by municipalities (MOE 2011). Vulnerability assessment focuses on evaluating and assessing the three elements- planning, emergency response, and recovery activity (Weichsalgrtner 2001). The Environment Canada Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol applies risk assessment approach to analyse, assess, and identify the

vulnerability of infrastructure to the climatic events (Environment Canada 2010). The risk assessment and management focuses on prevention and preparedness measures. Therefore, *assessment of potential risk, assessment of reconstruction need, and having a recovery plan* are considered as indicators.

Minimizing system impact: The second step after understanding the vulnerability is to minimize system impacts so that the resiliency of the system can be improved (Boin and McConnel 2007). To minimize the system impact, having a *well-planned source, conveyance and end of pipe control strategy for stormwater management (adaptation), and alleviation of the root cause (mitigation) of the problem* are considered. For example, the outflow from the detention ponds should be timed in such a way that the peak flow can be delayed. Source control is a major component of urban stormwater management. While contribution of individual property owner in solving urban stormwater problem in a given catchment may not be significant, the collective effort is important for source control. Changes in demography such as their ages, level of education, awareness, and other factors affect change in public behaviour when it comes to adaptation for climate change. Therefore, if there is not a mandatory requirement, the *number of properties opting for source control (or other forms of adaptation)/ total number of property served* should be an indicator. Source control can have water quality benefits by treating, managing or reusing stormwater at source where rain falls. This can also have synergistic effects on mitigation by reducing the energy use in conveyance thus reducing GHG.

Emergency Management: Emergency response is directly concerned with disaster management immediately after an incident occurs. Emergency management (EM) includes protecting people, assets, infrastructure, property, and the environment. The difference between emergency management and recovery is the difference in time scale. Recovery starts after the emergency or along with the emergency and could continue for months and years to restore the system to its functional state. A comprehensive EM plan is set to protect people, assets (infrastructure and properties), and environment. Therefore, *having an emergency response plan* is an important indicator. The characteristics of the emergency response is beyond the scope of this study, but it is critical and every municipality should have a sound ER plan in place.

Financial Resources: At the time when infrastructure system is facing funding deficit for maintaining the services, it is challenging to ensure more funding, but it is very important. Due to growing risk of flooding, it is desirable to have a mechanism to spread the risk. Household insurance in Canada does not necessarily cover the urban flooding related damage to the properties (ICLR 2011). Providing urban flooding insurance is in the early stages of study, and should be considered as an alternative to solely subsidizing the costs inccurred after/during an event. This will ease already stressed financial resources. However care should be taken to ensure that provision of urban flooding insurance should not marginalize the poor and vulnerable section of society adding to the social unsustainability in long term. As an example of how funding need can change for individuals, the insurance cost of flooding has exceeded the insurance cost of fire in last five years (Sandink et al. 2011) which can lead to increased premium payments. Being outside the scope of this study, this is not considered further, however recommended for further study.

6.4.3 Sustainability

For sustainability, indicators are developed with a long term temporal and spatial scale given that stormwater infrastructure serves greater environmental purposes of maintaining water balance, protecting receiving water quality, and so on. The assessment of sustainability should be done on the basis of resource, people's health and change management (RPC) criteria.

Resource**:** Most of the current indicators are resource oriented, and most of the time focus on stormwater flow, and financial information. Because many scientists are concerned about the temporal and spatial availability of water, maintaining the hydrological balance should be encouraged for sustainability. Therefore *having a water balance for the catchment* should be considered as an indicator. Careful modelling of each component of the water balance is necessary to ensure that the ground water recharge (infiltration) is increased whereas surface runoff is decreased.

The “energy-water nexus” is now understood: every liter of water conveyance translates to the increased energy (as well as money) consumption. Even though the stormwater systems may not be as energy intensive as the drinking water or wastewater systems, the energy usage potentially increases GHG which is the primary cause of climate change. Therefore, the *energy used to convey stormwater/ ML of stormwater/ year* should be another indicator under resource category.

Public Health: For public health the following indicators are identified:

Disease outbreak: Encephalitis, which is caused due to West Nile virus and carried by mosquitoes, is a growing concern and many ISMs could be a breeding ground for mosquitoes. In the event of flooding the floodwater could impound in low lying areas which can also create mosquito breeding grounds. Climate change can cause rise in vector borne illness. Therefore *cases of vector borne disease reported/ 1000 population/ year is considered an indicator*. Flooding can contaminate the source of drinking water and residents can come in contact with the floodwater in streets and basements. Therefore, c*ases of gastrointestinal disease reported/ 1000 population/ flooding event* should be an indicator of public health. There may be many other factors responsible for outbreaks and it may be challenging to establishing a source-exposure-impact relationship. However, it is important to *monitor these indicators* to see whether the reported cases are higher at the time of flood events. After a long term monitoring, an interaction can be dismissed or established.

Receiving water quality: Contaminated runoff can also lead to the outbreak of waterborne diseases when rivers and lakes become contaminated with human and pet waste. In recent years, several water-borne infectious diseases outbreaks have occurred in Canada and the United States including *Crytosporidium* and *Giardia.* The potential threat of drinking water contamination was evident in Walkerton in 2000 when seven people died and more than 2300 became ill after drinking *E. Coli infected water*. A strong correlation has been demonstrated between the concentration of *E. coli* in fresh waters and the risk of gastrointestinal illness among swimmers (Health Canada 2010). In August 2001, an outbreak of *E. coli* associated illness involving four children was linked to bathing at a public beach in Montreal (Health Canada 2010). This was the first reported incident of *E. coli* to be associated with recreational water activity in Canada. The International Joint Commission on Great Lakes' (IJC) report emphasized the goal of protecting human health. Toxicity of the receiving water is also a concern. Generally the toxicity in water is caused by heavy metals such as arsenic, lead, mercury and copper, and are associated with the carcinogenic effects in human. Storm water runoff is also associated with the pesticides and fertilizer wash-off to the local water bodies which are toxic to human in form of cyanobacterial toxicity. Therefore *E. coli* and *Toxicity whether present in the PWQO concentrations* are considered indicators.

Compliance with water quality guidelines ensures public health safety, but many emerging contaminants and their impact may not have been fully understood, for example, trihalomethens (THM) has been associated with birth defects and other maladies. The usual bacteriological indicators do not reflect the viral contamination and impacts of "chemicals of emerging concerns" (IJC 2010). Therefore, having a multi-barrier approach to water quality from source to sink is important and monitoring for receiving water quality should be considered for long term sustainability. *Monitoring of the water quality for viral strains and chemicals of concerns, and cyanobacterial toxicity* is recommended as an indicator.

Generally receiving water quality monitoring requires samples during the summer time for public health protection. The climate is changing and it is important to understand the climatic variation in the long term. Therefore these indicators should also be monitored for seasonal variations so that a trend can be established. Aquatic and biodiversity related indicators being outside the scope of this study, are not further discussed, nonetheless are very important.

Change Management:

Change management is about ability to manage change in a system as it arises. Therefore, the indicators related to change management can be system specific. For example, if a system is facing serious problem in terms of water quality, then the indicators for change management would be, for example, actions taken to address the water quality issues such as having frequent and effective sampling and monitoring program, or having long term plan for source protection, conservation, consumer education, etc. Therefore, ensuring that *actions taken to achieve sustainability objective is the main focus*, is considered an indicator. In all likelihood, this is more easily described than measured.

In addition to the system specific indicators, the following two indicators are prerequisite for change management:

- Having an effective data collection and *information management system* (IMS). Because it is important to make a fact based, sound decision about changing stressors and conditions of the infrastructure, it is important to monitor the inventory, state and performance of stormwater systems in order to assess vulnerability to climate change and aid adaptive decision-making for infrastructure renewal (MOE 2011).
- Having information sharing policy. There are multiple stakeholders involved in stormwater management and sharing the information will enable to generate new knowledge, to adapt and better prepare for flooding events in future. This was also emphasised by the survey participants. Therefore, *having updated data collection* and *a transparent information sharing policy* is important indicator of change management.

Table 6-1 lists all the criteria and indicators.

Table 6-1: Criteria and Indicators for Functionality, Survivability and Sustainability

Criteria	Indicator	Unit
Functionality		
Population (change + resource)	Dry weather and wet weather per capita flow (for combined sewer system) Monitoring of the demographic pattern	litres/ year Yes/No

Peak flow	Peak flow generated from the catchment	m^3/sec/ high rainfall event
Land use (resource + change)	Change in impervious area.	Percent/ year
Aging infrastructure (change management)	Storm sewer replacement	Percentage of required replacement/year
Funding (resource)	Type of pricing structure Savings on infrastructure project on O &M cost for conveyance of stormwater	Ordinal scale %/ year %/ year
Service (change management)	Reduction in flooding complained reported Number of stormwater related complaints/ thousand population/ year Increase or decrease in O& M Activities/ Service level	%/ year #/ 1000 population/Yr Ordinal scale
Water quality Disease outbreak	ISM specific water quality criteria met or not Percentage of total sample tested downstream of the stormwater catchment/ year that resulted in a swimming advisory Percentage of total sample tested downstream of the stormwater catchment/ year that resulted in a beach closure advisory Cases of vector borne disease reported/ 1000 population/ year Cases of gastrointestinal illness reported/ 1000 population / year	% of total sample/ year % of total sample/ year % of total sample/ year #/ 1000 population/year

		#/ 1000 population/year
Conservation (resource + change)	ML of stormwater replacing the demand of treated water (through demand management)	ML/ML of total water demand
Capacity Building (resource+ change)	Research and innovation activity CPD for engineers and staff	Ordinal scale Hrs/ year
Survivability		
Understanding the vulnerability (change)	Assessment of potential damage Assessment of reconstruction need Recovery plan	Ordinal scale Ordinal scale Ordinal scale
Minimizing system Impact (change)	well planned source, conveyance and end of pipe control strategy for stormwater management (adaptation), and alleviation of the root cause (mitigation) of the problem #of property opting for source control (or other forms of adaptation)/ total number of property served	Ordinal scale #/# (ratio)
Emergency response(change)	Well developed emergency response plan	Ordinal scale
Financial (resource)	Provision of urban flooding insurance	More study
Loss or damage to life (Public health)	Death or injury caused by damage in infrastructure systems due to flood events	#/ incident
Sustainability		
Resource	having a water balance model for the catchment energy used to convey stormwater/ ML of stormwater/ year	Yes/No KWh/ ML/year

Public health	*e-coli* exceedence in receiving water sample *toxicity* exceedence in receiving water sample	% of total sample/ year % of total sample/ year
Change management	Having a updated data collection and Information Management System Transparent information sharing policy with all stakeholders Actions undertaken to achieve sustainability objectives are the main focus.	Ordinal scale Ordinal scale Ordinal scale

The PRPC approach advocates that sustainability assessment should be process based and that the evaluation of the adopted action should be done on the basis of resource, public health and change management (RPC) criteria. Furthermore, feedback should be incorporated on a regular basis.

6.4.4 R P, C based assessment

Two questions should be kept in mind for sustainability assessment:

1) Do the indicators fulfill the R-P-C criteria such that it can be used as an indicator of: a) functionality; b) survivability; or c) sustainability?

2) Within an indicator, what level of the parameter thrusts it into one of the three levels: a) functionality; b) survivability; or c) sustainability?

Because of the interconnected issues and dynamics involved it is not possible to prepare an absolute matrix of indicators that fall under R, P and C: same indicators can be used for one or more of the R, P and C depending on system variables, timeframe, priority of the assessor and spatial variability. A general RPC matrix guide is shown in Table 6-2 for the selected indicators. The Y/N designation indicates the degree to which an indicator fits the R, P, and C categories, with “Y” signalling a positive fit, and “N” signalling a poor fit.

Table 6-2: RPC Matrix

Indicators	R	P	C
Functionality			
Dry weather and wet weather per capita flow (for combined sewer system)	YY	N	N
Monitoring of the demographic pattern (for all)	Y	N	YY
Peak flow generated from the catchment/ event	YY	N	YY
Change in impervious area.	Y	N	Y
Storm sewer replacement	Y	N	Y
Type of pricing structure	YY	N	N
Cost savings on infrastructure project	YY	N	N
O&M cost savings for the conveyance of stormwater	YY	N	N
Number of flooding event/number of precipitation event	YY	N	Y
Number of stormwater related complaints/ thousand population/ year	Y	N	YY
Increase or decrease in O& M Activities/ Service level	Y	N	YY
ISM specific water quality criteria met or not	N	YY	N
Percentage of total sample tested downstream of the stormwater catchment/ year that resulted in a swimming advisory	N	YY	N
Percentage of total sample tested downstream of the stormwater catchment/ year that resulted in a beach closure advisory	N	YY	N
Cases of vector borne disease reported/ 1000 population/ year	N	YY	N
Cases of gastrointestinal illness reported/ 1000 population / flooding event	N	YY	N
ML of stormwater replacing the demand of treated water (through demand management)	YY	N	N
Research and innovation activity	N	N	YY
CPD for engineers and staff	YY	N	N

Survivability			
Assessment of potential damage Assessment of reconstruction need Recovery plan	YY YY YY	N N N	Y Y Y
Well planned source, conveyance and end of pipe control strategy for stormwater management (adaptation), and alleviation of the root cause (mitigation) of the problem Number of property opting for source control (or other forms of adaptation)/ total number of property served	N N	N N	Y Y
Well developed emergency response plan	N	Y	YY
Study the provision of urban flooding insurance	N	N	YY
Death or injury caused by damage in infrastructure systems due to flood events	N	YY	N
Sustainability			
Having a water balance model for the catchment Energy used to convey stormwater/ ML of stormwater/ year	YY YY	N N	Y Y
E.coli exceedence in receiving water sample *Toxicity* exceedence in receiving water sample	N N	YY YY	N N
Having a updated data collection and Information Management System Transparent information sharing policy with all stakeholders Actions undertaken to achieve sustainability objectives are the main focus.	N N N	N N N	YY YY YY

The indicators which fit with more than one of the P, R, and C, and the degree of goodness of fit will determine under which criteria this indicator should be assessed. For example, *energy used to convey stormwater/ volume of stormwater/ year* can be a resource indicator or a change management indicator, but it fits more appropriately with the resource indicator, therefore should be analysed and assessed under R. In case any indicator fits equally well with more than one criteria (R, P and C), the evaluator can choose which criteria it should be assessed in. For example, *change in impervious area* fits equally well with resource and change management, and so can be used for assessment in either category. Leaving the choice to the assessor of where to assign the indicator allows system specific aspects to be considered more effectively.

6.4.5 Criteria/Indicators for Additional Infrastructure

The indicators above are developed for stormwater systems; however, some of the indicators are general indicators that could be applied for other infrastructure systems. For example, the population related indicators and the aging infrastructure related indicators apply to water, wastewater, transportation, energy and building infrastructure, Table 6-3 shows the criteria and indicators for infrastructure in general and their applicability. The indicators can be modified according to the particular infrastructure studied. For example, indoor air quality related indicators for buildings, and outdoor air quality indicators for transportation infrastructure can be considered.

Table 6-3: General Criteria/Indicators and Applicable Infrastructure

Criteria	Indicators	Applicable Infrastructure
Functionality		
Population	Dry weather/wet weather flow	Wastewater
	Monitoring of the demographic pattern	Water, wastewater, transportation, energy
Land use	Change in impervious area	Buildings
Aging infrastructure	Replacement of infrastructure	Water, wastewater, transportation, energy, buildings
Funding	Type of pricing structure	Water, wastewater, energy
	Cost savings on infrastructure project	Water, wastewater,
	Cost savings on O&M	transportation, energy, buildings
Service	Number of related complaints/ thousand population/ year	Water, wastewater, transportation, energy, buildings
	Increase or decrease in O& M Activities/ Service level	
Disease outbreak	Percentage of total sample tested that resulted in a swimming advisory	Wastewater

	Percentage of total sample tested that resulted in a beach closure advisory cases of vector borne disease reported/ 1000 population/ year Cases of waterborne illness reported/ 1000 population / flooding event	Wastewater Water, wastewater Water, wastewater
Conservation	ML of stormwater replacing the demand of treated water (through demand management)	Water, wastewater
Capacity Building	Research and innovation activity CPD for engineers and staff	Water, wastewater, transportation, energy, buildings
Survivability		
Understanding the vulnerability	Assessment of potential damage Assessment of reconstruction need Recovery plan	Water, wastewater, transportation, energy, buildings
Minimizing system Impact	well planned source, conveyance and end of pipe control strategy for adaptation, and alleviation of the root cause (mitigation) of the problem #of property opting for source control (or other forms of adaptation)/ total number of property served	Water, wastewater
Emergency response	Well-developed emergency response plan	Water, wastewater, transportation, energy, buildings
Financial	Provision of insurance	Buildings
Loss or	Death or injury caused by damage in	Water, wastewater,

damage to life	infrastructure systems due to unforeseen events	transportation, energy, buildings
Sustainability		
Resource	Energy used to provide services/ year	Water, wastewater, transportation, energy, buildings
Public health	*E-coli* exceedence in receiving water *Toxicity* exceedence in receiving water	Water, wastewater,
Change management	Having a updated data collection and Information Management System Transparent information sharing policy with all stakeholders Actions undertaken to achieve sustainability objectives are the main focus.	Water, wastewater, transportation, energy, buildings

6.5 Summary

The overall sustainability assessment framework includes the functionality-survivability-sustainability (FSS) model. The FSS framework is built on a *process* based RPC approach to help make infrastructure more sustainable in the context of climate change. The use of the term *process* signifies the underlying assumption taken in developing the framework that the system is dynamic.

Different approaches and paradigms of sustainability currently in use do not explicitly include the climate change issue in the sustainability related decision-making framework. Current assessment and decision-making approaches are parameter based: a system is typically evaluated against the same parameters for many years, and the evaluation process may be unchanged for many years, even if different external issues (e.g., climate change) come into play. Therefore, the process-based approach is important for stressors whose characteristics and variations are not fully understood, or are uncertain. This development has led to developing or selecting indicators that are not conventional, such as the act of monitoring itself being considered an indicator, or identifying interactions between variables, such as between vector borne disease and stormwater trends.

A survey was conducted to incorporate the feedback from people involved in water management, and their opinion was incorporated into the overall framework development. This was aligned with the principle of involving stakeholders in decision making as a hallmark of sustainability. Criteria and indicators for the three domains, functionality, survivability and sustainability, were developed. The overall framework development is very comprehensive and iterative in nature. A list of indicators that can be applied to other infrastructure system as is or with modifications is also presented.

Multicriteria assessment (MCA) is utilized to derive the final sustainability score for the system, and is described in Chapter 7. As a case study, the framework was applied in area “X” of city “A” stormwater infrastructure system, which is presented in Chapter 8.

7. MULTI CRITERIA DECISION ASSESSMENT

The multi criteria assessment (MCA) approach was selected for sustainability assessment. Usually MCA is utilized when a decision has to be made to identify a preferred solution. In sustainability assessment, one system is assessed based on various criteria/ indicators, and determining whether the system is moving towards or away from sustainability is the main objective.

7.1 Steps in the MCA

7.1.1 Establish the Decision Context

MCA is not restricted to identifying the preferred options; it can be applied to evaluate a single option on the basis of multiple criteria too. We are not choosing between alternatives, but rather evaluating the sustainability of a stormwater system based on the RPC criteria within the functionality – survivability – sustainability framework.

7.1.2 Identify the Objectives and Criteria.

The objective was evaluate the system performance based on a number of indicators in each category. Resource, people's health and change management are identified as criteria for evaluation.

7.1.3 Describe the Expected Performance against the Criteria.

Each indicator would have scores assigned based on linear increment in performance. For quantitative indicators the increment is generally by 20%. However, in some cases regulatory requirement was taken into consideration. For example, for water quality compliance, the applicable water quality guidelines suggest a minimum of 40% of the samples be complained with the respective guidelines/objectives (MOE 2010). In such case, the number of samples exceeding the standard value more than 40% of the time was assigned zero score, and rest of the scores were linearly divided. Difficult-to-quantify indicators (primarily qualitative) were assessed against a defined interval scale ranging from 0 to 5, with 0 being unsustainable and 5 being the most sustainable. For two of the indicators - having an updated data collection and information system, and transparent data sharing policy – the same set of decision guide was prepared because these two aspects overlap. If there are well managed data, the likelihood of sharing them with others is generally high. Based on this assumption, the same decision guide is considered applicable for both indicators. A detail decision guide for the interval scale assessment is provided in section 7.2.4. The details of assigning scores are given in Table 7-1.

Table 7-1: Score Assignment

Indicators	Score assignment
Functionality	
Reduction in dry weather and wet weather flow (for combined sewer system) Monitoring the demographic pattern (for both combined and separate system)	>80% to 100%=5 >60% to 80%=4 >40% to 60%=3 >20% to 40%=2 >0% to 20% =1 0% or increased = 0 See Figure 7-1 for details
Peak flow generated/ high rainfall event	See Figure 7-2 for details
Increase in impervious area %/ Year	See Figure 7-3 for details
Storm sewer replacement (%)(km*100/total sewer length)/ per year (See Figure 7-4 for details)	100% – 5 <100% to 75% – 4 <75% to 50% – 3 < 50% to 25% – 2 < 25% to >0 – 1 Zero - 0
Type of pricing structure	See Figure 7-5 for details
Cost savings on capital infrastructure project	Savings realized- 5 Balanced-4

See Figure 7-6 for details	No savings, but can have long term tangible/ intangible benefit to society at large-3 No savings, at all but the project was necessary due to compelling reasons-2 Negative from all aspects- 1 Negative by more than 20%-0
Savings on O&M cost /Km of pipe/ Year	See Figure 7-6 for details
Reduction in # of flooding event reported compared to similar event in previous year Reduction in # of complaints/ 100,000population/year O&M activity with respect to service level	>80% to 100% reduction or no flooding report=5 >60% to 80% reduction =4 >40% to 60% reduction=3 >20% to 40% reduction=2 >10% to 20% reduction =1 No reduction or increased flooding= 0 >80% to 100% reduction or no complaints=5 >60% to 80% reduction =4 >40% to 60% reduction=3 >20% to 40% reduction=2 >10% to 20% reduction =1 No reduction or increased complaints= 0 See Figure 7-7 for details
Innovative Stormwater Management (ISM) feature-specific water quality criteria met or not Total sample tested downstream	100% of the time it was tested=5 > 80% to <100% of the time it was tested=4 > 60% to 80% of the time it was tested=3 > 40% to 60% of the time it was tested=2 > 20% to 40% of the time it was tested=1 < 20% of the time it was tested = 0 100% of the time it was tested=5

of the stormwater catchment that was not resulted in swimming advisory Total sample tested that was not resulted in a beach closure advisory Cases of vector borne disease reported/ 100, 000 population per year Cases of waterborne disease reported/ 100, 000 popultion/ flooding event	> 0% to <100% of the time it was tested=4 > 60% to 0% of the time it was tested=3 > 40% to 60% of the time it was tested=2 > 20% to 40% of the time it was tested=1 < 20% of the time it was tested = 0 100% of the time it was tested=5 > 0% to <100% of the time it was tested=4 > 60% to 0% of the time it was tested=3 > 40% to 60% of the time it was tested=2 > 20% to 40% of the time it was tested=1 < 20% of the time it was tested = 0 0=5 >0 to 2= 4 >2 to 4=3 >4 to 6=2 >6 to 8=1 > 8 or death =0 0=5 >0 to 2= 4 >2 to 4=3 >4 to 6=2 >6 to 8 =1 > 8 or death =0
Volume of stormwater replacing the demand of treated water for external use	100% of external demand replaced by using stormwater = 5 >80% to <100%=4 >60% to 80%=3 >40% to 60%=2 >20% to 40%=1

	<20%=0
Activities in research and innovation (see Figure 7-8 for details) CPD for engineers and staff hours/year (e.g., in Australia, 150 hours/3 years)	Degree of effectiveness of research activities is Excellent=5 Very good =4 Good=3 Moderate=2 Poor=1 None=0 Completed required hour in relevant area= 5 Completed >80% to <100% required hours =4 Completed >60% to 80% required hours=3 Completed >40% to 60% required hours=2 Completed >20% to 40% required hours=1 Completed <20% of required hours=0
Survivability	
Assessment of potential damage (see Figure 7-9 for details) Assessment of reconstruction need (see Figure 7-10 for details) Recovery plan	Degree of assessment of potential damage is excellent=5 Very good =4 Good=3 Moderate=2 Poor=1 None=0 Assessment of reconstruction need is excellent=5 Very good =4 Good=3 Moderate=2 Poor=1 None=0 Effectiveness of recovery plan is excellent=5

(see Figure 7-11 for details)	Very good =4 Good=3 Moderate=2 Poor=1 Non=0
Well planned source, conveyance and end of pipe control strategy for stormwater management, and alleviation of the root cause of the problem (see Figure 7-12 for details) Number of properties opting for source control (or other forms of adaptation) divided by total number of property served	Degree of effectiveness of plan is excellent=5 Very good =4 Good=3 Moderate=2 Poor=1 None=0 1=5 >0.8 to <1= 4 >0.6 to 0.8=3 >0.4 to 0.6= 2 >0.2 to 0.4=1 <0.2=0
Well-developed emergency response plan (see Figure 7-13 for details)	Degree of effectiveness of emergency plan is Excellent=5 Very good =4 Good=3 Moderate=2 Poor=1 None=0
Provision of urban flooding insurance	Recommended for future study
Death or injury caused by flooding (directly or indirectly by damage in infrastructure	0=5 >0 to 2= 4 >2 to 4=3

systems)/100, 000 population /year	>4to 6=2 >6 to 2=1 >2 or death =0
Sustainability	
Having a water balance model for the catchment Reduction in energy used to convey stormwater/ ML of stormwater/ year	100% pre development peak flow is attenuated=5 >80% to <100% stormwater infiltration =4 >60% to 80%=3 >40% to 60%=2 >20% to 40%=1 <20%=0 >80% to 100%=5 >60% to 80%=4 >40% to 60%=3 >20% to 40%=2 >0% to 20% =1 0% or increased = 0
E.coli in receiving water sample Toxicity in receiving water sample (lead, mercury, copper, arsenic) Cyanobactiria, chemicals of emerging concern and new	0% of the time it was tested=5 > 0% to 10% of the time it was tested=4 >10% to 20% of the time it was tested=3 >20% to 30% of the time it was tested=2 >30% to 40% of the time it was tested=1 >40% of the time it was tested = 0 0% of the time it was tested=5 > 0% to 10% of the time it was tested=4 >10% to 20% of the time it was tested=3 >20% to 30% of the time it was tested=2 >30% to 40% of the time it was tested=1 >40% of the time it was tested = 0

strains of virus	Recommended for monitoring
Having a updated data collection and Information Management System, and	(see Figure 7-14 for details)
Transparent information sharing policy with all stakeholders	(see Figure 7-15 for details)
Actions undertaken to achieve sustainability objectives are the main focus of the authority/organization	(see Figure 7-16 for details)

7.1.4 Decision Guide for Assigning Score for Non-quantifiable Indicators

For quantifiable indicators, an appropriate scoring system can be defined. For non-quantifiable, qualitative indicators, deciding scores based on ordinal scale would be challenging. Therefore a detailed decision analysis process was mapped out for following indicators: monitoring of the demographic pattern; peak flow; change in impervious area; storm sewer replacement; type of pricing structure; O&M activity; research and innovation activity under functionality; assessment of potential damage; assessment of reconstruction need recovery plan; well-planned control and conveyance measures for adaptation and mitigation; emergency response plan under survivability; having updated data and information system; transparent information sharing policy; and actions undertaken to achieve sustainability goal under sustainability. Figures 7-1 to 7- 16 shows how the scoring mechanism was derived. The storm sewer replacement, impervious area and cost savings (for both infrastructure project cost and O&M cost) are the quantifiable indicators, however, a decision guide was provided to better illustrate the process because of its broad based nature.

Demographic Pattern:

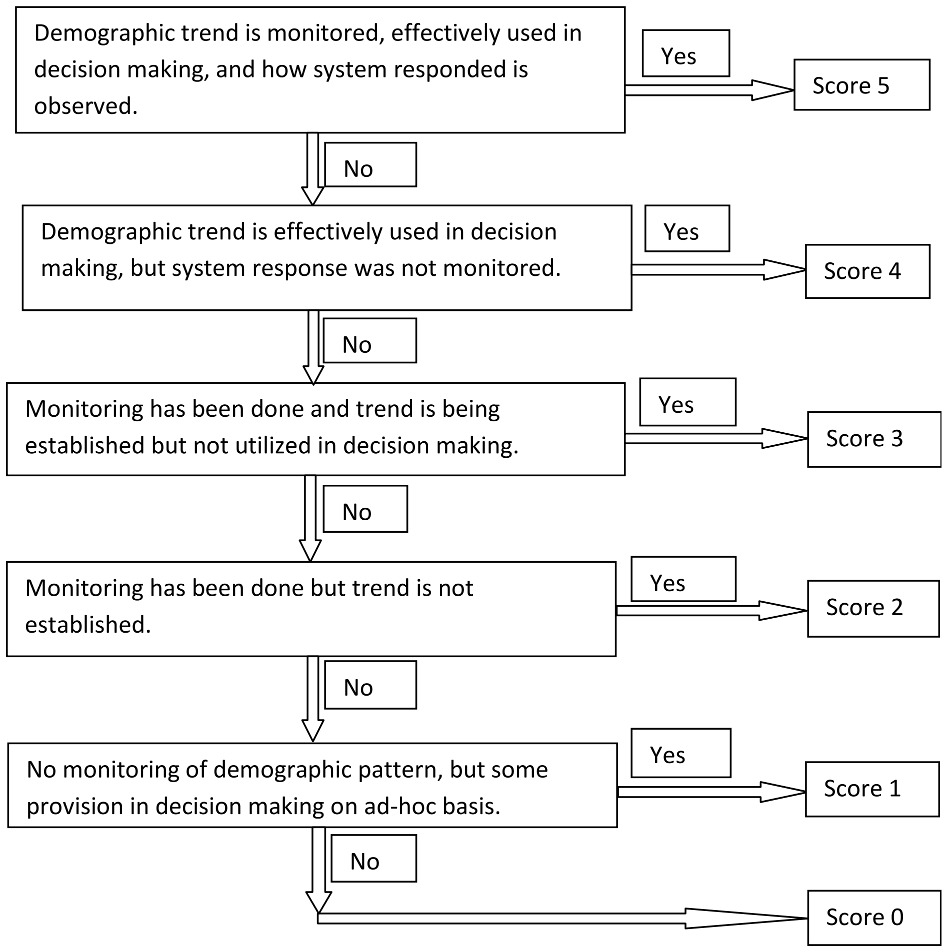


Figure 7-1: Decision Guide for Demographic Pattern Indicator

Peak Flow:

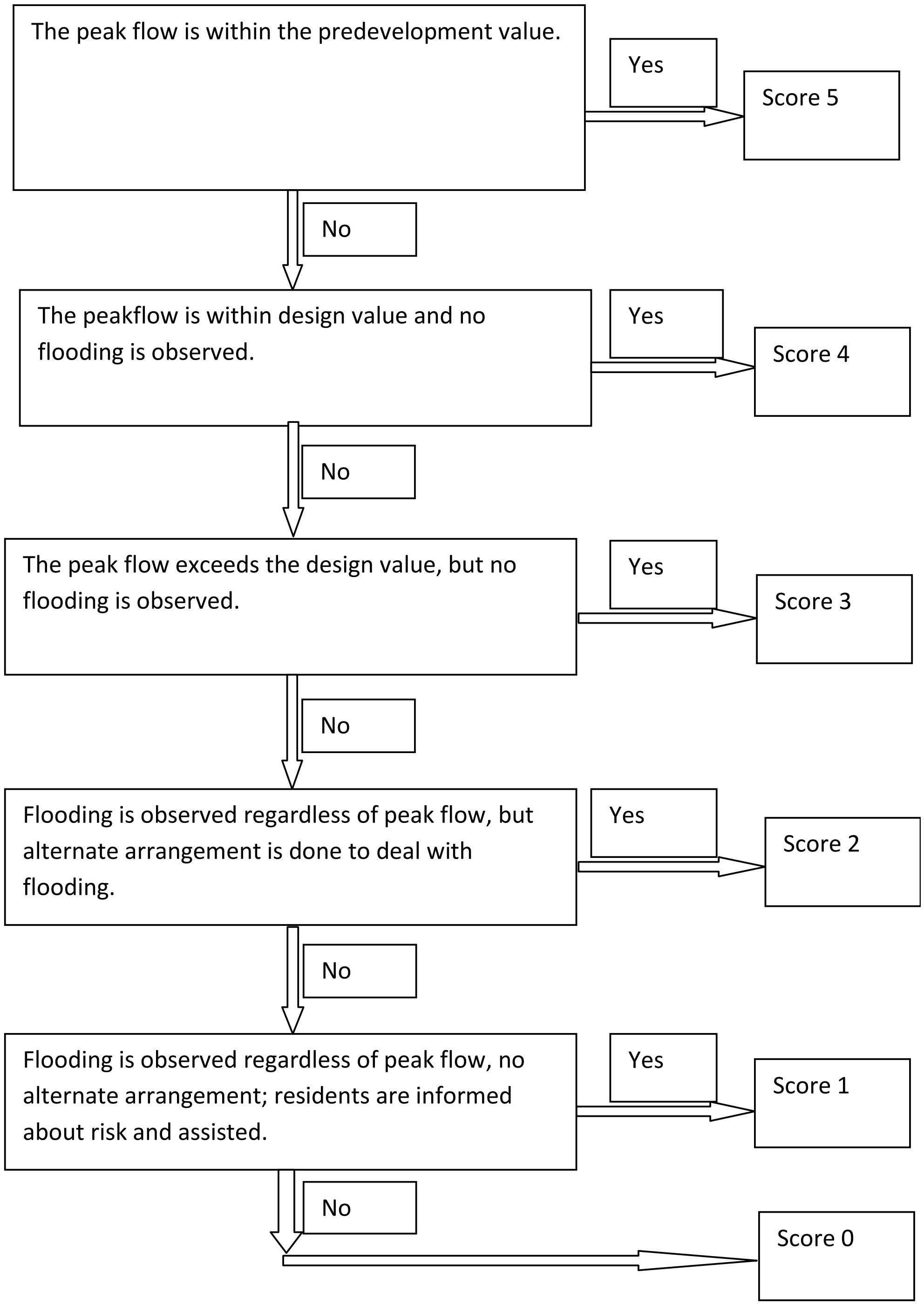


Figure 7-2: Decision Guide for Peak Flow Indicator

Change in impervious area:

Although quantifiable, some details are needed to assign scores, therefore the following guidance is mapped out.

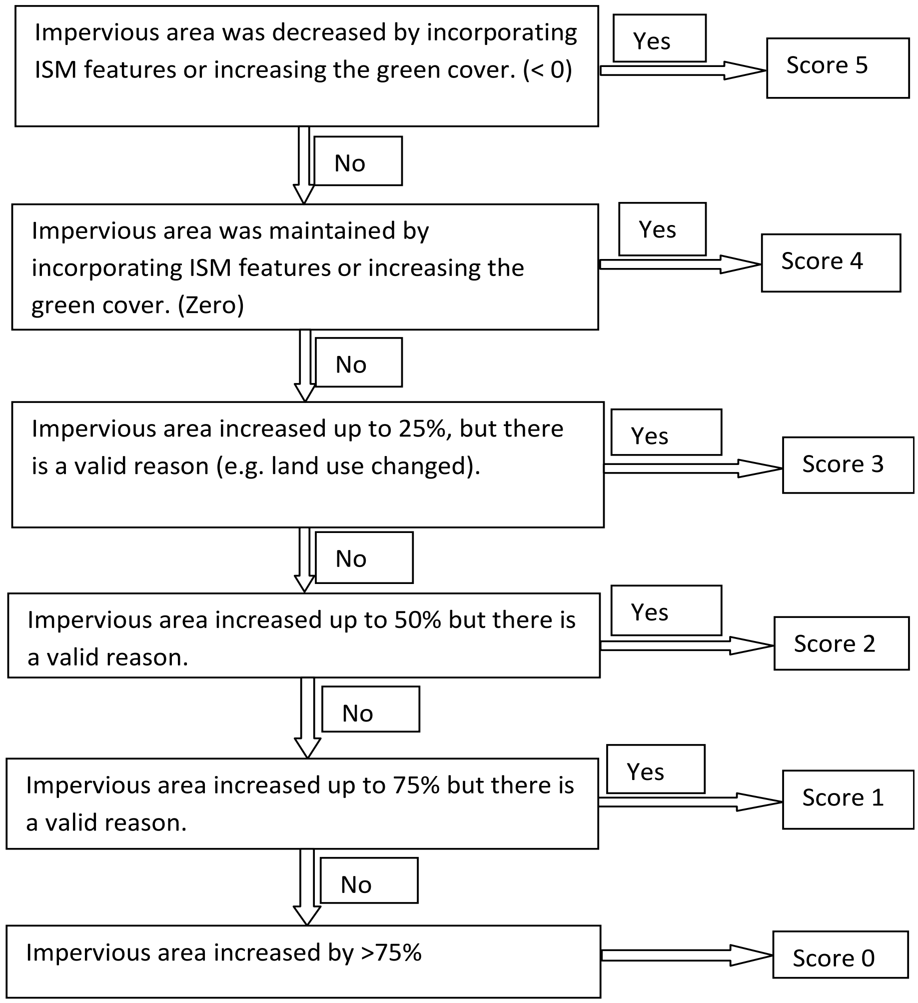


Figure 7-3: Decision Guide for Change in Impervious Area Indicator

Storm Sewer Replacement:

Although quantifiable, some details are needed to assign scores, therefore the following guidance is mapped out.

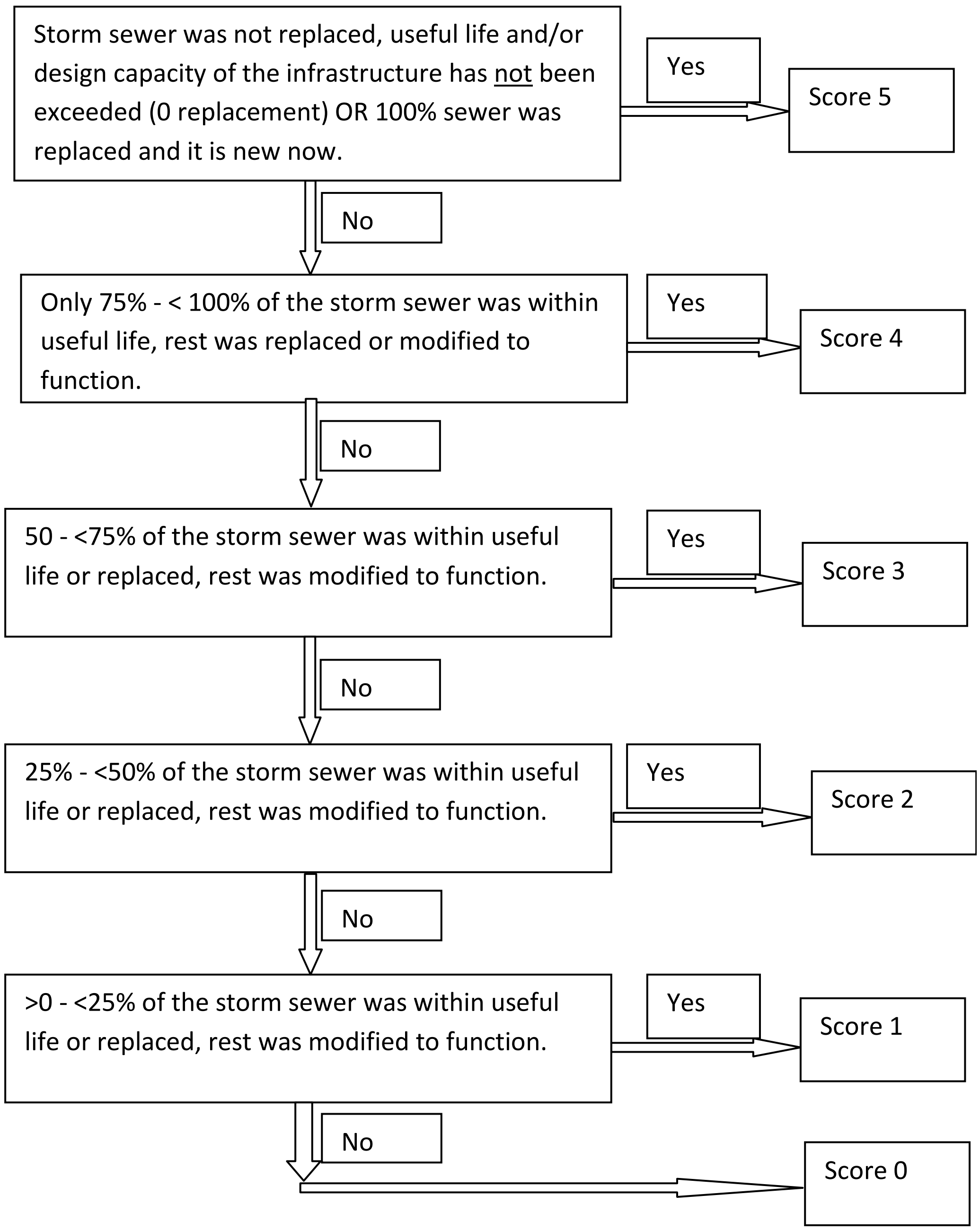


Figure 7-4: Decision Guide for Storm Sewer Replacement Indicator

Type of pricing/revenue Structure:

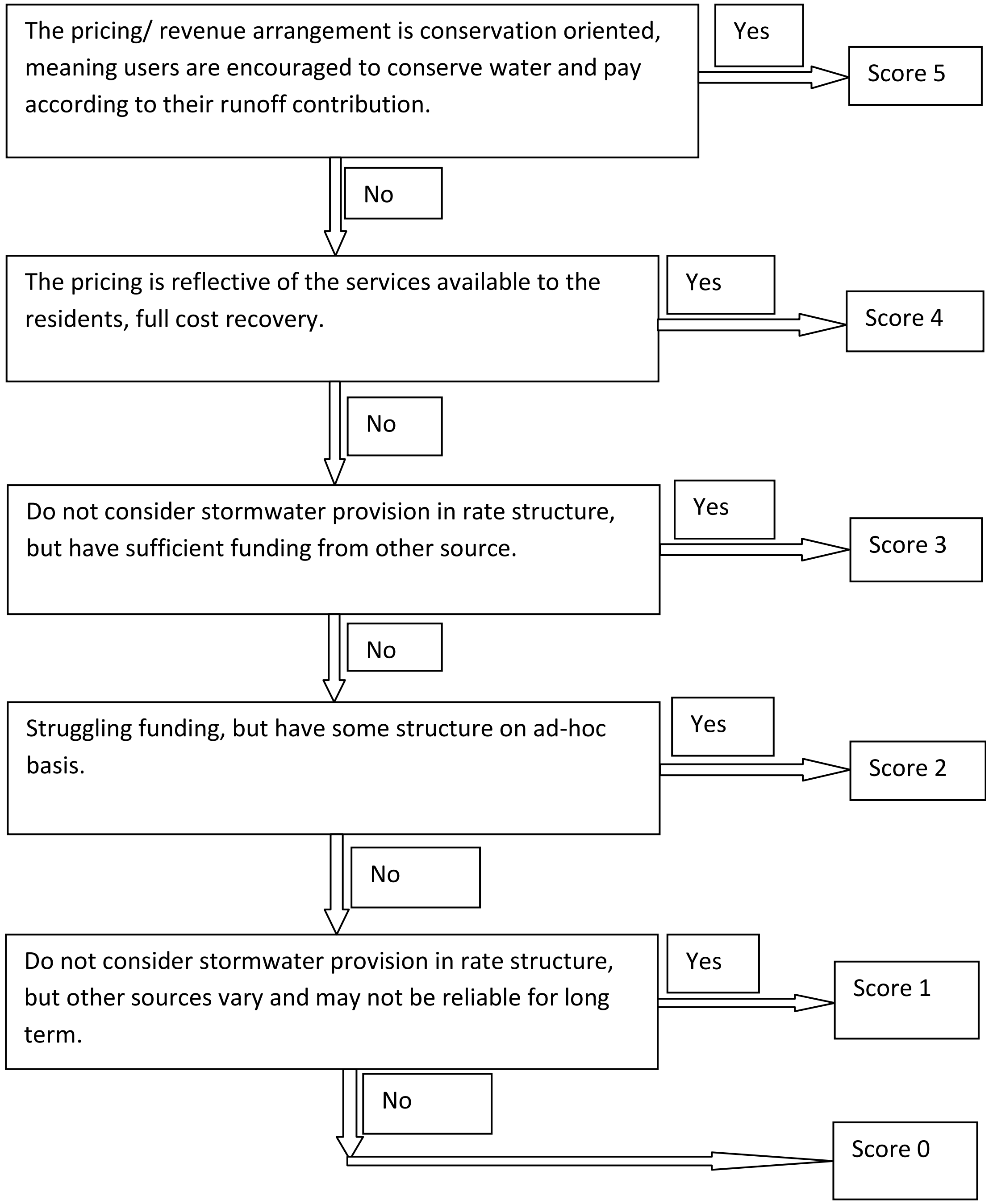


Figure 7-5: Decision Guide for Type of Pricing/ Revenue Structure Indicator

Cost Savings (for both infrastructure project cost and O&M cost):

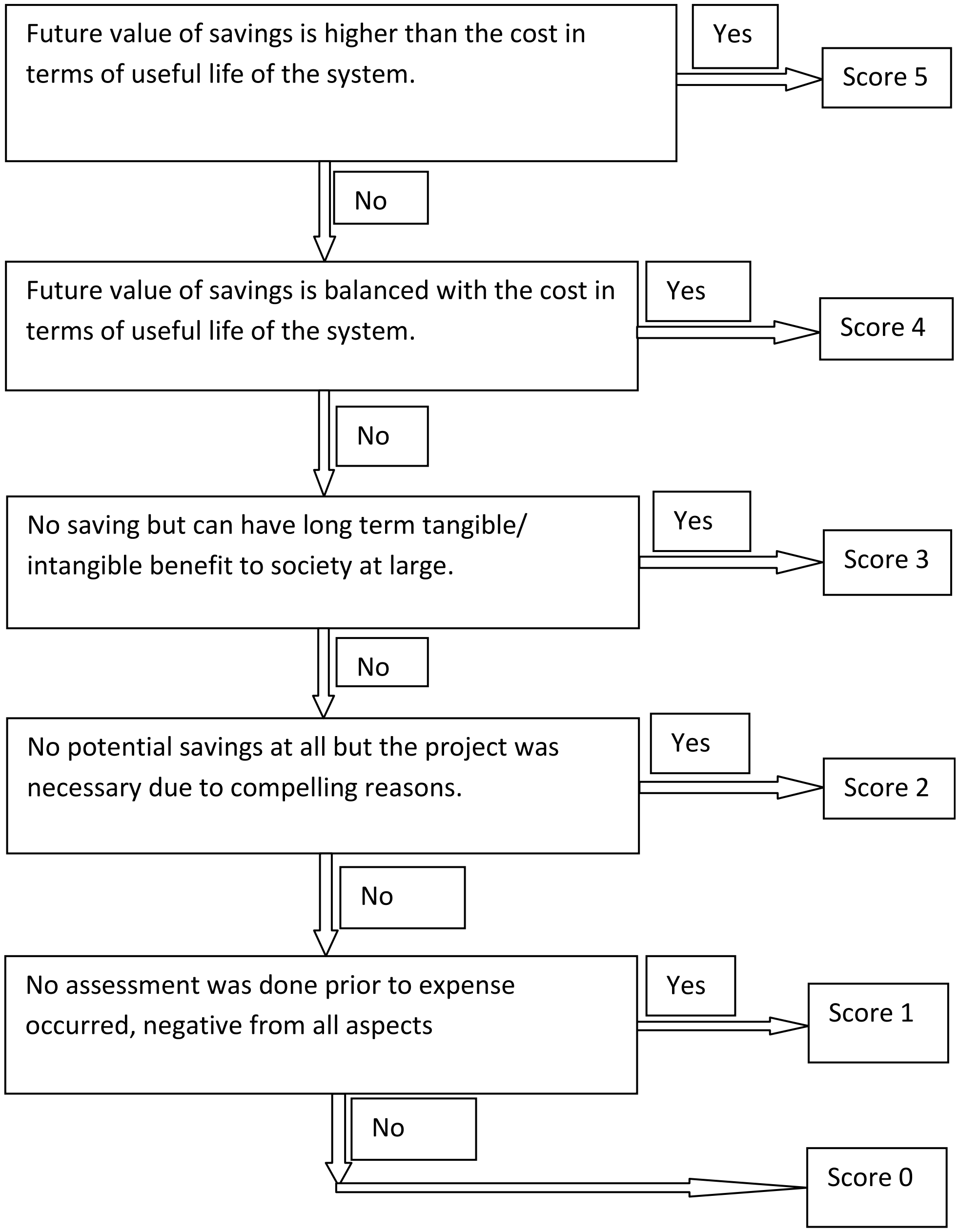


Figure 7-6: Decision Guide for Cost Saving Indicators

O& M activity with respect to service level:

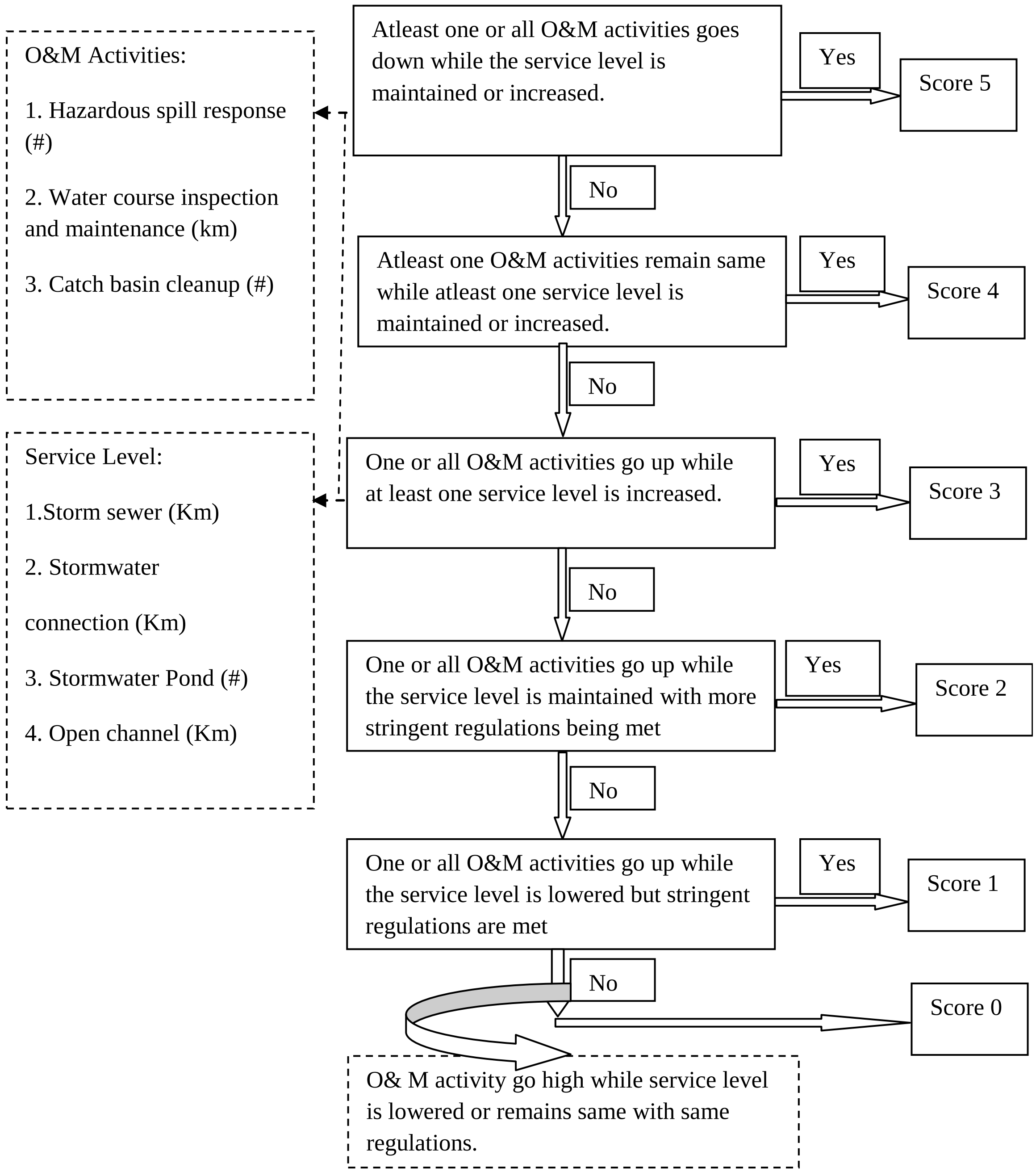


Figure 7-7: Decision Guide for O&M Activity with respect to Service Level Indicator

Research and Innovation:

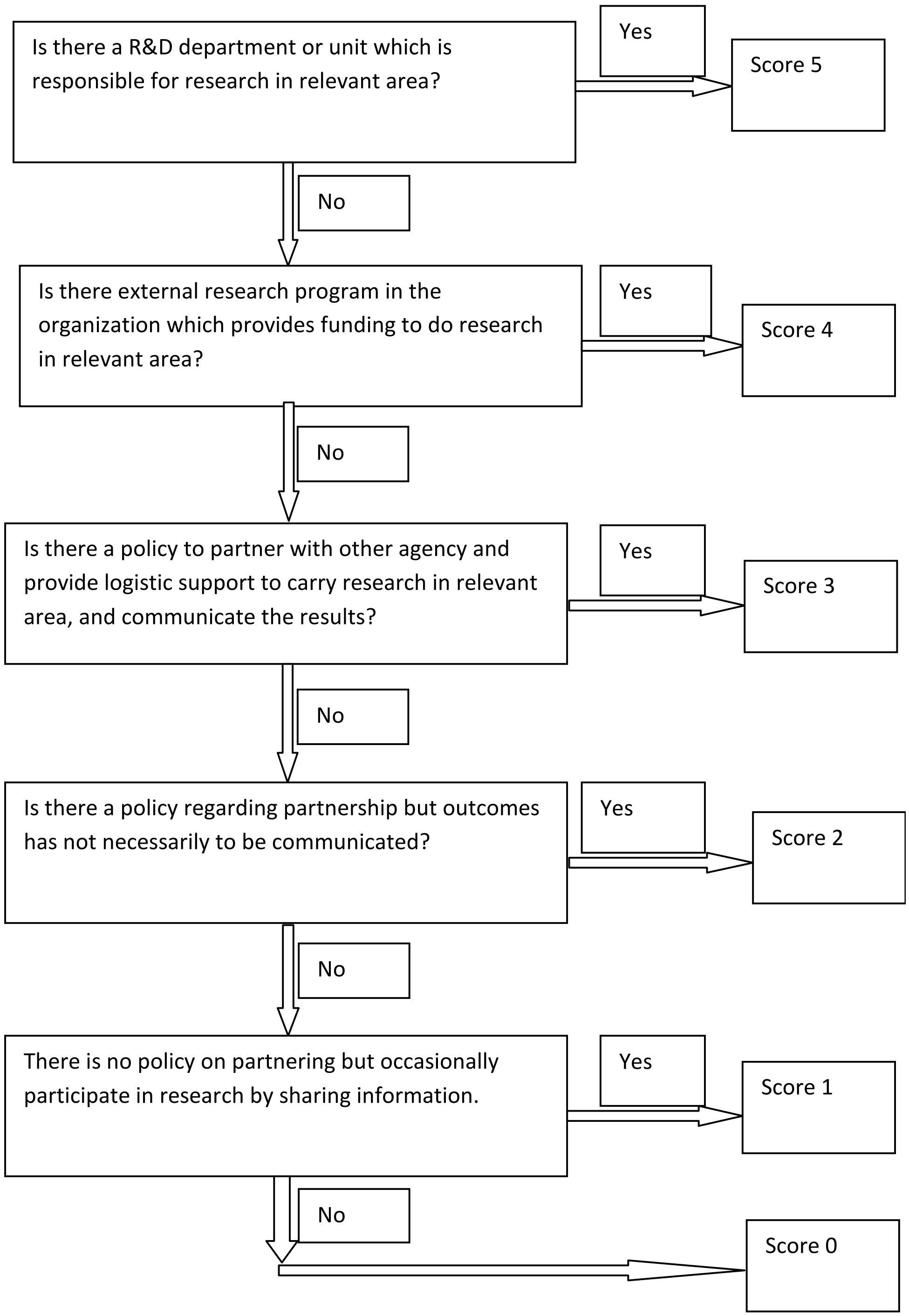


Figure 7-8: Decision Guide for Research and Innovation Indicator

Survivability

Assessment of potential damage:

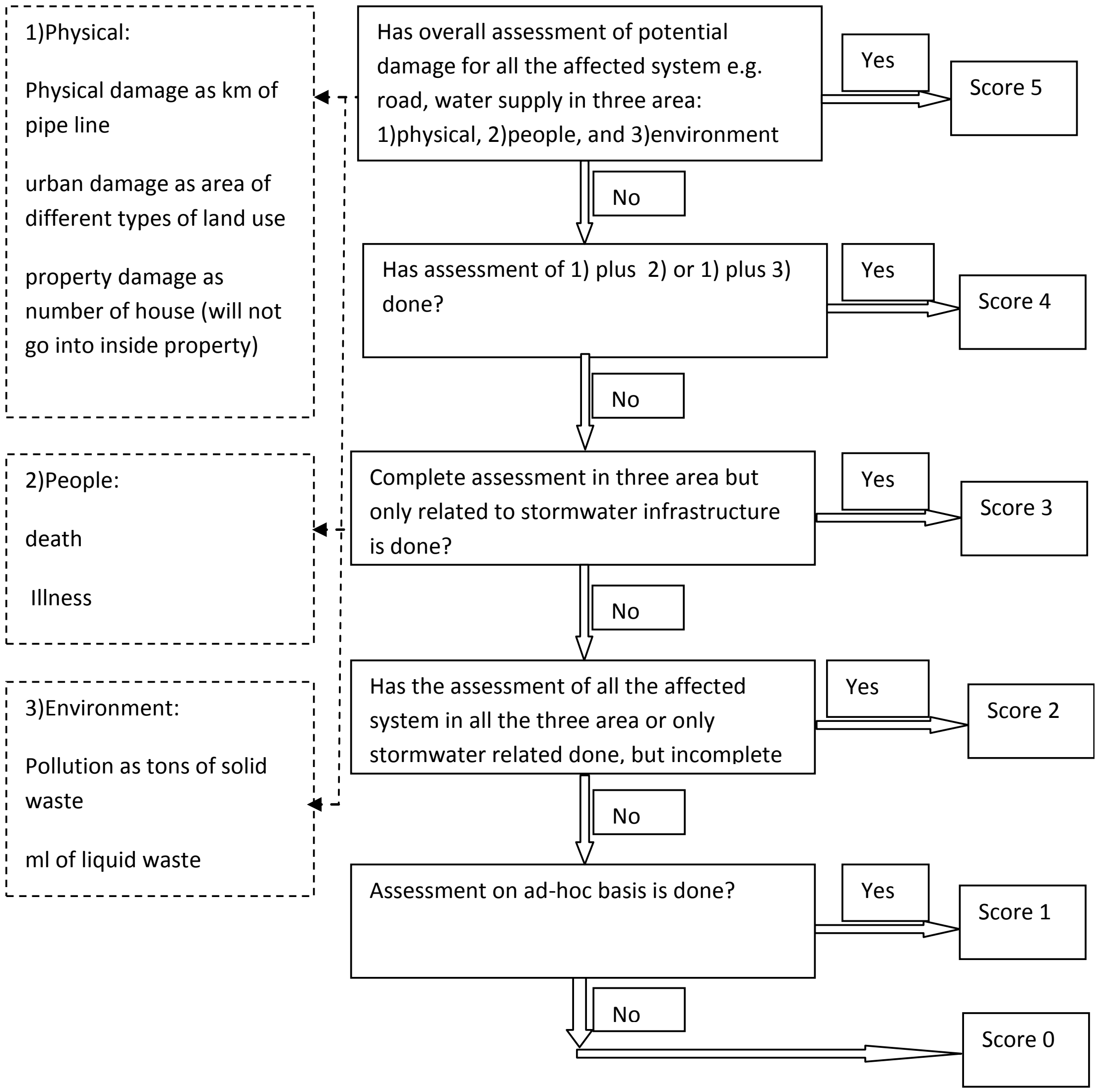


Figure 7-9: Decision Guide for Assessment of Potential Damage Indicator

When flooding occurs it can affect other infrastructure systems such as roads, water supply and wastewater systems, gas, electricity etc. Therefore an overall assessment is necessary. In the meantime only the physical damage is not enough and environmental impacts and long term health impacts on people is also crucial. If complete assessment of all the aspects has been done for all the impacted infrastructure system, a score of 5 is assigned. If assessment of physical damage of all the affected system is done, and additionally impact on either Environment or people is done, a score of 4 is assigned. If assessment of all the affected system is not done because of some limitations such as jurisdictional or limited objectives of the organization, a complete assessment of stormwater related impacts in all the three area: physical damage, people and environment is done, a score of 3 is assigned. If assessment of physical damage either for all the affected systems or only for stormwater system is done but impact on Environment and people is not assessed then score of 2 is assigned. If the assessment is carried out on ad hoc basis and no structure has been followed, a score of 1 is assigned. If no assessment of potential damage is done at all, the score is 0.

Assessment of Reconstruction need:

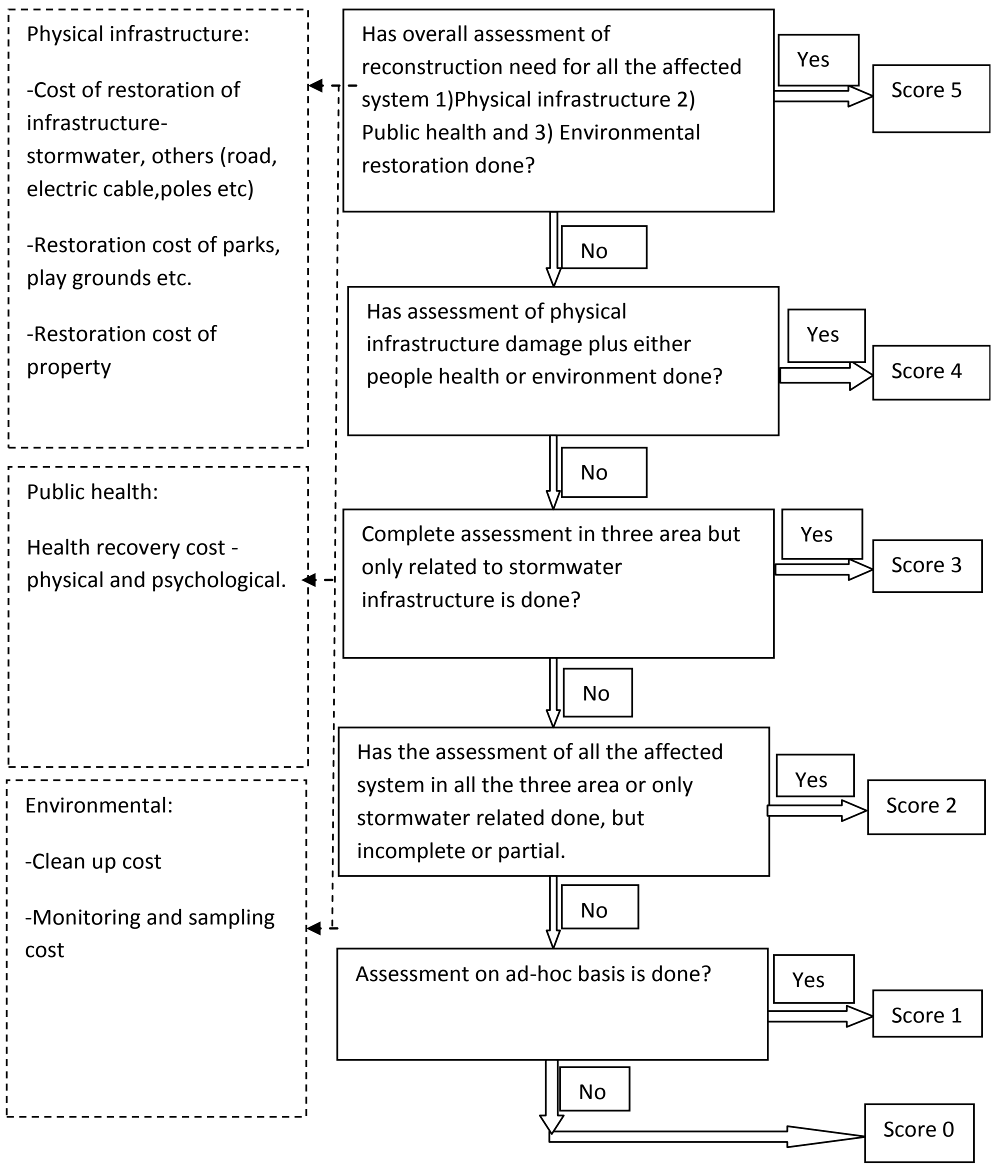


Figure 7-10: Decision Guide for Assessment of Reconstruction Need Indicator

Recovery Plan:

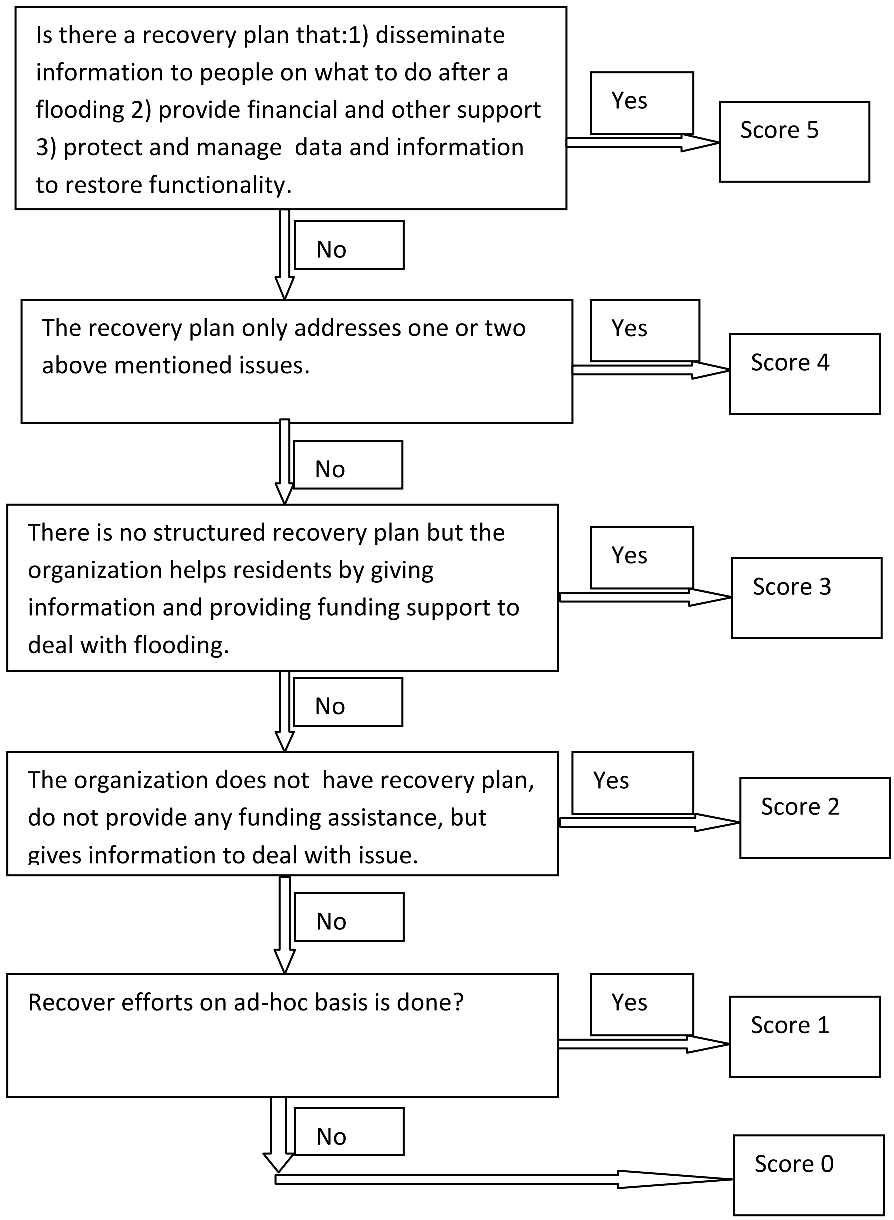


Figure 7-11: Decision Guide for Recovery Plan Indicator

Well planned source, conveyance and end of pipe control strategy for stormwater management, and alleviation of the root cause of the problem is in place or not:

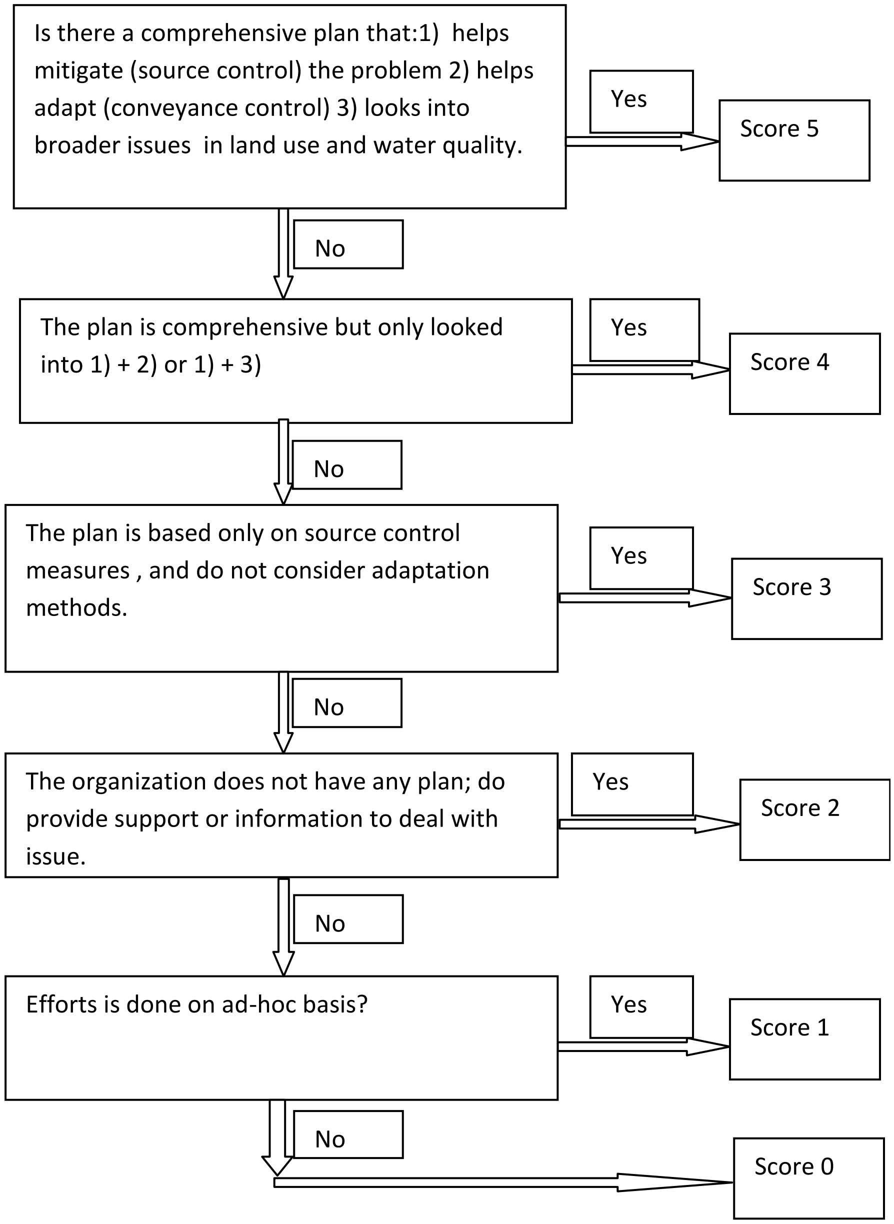


Figure 7-12: Decision Guide for Adaptation and Mitigation Indicator

Emergency Management Plan:

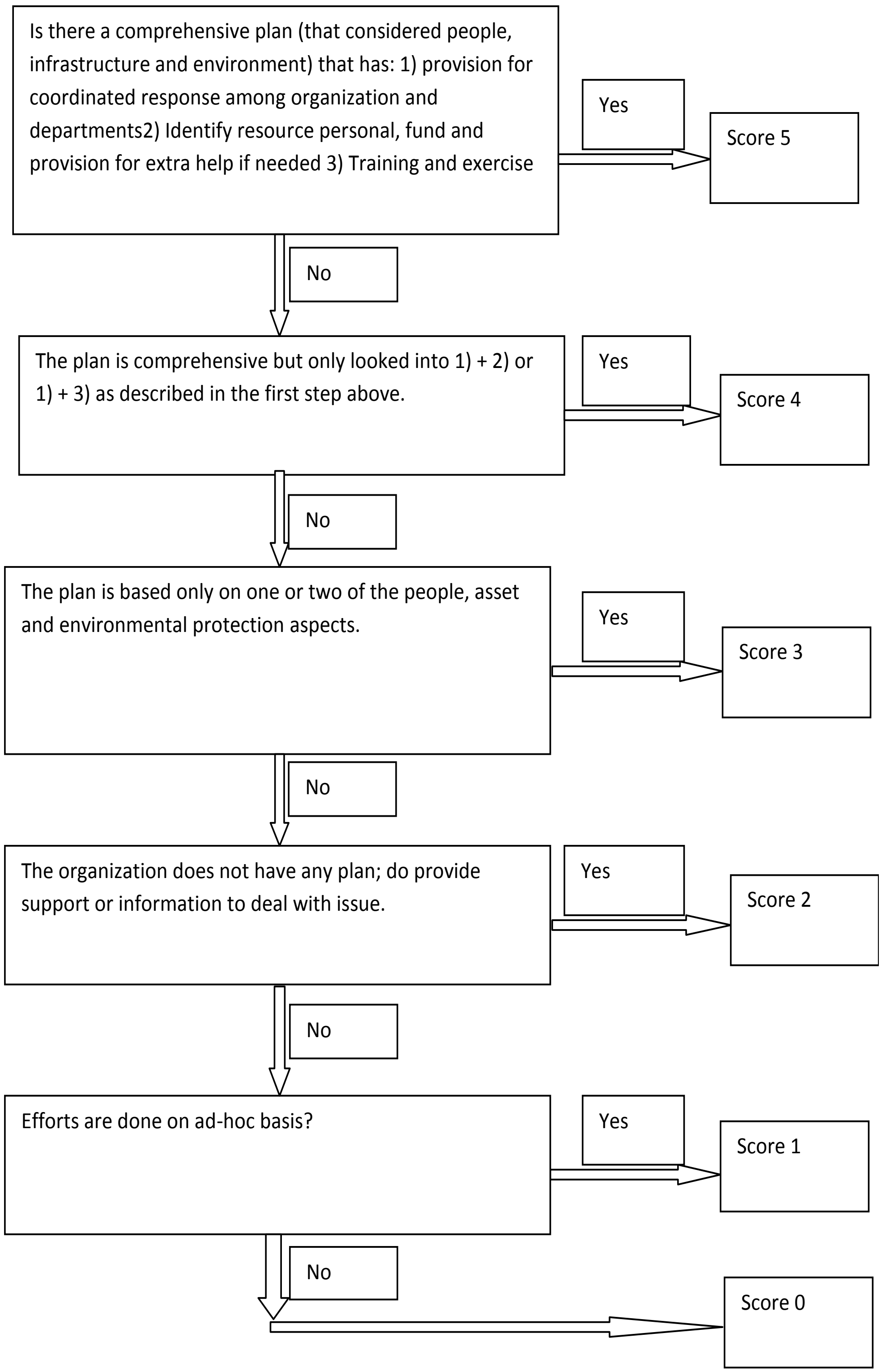


Figure 7-13: Decision Guide for Emergency Management Plan Indicator

Having an updated data collection and information management system indicator:

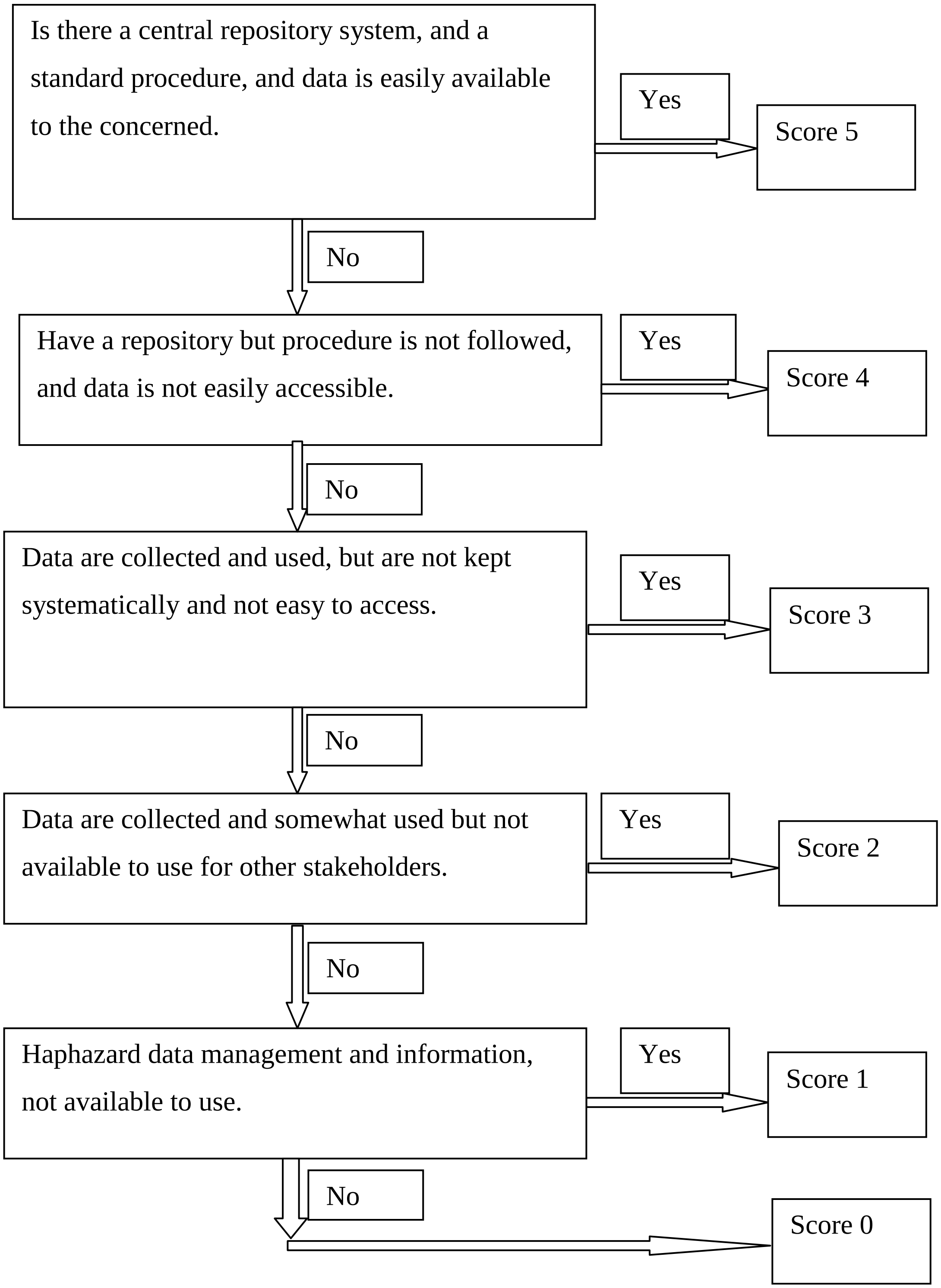


Figure 7-14: Decision Guide for Data and Information Management Indicator

Having transparent information sharing policy indicator:

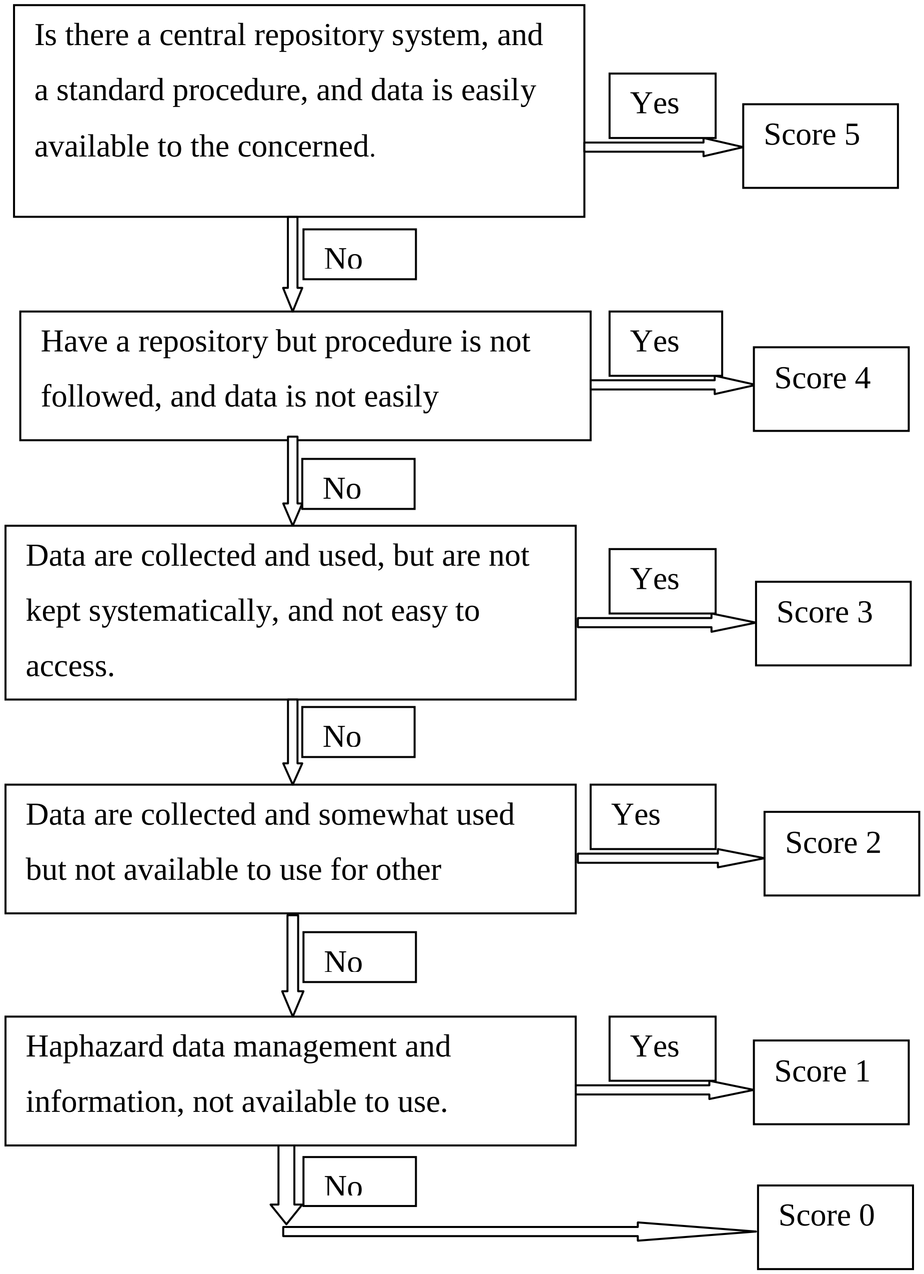


Figure 7-15: Having Transparent Information Sharing Policy Indicator

Actions undertaken to achieve sustainability objectives are the main focus:

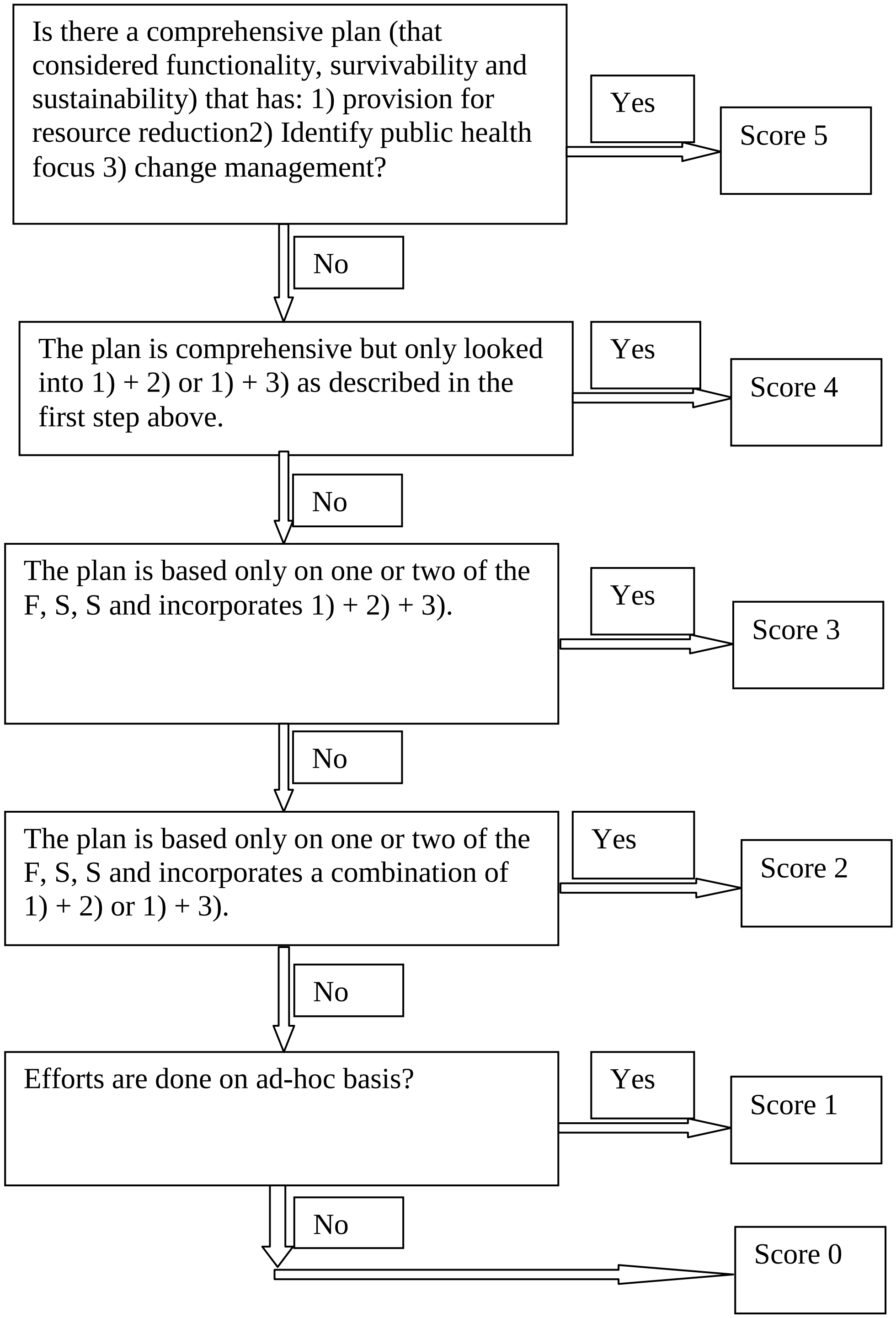


Figure 7-16: Action Undertaken to Achieving Sustainability Objectives Indicator

7.1.5 Assigning Weights

Two sets of weightings are being used in this analysis:

1) Weighting based on the interpretation of the expert opinion.
2) Weightings interpreted from the literature on application of MCA.

Consumers, in this case, are not involved in assigning weight as they normally may be because: 1) the main focus of this study is not to explore the various weighting methods; and 2) the assessment is not aimed at choosing a preferred solution from different alternative solutions, but to assess the system specific performance on multiple criteria.

This is not to suggest that involving consumers in decision-making is not important - it is very important and they should be involved in the planning phase of any project. This was also reflected during the survey when in response to question 13B in which 54% of the respondents replied that consumers are/should be involved in the conceptualization phase of any program or project related to water sector. Involving consumers during EIA is mandatory in Canada and many parts of the world. Moreover, after undertaking the sustainability assessment, if it is deemed that a system is underperforming and needs improvement, consumers should be then involved to identify solutions. The consumer's involvement in decision making is beyond the scope of this study, but their importance must be noted.

7.1.6 Weighting Interpreted from the Professionals Working in the Field

In order to get a direct opinion from the experts, the *Infrastructure Decision Making Survey* participants were asked a follow up question to assign weighting values for R, P and C. The initial survey was conducted among the managers, engineers, and technical staffs working in the water wastewater and stormwater sector in various municipalities across Canada. The follow up question is given below and responses are listed in Table 7-2.

Q. How much weight (out of 100%) would you assign to the following three criteria for stormwater infrastructure management.

a) Change management (change in policy, program, design etc. to reduce future risks)

b) Public health

c) Resource

Table 7-2: Response from Professionals on Assigning Weights

Respondent	Weight on R	Weight on P	Weight on C
1	30	40	30
2	10	80	10
3	50	25	25
4	75	10	15
5	25	0	75
6	50	20	30
7	30	60	10
8	30	10	60
Average	37.5	30.62	31.7

Out of 8 respondents, three (37.5%) prioritised public health above resource and change management, two (25%) weighted change management the most while three (37.5%) respondents weighted resource the most. On average, resource weighted the highest, and change management slightly outweighed public health. This analysis confirms that:
Public health and change management are important criteria that should be considered in sustainability assessment.
The weight of the public health and change management are more or less equal, and are comparable with the resource criteria.

The assignment of weights may also change over time and so it is important to emphasize the *process based* approach in sustainability assessment to accommodate for dynamic changes.

7.1.7 Weighting interpreted from literature

The weights were also derived using Martin et al. (2007) as a reference. The weighting was assumed to be assigned by three groups of stakeholders: 1) engineer at local government agency; 2) regional planning body; and 3) resident group under “strategic” and “non strategic criteria”. Three pre-defined objectives were assumed: a) to minimize the cost (for local government); b) to improve amenity and contribution to sustainable urban development (for regional planning body); and c) to prevent against adverse environmental impacts (for resident group). The strategic criteria for one stakeholder was non-strategic for the other groups of stakeholders. A 1% weight for each of the non-strategic criteria was assigned, and remaining weight was equally distributed among the strategic criteria. This strategy was taken to highlight the differences between various criteria, and to remove any bias. As a result, for example, the maintenance cost criteria received 11.22%, 1%, and 1% weighting by the three stakeholders respectively: engineer at local government agency, regional planning body, and resident group. Indirectly, this method does not allows stakeholders to weight the criteria according to their preference, rather imposes a pre-assigned cap on the weighting. This is justified to some extent because different stakeholders have different preferences, and the weighting that they assign may be biased if the stakeholders feel obligated to assign a percentage value to every criterion. Rearranging the average weight scored by each criterion in the Martin et al. (2007) paper according to R, P, and C, the following weightings are obtained as shown in Table 7-3, and average weights for R, P and C are given below the table.

Table 7-3: Weightings Interpreted from Martin et al. 2007

Broad category identified in this study	Criteria	Interpreted average weight (%)
Change management	Contribution to sustainable development	16.33
	Amenity level	16.33
	Probability of system failure	1
Resource	Maintenance cost	11.22
	Capital cost	11.22
	O&M need and frequency	11.22
Public health	Pollution retention	16.33
	Impact on ground water quality	16.33

P=32.66%, R=34.66%, C=33.66%,

Qin et al. (2008) provide another basis for deriving weights. The resulting weights are shown in Table 7-4.

Table 7-4: Weightings Interpreted from Qin et al. 2000

Broad category identified in this study	Criteria	Interpreted average weight (out of 1)
Change management	Improvement in efficiency and performance of adaptation action	0.29
	Flexibility	0.146
Resource	Cost- economic feasibility	0.239
	Legal, technical, institutional, human, social and political resources should exist to implement the action	0.197
Public health (no specific criteria that can fit under this category)	Responsi6ty – adaptation response should be consistent with community's social, economic and environmental goals.	0.11

P =0.11, R = 0.436, C= 0.444.

Change management outweighed the resource criteria while public health received little attention.

Urrutiaguer et al. (2010) describe a multi criteria based innovative approach to select water sensitive urban design projects to implement in accordance with the government of 6ctoria, Australias's plan to tackle urban stormwater pollution. The assessment had two parts: 1) preliminary review based on site constraints and funding constrains, and 2) detailed multi criteria assessment based on environmental, engagement (capacity building among local government professionals), and financial criteria each weighting 0.4, 0.3 and 0.3 respectively. The indicators for these criteria were unconventional in the sense that they were meant to satisfy a specific project selection objective. Public heath (environmental) outweighed resource (financial) and change management (capacity building) goals.

In the environmentally preferable purchasing policy for building products in the US, Gloria et al. (2007) analysed the newly added LCA based criteria in the BEES (building for environmental and economic sustainability) software developed by the National Institute of Standard and Technology (NIST) and the Harvard university. The weightings assigned for various criteria are summarised in column 2 and 3 in Table 7-5, and are grouped under main category identified as resource, public health and change management in column 1.

Table 7-5: Weightings Interpreted from Gloria et al. 2007

Broad category identified in this study	Criteria	Weight (%)
Change management	Anthropogenic contribution to global warming	29
	Ozone depletion	2
Resource	Fossil fuel depletion	10
	Land use	6
	Water intake/ use	
Public health	Criteria air pollutants	9
	Human health carcinogenic	
	Human health non carcinogenic	5
	Ecological toxicity	7
	Eutrophication of water bodies	6
	Smog formation	4
	Indoor air quality	3
	acidification	3

In aggregation, P = 45%, C = 31%, and R = 24%.

In research by Burton and Hubacek (2007), public health is emphasized over change management followed by resource. Weights assigned for various criteria are summarised in column 2 and 3 in Table 7-6, and are grouped under main category identified as resource, public health and change management in column 1.

Table 7-6: Weightings Interpreted from Burton and Hubacek 2007

Broad category identified in this study	Criteria	Weight (%)
Change management	Carbon emissions	15
	Social (not clearly defined in the paper)	13
	Life span	13
Resource	Capital cost	13
	O&M cost	12
	Generation capacity	15
Public health	Noise	9
	Natural Environment	10

Resource = 40%, Public health = 19%, Change management = 41%.

In the previous case, resource and change management are comparable, but public health is comparatively less important.

Based on the above five papers, average weightings for R, P and C are summarised in Table 7-7.

Table 7-7: Weights Derived from Literature

Paper Reviewed	Weight on R (%)	Weight on P (%)	Weight on C (%)
Martin et al. 2007	34.66	32.66	33.66
Qin et al. 200	43.6	11	44.4
Urrutiaguer et al. 2010	40	30	30
Gloria et al. 2007	24	45	31
Burton and Hubacek 2007	40	19	41
Average	36.45	27.69	36.01

The weightings for the three criteria are very close to each other.

7.1.8 Normalization of Weight

The weights are normalized to the minimum weight of P in case of both expert opinion and literature to obtain the normalized values of weights for R P and C as shown in Table 7-8.

Table 7-8: Normalized Weight for R, P and C

Criteria	Normalized Weight (%) – from profesionals' opinion	Normalized Weight (%) – from literature
R	1.224	1.316
P	1	1
C	1.041	1.300

This is an absolute normalization method widely used in environmental decision-making in which weights are normalized with respect to a given minimum or maximum value (Steele et al. 2008).

7.1.9 Combining the Weights and Scores to Obtain Overall Value.

The weights and scores were combined based on slight modification in the weighted sum model (Tryanthaphylou 2000). Generally in the weighted sum model, the sum of the product of indicator scores and indicator weight gives the criteria score, and sum of all the criteria scores gives the final score. This method is slightly modified to reflect the comparative status of the three criteria in this case: P, R and C. In sustainability assessment, because we are not comparing alternatives per se, a single value index or letter grade is of little value: what does a single value or a letter grade (A, B) for example means in terms of infrastructure sustainability? The main goal here is to identify the area of improvement; so the evaluation is done for individual P, R and C criteria, to show the sustainability status of the system for each criterion within the FSS instead of coming up with a single value or letter grade. The details are given in Table 7-9.

Table 7-9: Score Calculation

Criteria weight for each indicator = criteria weight / # of indicators. Final indicator score = score * criteria weight for each indicator. Criteria score (R, P and C each) = average of the final indicators score (in R, P and C each criteria). Score for functionality = average score for criteria R, P and C under functionality. Score for survivability = average score for criteria R, P and C under survivability. Score for sustainability = average score for criteria R, P and C under sustainability.

7.2 Reporting the Results.

The results are characterized by three levels of performance as established earlier: functionality, survivability and sustainability. If all the RPC criteria scores more than zero within each domain, then the system can be considered progressing within functionality, survivability, and sustainability respectively. Three levels of trends are proposed as shown in Figure 7-17: declining (level 1), steady (level 2) and improving (level 3). A further sub level is proposed based on the combination of performances.

The last aspect or domain – sustainability – is the one that determines if the infrastructure system is becoming sustainable or conversely, less sustainable. At the same time, this progress (or decline) can also be seen in the other two domains: functionality and survivability. As argued previously, it stands to reason that progress in these other two are related to sustainability and therefore, their progression will likely correlated to progression in sustainability, although not necessarily so depending on the circumstances. However, a system that is declining or at best stagnant in its ability to serve user function or survive disaster scenarios is unlikely to achieve any sort of sustainability.

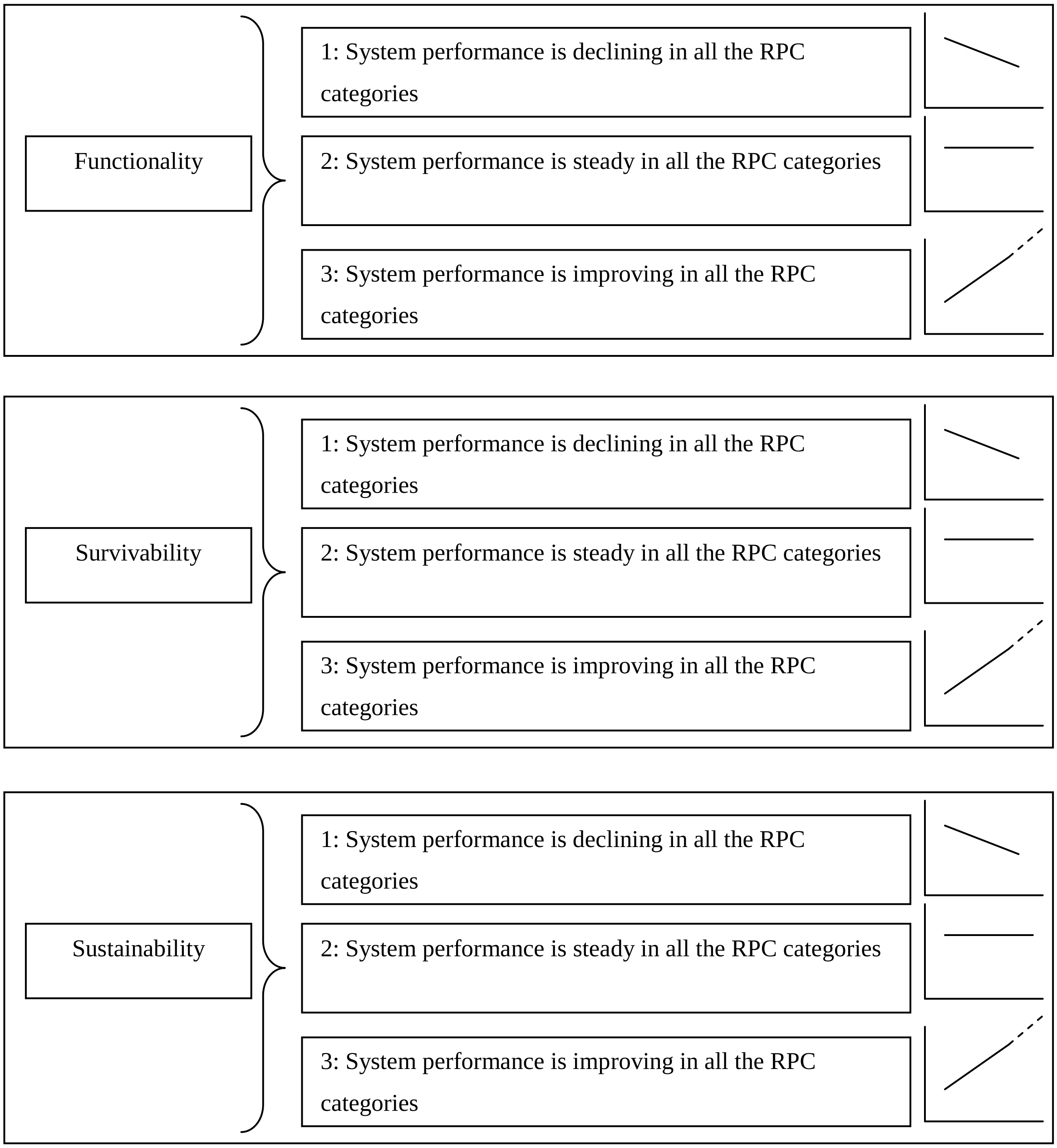


Figure 7-17: Performance Levels for FSS

It is likely that the system might be able to achieve “steady” or “improving” performance in only one or two of the R, P and C categories. In such circumstances further sub level “a” and “b” can be assigned as shown in Table 7-10. The following hierarchy is suggested in terms of preference: 2a> 2b>2, and 1a>1.

Table 7-10: Sub Levels of Performance for FSS

Description	Performance Level
Any two of the R, P and C are "improving", and the other one is "steady"	Level 2a
Any two of the R, P and C are "improving", and the other one is "declining" Only one of the R, P and C are "improving", and other two are "steady"	Level 2b
Any two of performance are "steady" and the other one is "declining" Only one of the R, P and C are "steady", and the other two are "declining"	Level 1a

For indicators for which an evaluation cannot be done because of lack of data, monitoring is recommended, and data be available to inform the decision making. Monitoring should be started for indicators which were not previously monitored. For this study the details of monitoring plans, temporal and spatial range, and functional unit are beyond the scope.

It should be noted that there may be indicators which are applicable but could not be assessed because of lack of data and information, and so will score zero. In a conventional assessment, such indicators would usually be dropped from assessment but that is not preferable in this framework. Not having information on any aspect of a system is in some respects worse than knowing that the system is performing poorly in a particular aspect. Not knowing anything about an indicator may jeopardize the sustainability of system: we are unable to know how bad or critical the system is performing on that aspect, and there is no means to flag that information should be gathered.

7.3 Summary

The functionality – survivability – sustainability model provided the structure for the sustainability assessment framework, which encompasses the resource, public health and change management aspect. The infrastructure decision making survey informed the framework development. Various indicators were developed to provide information on the state of the system, and a modified multi-criteria assessment is proposed for the assessment. The next objective was to demonstrate how the framework can be applied via an illustrative case study.

8. CASE STUDY: APPLICATION OF THE FRAMEWORK

This chapter describes a case study that demonstrates making assumptions, applying relevant indicators, undertaking the analysis, and assigning scores as proposed in the developed framework. Area “X” in city “A” was considered as the case study to implement the FSS framework. Although this is an illustrative case study, it is based on actual data to the greatest extent possible.

8.1 Background

Area X covers about 800 ha, 6500 properties and had a population of about 40,000 in 2006. The land use is mainly residential. The land slope is mild, 1% to 3% grade, with steeper slope towards a valley. Some stretches of streets sag, causing ponding or inflow in the storm sewer systems during heavy rain event. About 80% of the area drains in the west and 20% of the area drains in the east through the following combination of separate storm drainage system: 59 km pipe with 20 catch basins and outfalls in the west; and 17 km of pipe with 10 catch basins and outfalls in the east.

The stormwater sewer systems have been designed for 1 in 2 to 1 in 5 years storm events according to the prevailing regulations from the 1960s. Area X is prone to urban flooding. Recently, a flooding improvement project is being implemented in the area X after a flood event occurred in 2005 which damaged major infrastructure such as bridges, culverts, sewers, and flooded many households in city A. The city received more than 4200 basement flooding complaints. $34 million was spent in immediate repair, significant clean up and staffs over time work hours were required, and an estimated $400 million was paid in insurance coverage to the residents. The environmental cleanup cost after the spills from wastewater treatment plant was not known.

8.2 Assumptions

1) In order to effectively demonstrate the application of the framework into sustainability assessment of Area X stormwater system, the following assumptions were made:

Urban flooding occurs from either excessive storm water or sanitary flow. It was assumed that the stormwater flow is the cause of flooding. In an area with a separate drainage system like area X, surcharge in storm sewers may not directly cause basement flooding unless the house floor drains were connected with the storm sewers. If foundation drains (weeping tiles) are connected with storm sewers, the storm sewer surcharge may lead to high subsurface water level around the house, inducing seepage into the house basement through foundation wall and/or floor cracks. It was assumed that the house floor drains and the foundation drains were connected to the storm sewers.

2) The rate of population growth for the study area was assumed to be proportional to the population growth of the city.
3) It was assumed that the number and types of commercial and institutional customer did not change significantly indicating a stable revenue base for the city.
4) The area X storm sewer system was simulated for different storm events prior to implementing the basement flooding remediation project. The case study primarily built on the findings of the sophisticated hydraulic and hydrological modelling results. However for illustration purposes, the rational method is used for calculating the peak flow. Generally, the rational method is applied for calculating peak flow when designing a drainage system in a small watershed where complex hydrological conditions such as storage, impounding, watershed overflow do not exist (Chow et al. 1989). Although the study area X may be large, the characteristics of the geographical area were not complex. The initial design was based on the rational method, and because the intent of this analysis is not to design a sewer system or develop a water budget, this approximation is valid for case study purposes (Bolisetti 2011, personal communication). The following equation is used in rational method:

$Q_{peak} = 0.00278\ C * I * A$ ---------------------Equation I

Where, Q_{peak} = Peak flow in m^3/sec

C = Runoff coefficient (depends on land use)

I= Intensity of rainfall mm/hr

A= Area of the catchment in ha

The peak flow rate for rainfall event that had occurred in area X was not available; however, flow rate during major flood event between 1986 to 2005 in one of the four adjacent areas with similar land use characteristics, and in which basement flooding remediation project is implemented, were available. Rainfall event was also monitored during the October - November 2006 and April - May 2007 periods, and no flooding occurred during these periods. These data were used in the analysis assuming that area X also received rainfall of same intensity and for same duration during these high storm events as the adjacent area. It was assumed that the change in impervious area is directly proportional to the change in the number of dwellings, and the growth of dwellings in the area X is proportional to the general growth in dwellings in the city A.

6) Considering that the infrastructure was built in the 1960s to the 1970s, the average age of the storm sewer in area X is assumed to be 40 to 50 years.
7) There is no information available on whether and when the sewers were replaced in the past, therefore it was assumed that all the sewers are aging at the same rate in area X.
8) The basement flooding remediation project is implemented in four areas including area X. It was assumed that resources and funding are equally distributed for each area.
9) For vector borne and waterborne diseases, since no particular reported numbers were available for the study area, the citywide information was considered representative of this area. The population of the city was estimated based on the five year census data in order to find out the cases of disease per 100, 000 population.
10) The flow units are m^3/hr, and units of concentration of water quality indicators are mg/L, unless specified otherwise.
11) In many cases, specific data for an indicator category on area X were not available; the analysis was undertaken using available city wide information.

The sustainability assessment framework was applied to analyze the performance of the stormwater system in area X. The framework has a three-tier approach involving functionality, survivability, and sustainability. For each of the tiers, different indicators were identified. The area X stormwater system was analysed for each of these indicators and assessed using the multi criteria assessment procedure developed previously.

8.3 Framework application

The functionality – survivability – sustainability framework was applied to assess the sustainability of area X stormwater infrastructure system. The indicators were selected based on their relevance, criticality, and the likelihood of capturing long-term issues. However, the availability of data played a critical role in selecting the indicators. Table 8-1 lists the indicators applied for area X stormwater system, and details are given in following paragraphs.

Table 8-1: Indicators Applied in Area X

Indicators	**Unit** (“#” denotes number of)
Functionality	
Monitoring of the demographic pattern	Ordinal scale
Maximum peak flow generated from the catchment	m^3/ hr
Change in impervious area	%/ year
Storm sewer replacement	km / km of pipeline /year
Type of pricing structure Savings on future cost of infrastructure project Savings on future O& M cost	Ordinal scale Ordinal scale Ordinal scale
O&M Activities with respect to service level # of reports of flooding by property owners Number of stormwater related complaints	# of activities/service level # /year #/ 100, 000 population/year
Cases of vector borne disease reported Cases of gastrointestinal illness reported	#/ 1000 population/year #/ 1000 population/event
Stormwater replacing the demand of treated water	ML/ML of total water demand
Involvement in research and innovation Continuous professional development for engineers and staff	Ordinal scale hrs/ year
Survivability	
Assessment of potential damage Assessment of reconstruction need Recovery plan	Ordinal scale Ordinal scale Ordinal scale

Well planned source, conveyance and end of pipe control strategy for stormwater management (adaptation), and alleviation of the root cause (mitigation) of the problem #of property opting for source control (or other forms of adaptation)/ total number of property served	Ordinal #/# (ratio)
Well developed emergency response plan	Ordinal scale
Death or injury caused by damage in infrastructure systems due to flood events Death or illness caused by flooding event	#/ incident #/ incident
Sustainability	
Having a water balance model for the catchment Energy used to convey stormwater	Yes/No KWh/ ML/year
E-coli exceedence in receiving water sample Toxicity exceedence in receiving water sample	% of total sample tested/ year % of total sample tested/ year
Actions undertaken to achieve sustainability objectives are the main focus. Having an updated data collection and information management system Transparent information and data sharing policy	Ordinal scale Ordinal scale Ordinal scale

8.3.1 Functionality

Monitoring demographic pattern: The demographic pattern is important to establish projections for better managing stormwater in the future. The customer demographic of area X was not available however the land use data indicated that 69% of the area was covered by residential properties. The population in area X, mainly residential, was estimated to be about 40, 000 in 2006 – approximately doubled since 1980. There is no information on how and if the industrial, commercial and institutional (ICI) customers changed since 1970s. Therefore, it is assumed that in the initial stage of building the infrastructure, population demographic were considered and monitored but a trend was not established since then. A score of 2 is assigned.

Peak flow: Peak flow is an important indicator of change in the storm runoff generated from the drainage area for a given storm of given duration and return period. Peak flow was calculated based on the measured rainfall intensity during the high rainfall event from 1986 to 2007 and using an estimated runoff coefficient 0.4, as shown in Figure 8-1. The monitoring during October – November 2006, and in May 2007 was done prior to implementing the basement flooding improvement project.

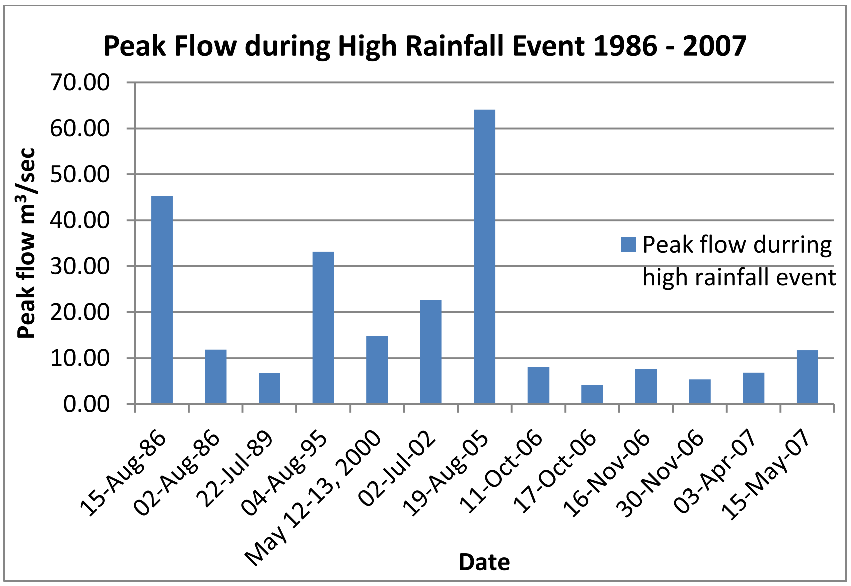


Figure 8-1: Peak Flow during High Rainfall Event between 1986 - 2007

A maximum peak flow of 64.0 m^3/sec was observed during the flood event of 15 August, 2005. All the storm events other than 2006 to 2007 period resulted in flooding, indicating that the peak flows during these events might be higher than the design peak flow. The system design was based on return period of 1 in 2 years, rainfall intensity of 50 to 123 mm/hr and runoff coefficient of 0.35 to 0.5. The observed average rainfall intensity during the flooding events was within the design intensity, but the return period was higher as shown in Table 8-2.

Table 8-2: Rainfall Intensity during the Flooding Event

Date	Rainfall mm	Duration hr	Return Period 1/yrs	Average Intensity mm/hr
August 15, 1986	47	1	10	47
August 26, 1986	92	7.5	2 to 5	12.27
July 22, 1989	14	0.5	< 2	7
August 4, 1995	6.6	2	25-50	34.4
May 12-13, 2000	70.4	4.5	5-10	15.4
July 2, 2002	47	2	10-25	23.5
August 19, 2005	99	1.5	>100	66.53

A storm event of the same intensity occurring at a different return period for different duration and frequency could result in different flow conditions because the soil infiltration and storage capacity might be different during these separate events. This would result in a different peak flow. Soil characteristics are still poorly understood concepts in stormwater management (Chow 1989, Marsalek 2009), but can have significant impacts. Another factor is that the reported rainfall intensity might not have been measured for the duration of rainfall equal to the time of concentration, which is the underlying assumption of the rational method. Instead, it was derived from the observed total duration of the storm. This could underestimate the peak flow (Bolisetti 2011, personal communication). The design runoff coefficient also varied widely, it is likely that the sewers that were designed based on the lower runoff coefficient values were the one being flooded. During the flood events only some portion of the network were flooded.

Because the exact estimation of peak flow was not the objective here, it was not analysed further. Based on the analysis above, a score of 2 was assigned because the network is theoretically still capable of handling the original design storm.

Change in impervious area: The change in impervious area for area X was estimated.

The land use data for year 2001 indicated that 42% of the area was occupied by residential property. Industrial, commercial and institutional (ICI) properties and roads occupied 39% of the area, parks and conservation area covered 11%, and % area were termed as other, which could include brownfields. Assuming that the ICI, park area and other area have not changed recently, the change in impervious area depended then on changes in the residential area. The population in 2006 was about 39,900 within a total 6500 properties in 2006. Assuming that all the growth was in residential area, and about 25% of the residential properties constitute impervious area, a total annual increase in impervious area was 0.1%. It should be noted that in order to maintain the water balance, the impervious area should be minimized so that infiltration can increase. A score of 4 was assigned.

Storm sewer replacement: There are total 76 km of storm sewers in area X ranging from 150 mm to 5000 mm in diameter. According to Statistics Canada (Gagnon et al. 2008), the average useful age of sewer infrastructure is 40 years. According to city A's annual report 2005, 77% of the city's stormwater infrastructure are less than 50 years old, 15% are between 50 to 80 years old, 5% are between 80 to 100 years of age and 3% are above 100 years old. Because of the lack of detailed breakdown of the age of the sewers in area X, it is assumed that majority of the 77% sewers that are less than 50 years old are within its useful life. The city has scheduled replacement of about 1.25 km sewer as part of the flood improvement project in area X and plans to have more in future. The replacement work was planned only for cases when the useful life of infrastructure cannot be upgraded by twinning or inline storage. Since the majority of the infrastructure is within useful life, some being extended and some being replaced, a score of 4 is assigned.

Type of pricing structure: The major source of operating and capital investment for City A is through water and sewage rates established each year by city council. Other sources of funding include the revenue from the sale of water to adjacent municipalities, industrial waste surcharges, private water agreements, service charges, and sundry revenue such as late fees, interest charges and investment income. For the 2011-2020 capital budget plan, the following sources of funding were identified:

1) Reserve fund from previous years.
2) Infrastructure Stimulus Fund (ISF).
3) User fee for construction of new water mains and sewer.
4) Development charges.

Due to conservation efforts, water demand has been reduced and revenue is likely to decrease. The water authority has been implementing improved metering program to 66,000 former flat rate customers, replacing old meters with automated meter reading systems, and planning to recover an estimated $2,000 million per year loss in revenue due to old and inaccurate large volume water meters. Detail information on metering in area X was not available.

After the flooding in 2005, the flood remediation project was implemented. The project cost did not impact the municipal property tax levy. A portion of the cost was funded by the federal government's infrastructure stimulus fund (ISF). Federal and provincial funding had been used to support the project. The city had taken a new approach to funding a project on the basis of benefiting household. Those projects costing $25000 per household will be implemented by 2015, and those requiring $32000 per household will be implemented by 2020. Clearly a prioritization was made because of limited financial resources. Therefore a score of 2 was assigned.

Cost savings on infrastructure project: The future value of savings on infrastructure project is considered. How the current costs of remediation after 2005 flooding will avoid potential future costs is considered as an example to show that the project is successful in saving future costs that would potentially occur if the necessary work had not been done now.

The estimated cost of the basement flooding remediation project in area X was calculated as $68 million assuming that the $272 million total fund was distributed evenly in four areas, including area X. The actual cost of the project was about $25,000 per property that benefitted. For an estimated 6400 properties, the cost would be about $162 million. This is about 2.4 times more than the original estimated cost. This difference closely matches the information obtained during conversations with knowledgeable persons who indicated that the actual cost is 90% to 250% more than the estimated cost under various categories. The actual cost was higher than the estimated cost; therefore, no immediate savings were realized in this project.

However, the project is set up to avoid the cleanup, repair and maintenance costs, insurance payment cost, as well as the environmental cleanup of nearby streams and water bodies from future contamination and spills due to potential flooding in future. In the August 2005 storm event, $34 million was spent in immediate repair, cleanup and staff over time work hours, whereas an estimated $400 million was paid in insurance coverage to the residents. The cleanup cost of the environmental pollution due to the raw sewage spill is not available. These impacts and associate costs would highly occur in a future flooding situation if the project had not been implemented in the area. Considering the $436 million of present value of savings in 2005, which includes the insurance payment, and a time of compounding equal to the useful life of infrastructure as next 40 years, and an interest rate of 1.5%, the future value of the savings from flood related impacts would be about $791 million. Future savings on infrastructure project are therefore realized. Hence a score of 5 was assigned.

Infrastructure financing and value assessment is beyond the scope of this research but addressing funding deficit issues is recommended over the long term.

Savings on Operations and Maintenance (O&M) cost for conveying stormwater/ year: The city estimated that for a storm water utility to cover the cost of stormwater management would require over a billion dollars in capital expenses and $233 million in operating expenses for the next 25 years. Unlike capital costs, it is hard to accurately estimate the O&M cost because it depends on daily needs and situations such as breaks and leaks. An important factor is how much was saved in the O&M category. Based on the information available from 2002 to 2008, the future value of savings on O&M costs for the storm sewer infrastructure varied from about negative \$53.00/km/year (loss) in 2003 to about \$62.00/km/year in 2006, at a 1.5% interest rate for 40 years period, as shown in Figure 8-2.

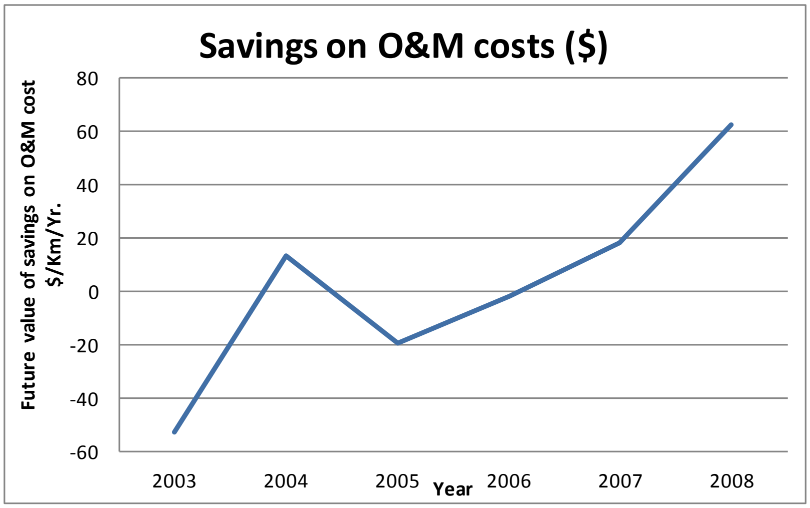


Figure 8-2: Cost Savings on O&M

The reason for a high cost saving per kilometer in 2006 is the massive expenditure on storm sewer replacement after the storm event of year 2005. In 2006, savings on the O&M realized because most of the infrastructure work was done under the separate basement flooding remediation project rather than regular O&M. The increased cost of capital infrastructure project decreased the O&M cost: this represents the interconnectedness of these two costs. Therefore having a cost saving indicator is important rather than having solely cost as an indicator. A score of 5 was assigned.

Operation and maintenance activities with respect to service: The operation and maintenance activities were assessed based on the service level of the infrastructure. Hazardous spill response, water course inspection, and catch basin clean up are considered operation and maintenance (O&M) activities. Storm sewer length, stormwater connections, stormwater ponds, and open channel (km) are considered service level indicators.

In city A although the service level remains same for the period of 2002 to 2008, the O&M activities have been increased during the same period as shown in the graphs below, except for a hazardous spill response as shown in Figure 8-3 and Figure 8-4.

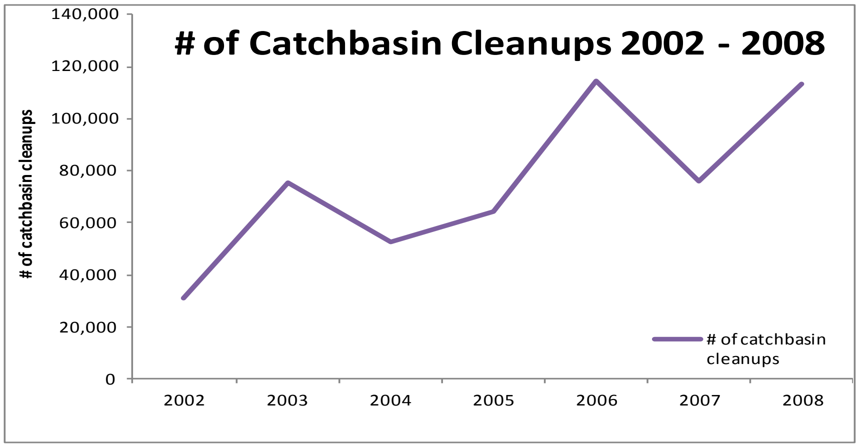


Figure 8-3: Catch basin Cleanups

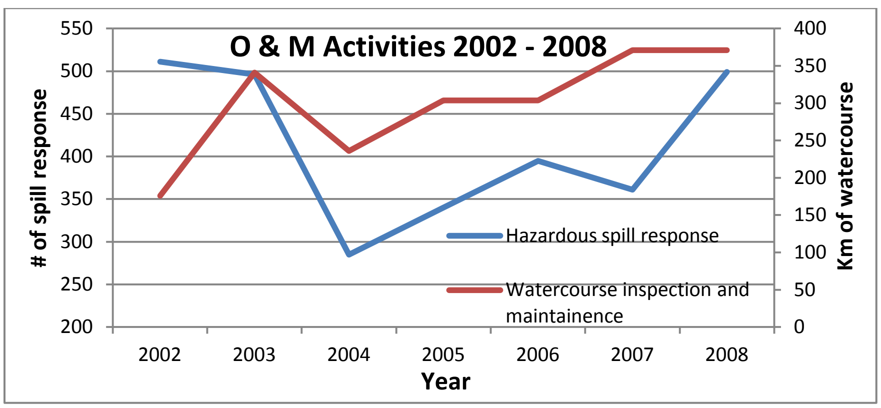


Figure 8-4: O&M Activities

In this case the O&M activities in area X are assumed to follow the overall city-wide trend. A score of 2 was assigned.

There is not enough information to suggest whether the increased inspection and maintenance of watercourse is a result of the water quality issues of the incoming flow into the sewershed. Similarly it is not known what exactly led to the increased catch basin clean up. In such cases, long term monitoring is emphasized.

Number of properties reporting flooding: Flooding was not reported annually**.** In 2006 - 07 monitoring period, no flooding event occurred. The number of reported flooding event had been increasing since 1996 to 2005 as shown in Table 8-3.

Table 8-3: Reported Flooding during High Rainfall Event 1996-2005

Year	Number of properties reporting flooding
1996	44
1996	11
1999	4
1995	9
2000	31
2002	39
2005	21

However, the percentage of properties reporting flooding had been decreased ranging from about 0.1% to 3.3% with an average decline of 0.16% as shown in Figure 8-5. A score of 1 is assigned.

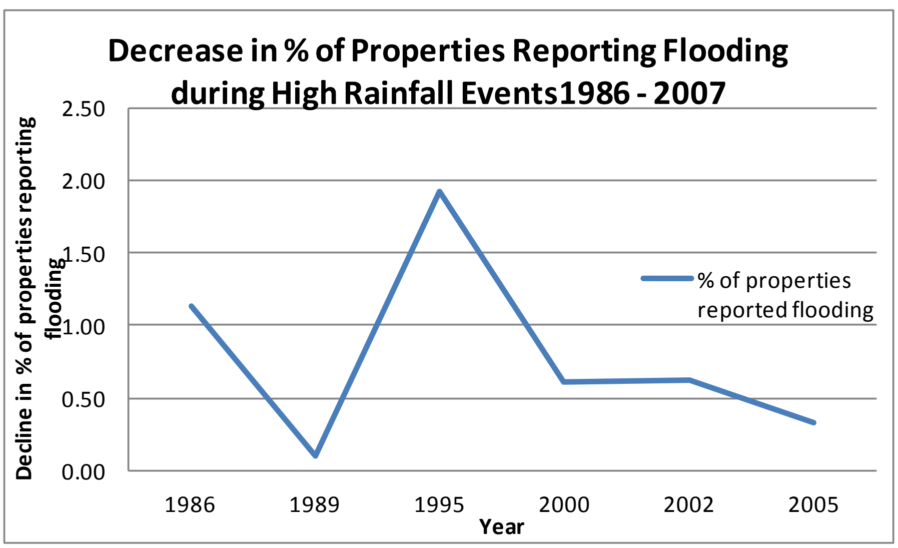


Figure 8-5 Percentage Decline in Properties Reporting Flooding

Number of stormwater related complaints/ 1000 population / year: There was no specific information on complaints related to stormwater service in area X or city A as a whole; however, there were 6,098 reports of blocked drains or basement flooding complaints for 2005. Some of the complaints can be attributed to the massive flood event that might have caused some damage to the system which might not have been identified earlier. Alternatively, the city may have been working on it, and the complaints might be a follow up of the previous report. However, such a high number of complaints should be investigated. Other service related complaints should also be accounted for such as inflow and infiltration (I&I), unauthorised connections, and so on. Although the indicator is applicable to area X, the limited information available meant that this parameter could not be assessed. A score of zero was assigned.

Cases of vector borne disease reported/ 100,000 population/ year: Cases of West Nile virus (WNV) in humans, the primary carrier of which is a mosquito, have been reported in city A. Cases of WNV are considered an indicator of vector borne disease by Public Health Ontario (2011), and city A does monitor this indicator. The area X specific values are not monitored therefore the overall city data are considered. 163 cases were reported in 2002 at a rate of 6.2 per 100,000 population. After the municipality's aggressive effort to curb the spread of WNV, the number dropped down to zero in 200, but in 2011 total 22 cases were reported as shown in Figure 8-6 below. A long term monitoring is important in this regard to establish direct cause and effect relationship between infrastructure and public health. A score of 5 is assigned because the average number of cases is 1.14. If factored to the population of area X, this value will be close to zero.

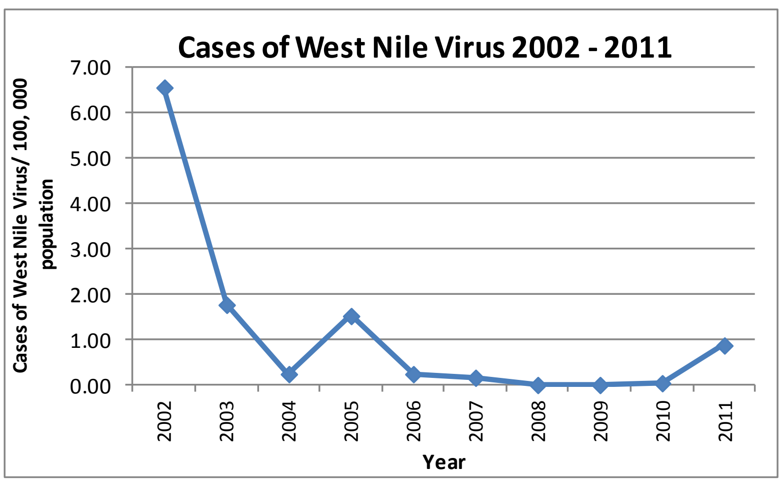


Figure 8-6: Vector Borne Disease 2002-2011

Cases of waterborne illness reported/ 100, 000 population / year: This indicator was also assessed based on city-wide information. As shown in Figure 8-7, cryptosporidiosis is on rise and in 2006, after the major flooding event, this population was at its highest. While the parasite of cryptosporedisis can be spread in several different ways, water (drinking water and recreational water) is the most common method of transmission (CDC 2011).

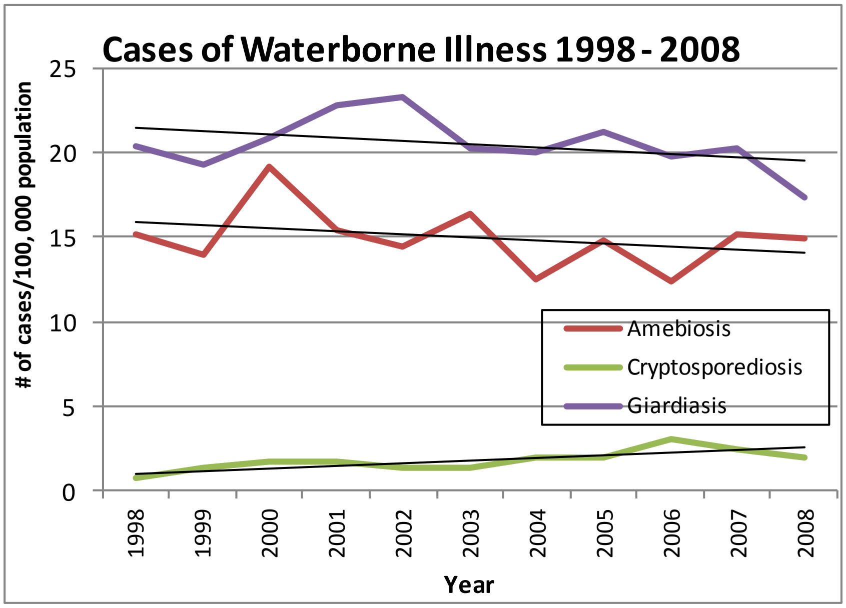


Figure 8-7: Waterborne Illness 1998-2008

On average the # of cases/ 100, 000/ year was 1.77 for cryptosporidium, 14.49 for ameabiosis, and 20.5 for giardiasis. These are city-wide data, so if factored for area X for which the population is only about 1/152 as large, the average value of cases would be approximately 0.1. Therefore a score of 4 is assigned.

Since the drinking water source and recreational water source could overlap depending on the temporal and spatial distribution, these parameters should be monitored for long-term to confirm the stormwater exposure route.

ML of stormwater replacing the demand of treated water (through demand management): City A had implemented a conservation program such as down spout disconnection and rain barrel installation in area X. However, the number of properties opting for this option is not known. Therefore this indicator cannot be assessed, and a zero score was assigned. The downspout disconnection will be mandatory for city A starting between 2011 to 2016, it is not known if the mandatory disconnection has been implemented in area X yet.

Involvement in research and innovation activity: To support the Wet Weather Flow Master Plan, and to help advance the goals and objectives of the WWFMP through community led stormwater management initiatives, the city initiated the Community Program for Stormwater Management in 2004 to provide funding up to a maximum of $25,000 to non-profit groups and organizations (to a total maximum annual program funding of $250,000). The city has also helped organize conferences, workshops and seminars to create a dialogue between the stakeholders, increase the awareness and find the solution. For example, in 2008 the city organized a conference on managing stormwater ponds to deal with mosquito larvae. The city does not have a research and development department, but has partnered with universities (e.g., for example, on the cost and benefits of green roof) in the past. Most of the time, however, such partnerships were formed on ad-hoc basis rather than driven by a policy. There is no clear policy regarding involvement with external agencies or providing logistic support to external people or agencies. In terms of sharing detailed data and information, despite good intentions, the lack of resources (e.g., manpower) plays a central role that prevents the opportunity for the city to be in forefront of innovative research. A score of 1 was assigned.

8.3.2 Survivability

Assessment of potential damage: The potential for future damage was not assessed, even though the area had a history of flooding for over twenty five years before the disastrous flooding of 2005 occurred. However, the city developed a Wet Weather Flow Management Guideline in 2003, and has revised the Intensity-Duration-Frequency curve on which storm infrastructure design is based. The fact that the revised IDF curves mostly provide the opportunity to design new infrastructure does not necessarily "flood proof" the area for potential flooding and potential damage in future. The potential damage was not assessed prior to implementing the basement flooding program in area X, otherwise the estimated cost would have been realistic and the actual cost of the project would not have gone 90 to 250 percent above the estimated cost. In this sense, the assessment is a post assessment: a score of 1 was assigned.

Assessment of reconstruction need: The reconstruction need of area X was assessed after the flooding event of 2005. The existing overland drainage system and storm sewer system was simulated for a 5 year design period and then for 100 year design period to identify the segment of drainage system that would be surcharged or flooded for 1 in 100 year storm event. The major storm flows are to be maintained no more than 100 mm above the crown of the local roads, and the hydraulic grade line (HGL) in the storm sewers should be maintained at no surcharge level. Based on the simulation results, reconstructing the conveyance system was identified for every street in terms of pipe diameter and length and grouped in 14 clusters. About 11 km of pipeline ranging from 300 mm to 2700 mm diameter was necessary, mostly for twinning, diversion and replacement. Six inline storage tanks of various sizes ranging from 67 m to 360 m in length, and an offsite storage dry pond of area 11,700 square metres are needed. In addition a number of catch basins and inlet diversions are required. A score of 2 was assigned.

Recovery plan: Area X does not specifically have a recovery plan per se in case a disastrous flooding event occurs in future. However, the city adopted a Basement Flooding Subsidy Program and a Flood Damage Grant Program for properties that were flooded by August 19, 2005 rainfall event. The basement flooding subsidy program provides a subsidy to isolate the home from municipal sewer system by back flow valve installation, sum pump, and pipe severance. The program offers up to $500 or 80% of the cost of fixtures whichever is less. For the flood damage grant program, eligible homeowners are grouped in A and B category depending on the damage in their property. Group A homeowners are eligible to receive a grant of up to $ 1100, and group B homeowners are eligible for up to $ 2000 to cover for the relocation costs. Data and information recovery from city's own system in case of a flooding situation is not mentioned, which is a critical issue. The city has developed informative brochures describing "what to do" in case of flooding, which can be considered a recovery plan from a health and safety perspective. A score of 4 was assigned.

Well planned source, conveyance and end of pipe control strategy for stormwater management and to alleviate the root cause of the problem: In area X, the following causes of flooding were determined: high overland flow depth, low lying areas, reverse slope driveways, overloaded storm sewers and high ground water table. Table 8-4 outlines the source and conveyance control measures taken in area X. These measures are detailed out on street level, however the solutions are heavily oriented towards how to manage high intensity storm event.

Table 8-4: Source and Conveyance Control Measures

Source Control	Conveyance control
Downspout disconnection	Increase inlet capacity by increasing catch basins or trench drains
Soak away pit	Inlet control devices
Porous pavement	Increase inline storage by providing online/offline system storage
Inlet control device	Storm relief sewer
Backflow valve	Provide SWM systems
Sump pump for foundation draining	Overland flow diversion and outlet
Lot grading	
Rain barrel	

There are multiple root causes for the flooding; climatic variations are uncertain: a preventative strategy should be used to design and retrofitt infrastructure in future. In this sense the solutions are “conventional” rather than “comprehensive”. Recently, the water quality benefits of reduced runoff to the receiving bodies were identified. The Wet Weather Flow Management Guidelines requires new developments to manage the stormwater onsite. They are now incorporated into the city’s Green Standard released in 2007. The city had a firm handle of financial and other aspects, and consumer relation staff were mobilized in the area to facilitate the recovery process. However, data management and information dissipation to other parties was not managed accordingly.

Changes in land use and increasing infiltration could have been emphasized more. Therefore the system scored 4.

Number of property opting for source control (or other forms of adaptation)/ total number of property served: A subsidy program was implemented citywide for downspout disconnection since 2000, and 15,000 households voluntarily disconnected their downspout by 2000. The downspout disconnection has been mandated since November 2011, and the voluntary program has been terminated so that all the downspouts in area X have to be disconnected by December 3, 2013 except for those who have an exemption permit. The city has also developed a rain barrel subsidy program as a source control measure. However these information were not available for area X, and therefore cannot be analysed further. Although the plan is good, this lack of data indicates that having an action plan is good as long as the data is available on the performance, to be factored in the decision making. A score of zero is assigned because no data was available.

Well developed emergency response plan: The city's emergency management plan identifies infrastructure disruption and severe weather as a hazard, and has grouped severe weather, floods, blizzards, tornadoes, food or human health under the natural event category. The emergency plan has provisions for the earliest possible coordinated response to an emergency, an understanding of the personnel and resources available to the city, and recognition that additional expertise and resources can be called upon if required. The city is required to conduct training program and exercises for staff and other resource persons. The emergency plan does not categorically spell out the response planning in case of flooding however: the public health office links to the US center for disease control and prevention (CDC) website which describes the steps to undertake before and after flooding such as preparing food before flooding, learning about flood recovery, sanitation and hygiene, re-entering flooded house, cleanup of flood water, precautions after flood, mold prevention and water safety after flood. The emergency response plan was considered comprehensive and a score of 5 was given.

Death or injury caused by damage in infrastructure systems: No death or injury has been reported in area X due to flooding or any other infrastructure damage. Therefore the system is scored a 5.

8.3.3 Sustainability

Having a water balance model: Water balance model was not developed for area X to account for inflow, outflow, groundwater discharge, evaporation etc. In new developments, the Stormwater Design Manual (MOE 2006) requires municipality to have a water balance model so that the post development stormwater peak flow from the drainage area can be attenuated to the pre development peak flow. At the time when area X was developed, such a model was not required by the law. However, a water balance for a developed area should be constructed with the help of hydrological modelling to account for all the inputs and outputs of a system. It is highly recommended for area X and other built up areas. This indicator is applicable but could not be assessed further because of lack of data, hence zero score was given.

Energy used to convey stormwater: The stormwater in area X is conveyed by gravity therefore energy is not consumed directly. However there may be cases when stormwater has to be pumped out of basements, parking lots, sagged section of roads and other surfaces after flooding. This indicator is applicable but could not be further assessed because data was not available and zero score was assigned.

E-coli in receiving water body: No specific data was available for the receiving water body, which is a nearby creek for area X. However, a study at the river of which the creek is a tributary, between years 2002 to 2005, revealed that the E-coli count ranged between 10 to 10000 CFU/ 100 ml for the 37 samples tested, resulting in 97 percent non-compliance with the Provincial Water Quality Objectives' (PWQO) recommended value of 2000 counts/L (the geometric mean of at least 5 samples, taken during a period not to exceed 30 days) and the recreational water quality guidelines (2009) of Health Canada's value of 200 – 400 counts/ 100mL for primary contact and 1000 counts/ 100 mL for secondary contact**.** The exceedences are significant, and a zero score was given. It was assumed that the river water quality represents the runoff from area X.

Toxicity level: The heavy metals counts for the river were within the PWQO values. Data for four indicators: lead, copper, mercury and arsenic were found for a different time period from the published reports as shown in Table 8-5.

Table 8-5: Toxicity Level

Toxicity	% of time the samples exceeded the PWQO	Period
Lead	0	January 2002- July 2005
Copper	12	January 2002 – July 2005
Arsenic	5	1990 - 1999
Mercury	0	1991 - 1999

A score of 5, 3, 4 and 5 was assigned for lead copper, arsenic and mercury categories respectively. The cyanobacterial toxicity indicator was not considered before therefore monitoring is recommended. Similarly monitoring for emerging chemicals of concern and new strains of virus are also recommended.

Having data and information management system: Although city divisions have developed routine disclosure plans that identify general records available to the public, and data and information are collected and reported as part of routine discloser in form of annual reports and many other forms; there is no central repository of data and information that can be accessed by stakeholders including researchers to make informed decisions or guide innovation and research. There appears to be a lack of adequate attention to the management. The corporate access and privacy (CAP) unit recommended to divisional managers that they seek advice from the records and information management (RIM) unit and implement the proper information management systems that allow for retrieving records in response to requests. It was also noted during the conversation with related parties that much of the data that are over five years old, and can be destroyed because legally the utilities are not responsible to retain data for a longer period of time (Manzon 2010, personal communication). Choosing to retain data beyond the legal requirement would therefore be a progressive action. On the other hand, it is extremely important to safeguard the data from unauthorized access, which has been an increasing threat in recent days. For example, in a water utility in Texas, the supervisory control and data acquisition (SCADA) system was compromised (Infosec Island 2011). Overall, a score of 3 was assigned.

Transparent data and information sharing policy: The city's data and information sharing policy is guided by the Municipal Freedom of Information and Protection of Privacy Act (MFIPPA), which requires municipalities to report on the access to information and privacy performance. Many times it is not possible to locate a resource person to contact for further information. Often the availability of data and information depends on the staff's time, interest, priority and workload. This leads to major setback in any effort by external agency or individual to retrieve useful information or to consider new ideas or approaches. The system scored 2.

Actions undertaken to achieve sustainability goals: City A has taken a holistic approach to address the stormwater related flooding issue in area X. A number of short term and long term comprehensive steps were taken to manage the changing situation especially with the varying climatic factors and uncertainties associated with it. Specific details for area X were not available in many cases. However, change management – which would address long term sustainability - does not necessarily mean the "action on ground". Instead, a comprehensive holistic approach to the problem that can derive synergistic effects among the various components of the water cycle, people's health and well-being, and resources is preferred. In this regard, area X has good change management approach to address the flooding problem and to improve on the survivability and resiliency of the infrastructure; however, it did not address the receiving water quality issues while implementing flooding remediation project. There were many data gaps, and many indicators were not considered from a long term sustainability perspective. No consideration for energy or creating a water balance model was given. The system scored a 2.

8.4 Functionality -Survivability -Sustainability Assessment Results

The assessment was based on the multi-criteria method as described in chapter 7. Two sets of weights were used in the assessment – one obtained from the experts through the follow up question - and the other derived from the literature. The area X stormwater system was analysed for functionality, survivability and sustainability based on the resources (R), people (P) and change (C) criteria, and suitable scores were assigned according to the parameters in Table 7-1, and the detailed decision guide provided afterwards in Figure 7-1 to 7-16. The following section provides the details of the assessment.

8.4.1 Setting up R, P, C Criteria

The indicators were grouped in R, P and C based on the "goodness of fit" described in section 6.3.4 and as presented in Table 6-3. The summary of indicators implemented in the case study is given in Table 8-6.

8.4.2 Scores Assignment

Scores for quantifiable indicators were assigned based on the parameters defined in section 7.1.3, while scores for non-quantifiable indicators were based on the decision guide explained in section 7.1.4. The details of scores are given in Table 7-9.

Functionality: Under R, two indicators scored highest value of 5: future savings on infrastructure project costs, and future savings on O&M costs. Two indicators scored 4: change in impervious area, and storm sewer replacement. Under P, cases of vector borne illness indicator scored the highest of 5, followed by the waterborne illness indicator scoring 4. None of the indicators under C, scored above 2.

Survivability: Under R, assessment of reconstruction need scored 2, and the number of deaths or injuries per incident under P scored 5. Under C, having a good emergency response plan scored 5, followed by recovery plan and well-developed adaptation and mitigation measure indicators scoring a 4. The assessment of potential damage indicator scored the minimum value of 1.

Sustainability: Both the indicators for R - having water balance and energy used - scored zero because despite being applicable, data were not available for assessment. Within P, the E-coli indicator scored zero but the scores for toxicity indicators - lead, mercury, copper and arsenic respectively - were 5, 5, 3 and 4. For C, having the data collection and change management indicator scored 3, followed by the information sharing policy and actions undertaken to achieve sustainability goal indicators scoring as 2.

For those indicators which were applicable, but could not be assessed because data was not available for analysis, a zero score was assigned. In a more conventional analysis outside of this proposed framework, such indicators are typically ignored from the assessment. However, such an approach can misrepresent the "true performance": it is assumed that those particular indicators were not important or not applicable, but in fact, the *absence* of data is revealing. In this assessment, the following five indicators were used but scored zero: number of storm water related complaints and stormwater replacing the demand for potable water under functionality; number of properties opting for source control under survivability; and having a water balance model; and energy used in stormwater conveyance under sustainability. Finally, the indicator scores were calculated based on two weighting schemes: 1) weights derived from experts; and 2) weights derived from literature.

8.4.3 Results based on the Weights Provided by Experts

The normalized weights for R, P and C respectively were 1.224, 1 and 1.041 for functionality. These weights were equally divided among each indicator in each R, P and C category. The final indicator scores were then calculated based on the matrix given in section 7.1.9, Table 7-9. The criteria scores were then calculated by taking the average of the final indicator scores. The average of criteria scores for R, P and C provided the functionality score, and the details are given in Table 9-1. The average criteria score of R = 0.478, P= 2.25 and C=0.208 resulted in the functionality score of 0.979.

Similar calculations were repeated for survivability and sustainability. The criteria score for R, P and C within survivability was 2.448, 5 and 0.583 respectively resulting in an average survivability value of 2.677. The sustainability scored 0.358 on the basis of R= 0, P = 0.266 and C= 0.81.

In Table 8-6, the normalized criteria weight was equally distributed for each indicator to provide the indicator weight. The indicator score was obtained by multiplying the indicator weight and the individual score that was assigned for each indicator as outlined in section 8-3. For indicators with sub-indicators, the average score for the indicator is calculated by averaging the scores of the sub-indicators. For example, the average indicator score for toxicity was based on the values of four sub-indicators: lead, mercury, copper and arsenic. The pink, peach and green colour coding is done for R, P and C respectively for both Table 8-6 and Table 8-7 for convenience of reading.

Table 8-6: Scores for FSS based on Experts' Assigned Weight

	Criteria	Indicator	Unit	score	Normalized Criteria weight	Criteria Weight for each indicator	Indicator Score	Average Score for indicator	Average score for criteria (R P, C)
	Functionality								
	Population	Monitoring demographic pattern		2		0.153	0.306	0.306	
Resource	Peak flow	Maximum peak flow generated from the catchment/ 5 years	m3/sec	2	1.224	0.153	0.306	0.306	**0.478**
Resource	Land use	Change in impervious area.	Percent/ year	4		0.153	0.612	0.612	
Resource	Aging infrastructure	storm sewer replacement	*% replaced*	4		0.153	0.612	0.612	
Resource	Funding	Type of pricing structure	Ordinal scale	2		0.153	0.306	0.306	
Resource	funding	Future cost savings on infrastructure project	Ordinal scale	5		0.153	0.765	0.765	
Resource		Cost savings on O& M	Ordinal scale	5		0.153	0.765	0.765	
Resource	Service	Reduction in number of reports of flooding by property owners/ # of total properties	%	1		0.153	0.153	0.153	
P. Health	(public health)	cases of vector borne disease	reported case/ 100, 000 population/ year	5	1	0.500	2.500	2.500	**2.250**
P. Health	(public health)	Cases of gastrointestinal illness reported/ 1000 population / flooding event	reported case/ 100, 000 population/ year	4		0.500	2.000	2.000	
Change Management	Demography	Monitoring of the demographic pattern		2	1.041	0.208	0.416	0.416	**0.208**
Change Management	Service	O and M activity	activity number go high or low	2		0.208	0.416	0.416	
Change Management	Service	# of stormwater related complaints	#/1000 population/yr	0		0.208	0.000	0.000	
Change Management	Conservation	Stormwater replacing the demand of potable water	ML/ ML per year	0		0.208	0.000	0.000	
Change Management	Capacity Building	InInvolvement in research and innovation	Ordinal scale	1		0.208	0.208	0.208	
	Average score for functionality						0.000	0.000	**0.979**
	Survivability								
Resource	Understanding the vulnerability	Assessment of reconstruction need	Yes/ No	2	1.224	1.224	2.448	2.448	**2.448**
P. Health	Loss or damage to life (Public health)	Death or injury caused by damage in infrastructure systems due to flood events	#/ incident	5	1	1	5.000	5.000	**5.000**
Change Management	Understanding the vulnerability	Assessment of potential damage	Yes/ No	1	1.041	0.2082	0.208	0.208	**0.583**
Change Management	Understanding the vulnerability	Recovery plan	Yes/ No	4		0.2082	0.833	0.833	
Change Management	Minimizing system Impact	well planned source, conveyance and end of pipe control strategy for stormwater management (adaptation), and alleviation of the root cause (mitigation) of the problem	Yes/ No	4		0.2082	0.833	0.833	
Change Management	Emergency response(change)	Well developed emergency response plan	Yes/ No	5		0.2082	1.041	1.041	
Change Management		# of property opting for source control	#/# of total properties	0		0.2082	0.000	0.000	
	Average score for Survivbility								**2.677**
	Sustainability								
Resource	Resource	Water balance		0	1.224	0.612	0.000	0.000	**0.000**
Resource		Energy used		0		0.612	0.000	0.000	
Public Health	Public health Ecoli	E-coli exceedence in receiving water sample	% of total sample/ year	0	1	0.5	0.000	0.000	**0.266**
Public Health	Toxicity	Lead	% of total sample/ year	5		0.1250	0.625	0.531	
Public Health		Mercury	% of total sample/ year	5		0.1250	0.625		
Public Health		Copper	% of total sample/ year	3		0.1250	0.375		
Public Health		Arsenic	% of total sample/ year	4		0.1250	0.500		
Change Manageme	Change Management	Having a updated data collection and Information Management System	Yes/ no	3	1.041	0.3470	1.041	1.041	**0.810**
Change Manageme		Transparent information sharing policy with all stakeholders.	yes/no	2		0.3470	0.694	0.694	
Change Manageme		Actions undertaken to achieve sustainability goals are main focus	yes/ no	2		0.3470	0.694	0.694	
	average score for sustainability								**0.358**

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8.4.4 Results Based on the Weights Derived from Literature

The normalized weights for R, P and C respectively were 1.316, 1 and 1.300 for functionality. Following a similar calculation process as outlined in section 8.4.3, these weights were equally divided among indicators in each category. The final criteria scores of R, P, and C respectively were 0.516, 2.25 and 0.26 for functionality; 2.646, 5 and 0.728 for survivability; and 0, 0.266 and 1.011for sustainability. The functionality, survivability and sustainability scores of 1.009, 2.791, and 0.426 respectively were derived by taking average of R, P and C under each of the FSS. The results are shown in the Table 8-7.

Table 8-7: Scores based on Literature-Derived Weight

	Criteria	Indicator	Unit	score	Normalize	Criteria Weight	Indicator	Average Score	Average score
	Functionality								
Resource	Population	Monitoring demographic pattern		2	1.323	0.165	0.331	0.331	**0.517**
	Peak flow	Maximum peak flow generated from the catchment/ 5 years	m3/sec	2		0.165	0.331	0.331	
	Land use	Change in impervious area.	Percent/ year	4		0.165	0.662	0.662	
	Aging infrastructure	storm sewer replacement	*% replaced*	4		0.165	0.662	0.662	
	Funding	Type of pricing structure	Ordinal scale	2		0.165	0.331	0.331	
	funding	Future cost savings on infrastructure project	Ordinal scale	5		0.165	0.827	0.827	
		Cost savings on O& M	Ordinal scale	5		0.165	0.827	0.827	
	Service	Reduction in number of reports of flooding by property owners/ # of total properties	%	1		0.165	0.165	0.165	
P. Health	(public health)	cases of vector borne disease	reported case/ 100, 000	5	1	0.500	2.500	2.500	**2.25**
	(public health)	Cases of gastrointestinal illness reported/ 1000 population / flooding event	reported case/ 100, 000 population/ year	4		0.500	2.000	2.000	
Change Manageme	Demography	Monitoring of the demographic pattern		2	1.300	0.260	0.520	0.520	**0.26**
	Service	O and M activity	activity number go high or low	2		0.260	0.520	0.520	
	Service	# of stormwater related complaints	#/1000 population/yr	0		0.260	0.000	0.000	
	Conservation	Stormwater replacing the demand of	ML/ ML per year	0		0.260	0.000	0.000	
	Capacity Building	InInvolvement in research and innovation	Ordinal scale	1		0.260	0.260	0.260	
	Average score for functionality								**1.009**
	Survivability								
R	Understanding the vulnerability	Assessment of reconstruction need	Yes/ No	2	1.323	1.323	2.646	2.646	**2.646**
P. Health	Loss or damage to life (Public health)	Death or injury caused by damage in infrastructure systems due to flood events	#/ incident	5	1	1.000	5.000	5.000	**5**
Change Management	Understanding the vulnerability	Assessment of potential damage	Yes/ No	1	1.3	0.260	0.260	0.260	**0.728**
	Understanding the vulnerability	Recovery plan	Yes/ No	4		0.260	1.040	1.040	
	Minimizing system Impact	well planned source, conveyance and end of pipe control strategy for stormwater management (adaptation), and alleviation of the root cause (mitigation) of the problem	Yes/ No	4		0.260	1.040	1.040	
	Emergency response(change)	Well developed emergency response plan	Yes/ No	5		0.260	1.300	1.300	
		# of property opting for source control		0		0.260	0.000	0.000	
	Average score for Survivbility								**2.791**
	Sustainability								
R	Resource	Water balance		0	1.323	0.662	0.000	0.000	0
		Energy used		0		0.662	0.000	0.000	
Public Health	Public health Ecoli	E-coli exceedence in receiving water sample	% of total sample/ year	0	1	0.500	0.000	0.000	0.266
	Toxicity	Lead	% of total sample/ year	5		0.125	0.625	0.531	
		Mercury	% of total sample/ year	5		0.125	0.625		
		Copper	% of total sample/ year	3		0.125	0.375		
		Arsenic	% of total sample/ year	4		0.125	0.500		
Change Management	Change Management	Having a updated data collection and Information Management System	Yes/ no	3	1.3	0.433	1.300	1.300	1.011
		Transparent information sharing policy with all stakeholders.	yes/no	2		0.433	0.867	0.867	
		Actions undertaken to achieve sustainability goals are main focus	yes/ no	2		0.433	0.867	0.867	
	average score for sustainability								**0.426**

8.4.5 Comparing the Results of the two Assessment

There is little difference between the results obtained from two sets of weightings. In both cases, the highest weight was assigned to R while P had the lowest weight. The weights for R and C were normalised with respect to P, and the values were comparable in magnitude: R = 1.224, P =1, C= 1.040; and R = 1.323, P = 1, C = 1.308 respectively for the experts' assigned weights versus literature derived weights. The results based on these two sets of weights were also comparable, and are presented in Figure 8-7.

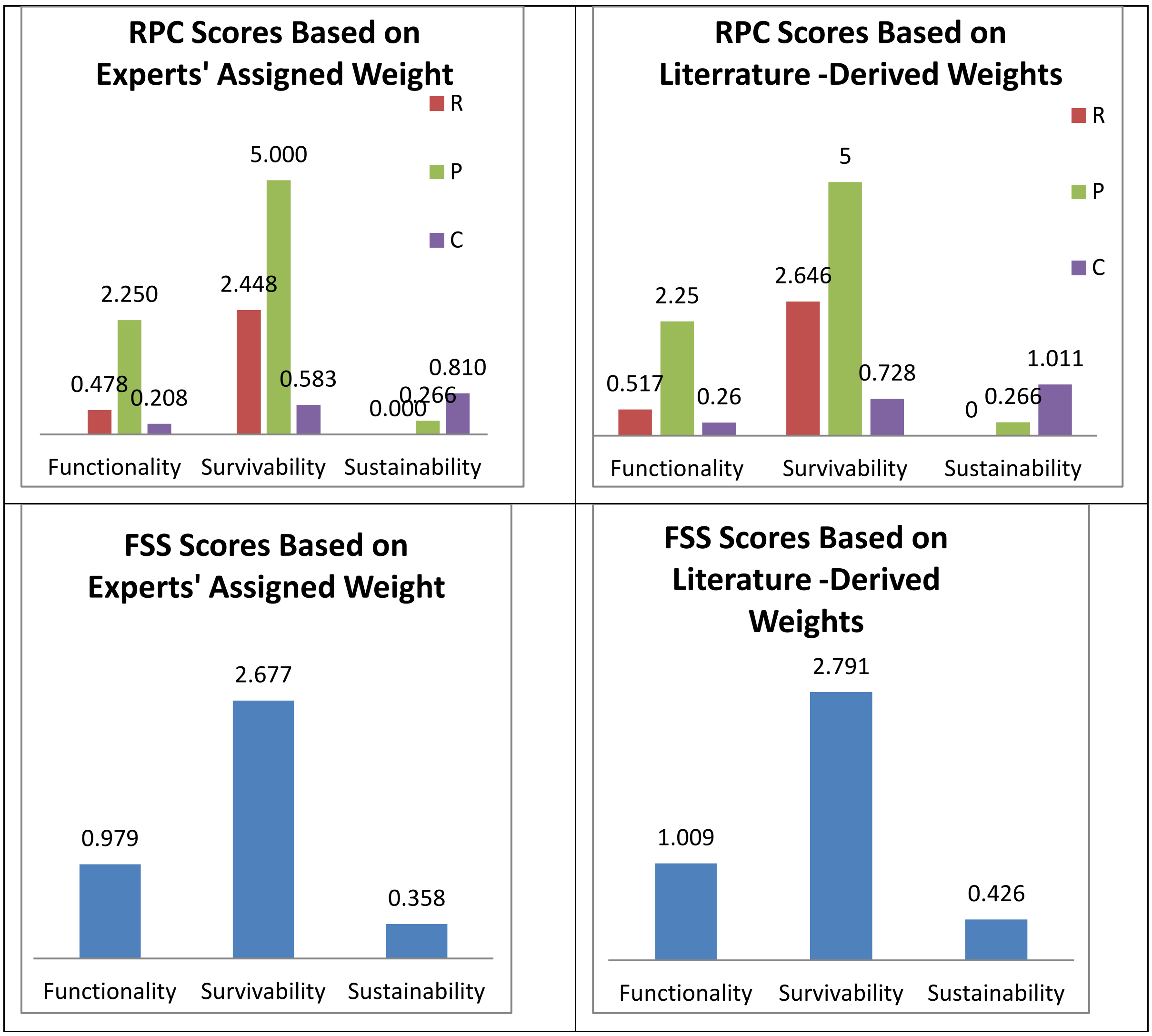

Figure 8-8: MCA Results for Area X Stormwater System

In expert assigned weight:

In the case of functionality, the highest weight was assigned to R. However, its final score of 0.478 was significantly lower compared to P (2.25), and more than twice that of

C (0.208). In the case of survivability, R was scored 2.448, which is lower than P (5), but higher than C (0.583). In the case of sustainability, R scored “zero”. The relatively low performance of R indicates that despite the attention and efforts to improve the resource aspect in area X stormwater system, the performance does not reflect the efforts. The zero score under sustainability suggests that system might be unsustainable in the long run, although it may be functional currently, and able to survive unforeseen stressors. The main reason for zero score was the unavailability of data under *water balance* indicator and *energy use* indicator.

The score for P in functionality was highest among the RPC (2.25) because of higher indicator scores of 5 and 4 and individual indicator weights of 0.5 each. Despite less weight assigned to public health in both sets of weights, the performance under P category was the best among R, P, C for functionality with a value of 2.25, and survivability with a value of 5. Under sustainability, the P scored 0.266, and did not perform as well as the other two. The main reason for this is the lack of compliance for *E.coli* indicator which resulted into a value of zero. Therefore, despite a higher indicator weight, the final score was lower.

The normalized weight for change management, C, (1.041) was slightly higher than P (1) and moderately lower than R (1.224). For functionality, the final C score of 0.208 was about half of the score of R (0.478), and significantly lower than the score of P (2.25). Under the survivability, the value of C was the lowest with a score of 0.583, or less than the quarter of the score of R (2.448), and more than eight times lower than the score of P (5). A possible reason could be that although the flood remediation project was implemented in area X, the primary focus was still on the resource side, and not enough was done on change management aspect. For example, conservation efforts such as down spout disconnection were implemented but were not followed through, and no data was available to assess the outcomes. As a result, important indicators such as stormwater replacing the demand of potable water, and the number of stormwater related complaints scored zero. The unavailability of data set back the analysis, and resulted in a zero indicator scores, and finally lowered the overall score of C.

Within functionality, change management (C) criteria performed the worst; public health criteria outperformed the other two criteria under functionality and survivability, and within survivability, resource scored the second highest. For sustainability, change management scored the highest (0.81) whereas public health scored second (0.266) and resource scored zero. This further suggests that change management is important for long term sustainability, and public health is critical for functionality and survivability in area X's stormwater infrastructure.

Overall, survivability scored the highest at 2.677 for area X. The functionality and sustainability scores were 0.979 and 0.358 respectively. The lower values of R and C in these two categories compared to the value for survivability suggests that although the flood remediation project implemented in area is X is likely to survive future extreme events, it is not functioning at the same level, and the long-term sustainability is expected to be relatively low. In the example, the flood remediation project was implemented as a reactive measure to the flooding in 2005. Functionality and sustainability objectives were probably not given much consideration.

In literature derived weight:
Under functionality, the R and C performance was slightly greater compared to the experts' derived weight (0.517 vs. 0.478 for R, and 0.26 vs. 0.208 for C). P scored the same (2.25) in both cases. In survivability, R scored slightly higher in the case of analysis based on the literature-derived weight than that in the case of experts' derived weight (2.646 vs. 2.448), P scored same (5 vs. 5), and C was slightly higher(0.728 vs.0.583). It is interesting that despite highest weight placed on the R, the performance of R was not significant for functionality. This indicates that there may be complex interaction between various indicators, and just emphasizing certain infrastructure aspects does not necessarily lead to sustainability. A sensitivity analysis may reveal the interaction; however, this analysis is beyond the scope of this research and there is insufficient data to perform a noteworthy sensitivity analysis.

The final scores for functionality, survivability and sustainability were 0.979, 2.677 and 0.358 respectively in case of expert's weight, and 1.009, 2.791 and 0.426 for the literature derived weights. Overall, area X's stormwater infrastructure performed better for survivability, followed by functionality and then sustainability. This may be because the flood remediation project was recently implemented as a reactive measure, and might have diverted resources in doing so, drawing attention to the "big item" recovery measures.

Although in the literature the application of multi criteria assessment in decision making is criticized because of the variations in assigning weights and its influence on the final outcome of the assessment, in this case, the outcome was influenced minimally by the different sets of weights derived from different sources because the weights were similar. A sensitivity analysis could predict the response to significantly varied weights; however in this case the normalized weights were not significantly different. Again, a sensitivity analysis was not done because the primary goal of this assessment was not to examine the applicability of MCA, but rather demonstrate the application of the FSS framework for sustainability assessment.

8.5 Reporting the results

The area X stormwater system is "unsustainable" in the long term based on the zero score under resources, while progressing in terms of functionality and survivability. Whether the level of performance is "declining", "steady" or "improving" cannot be fully established until a trend can be established, which would require significantly more data. Continued assessment on a regular interval basis (e.g., annually) would be needed.

8.6 Discussion

The sustainability assessment framework, structured on Functionality – Survivability – Sustainability (FSS) aspects, was applied in a case study, and the case was analysed with respect to the indicators for each of the three FSS categories on the basis of resource, people's health and change management. Twenty-nine indicators were applicable in the case of area X, out of which five indicators could not be assessed because data were not available. A score of zero was assigned for these five indicators, because they "should" have been known or at least some information has to be known. Most of the other indicators were assessed based on estimation and reasonable assumptions. Five indicators are recommended for monitoring: water quality at the stormwater outfall, cyanobacterial toxicity in receiving water body, emerging virus strains, and emerging contaminants because these were considered by other authorities but may not be for the stormwater management. Continuous professional development activities for engineers and staffs, and insurance provision were not considered before, and therefore are recommended for further study and consideration. The wet weather flow/dry weather flow indicator, ISM specific water quality, swimming advisory, and beach closer advisory indicators were not applicable. Table 8-8 represents the summary.

Table 8-8: Indicators applicability in Area X

Indicators	Performance characterization level		
	Functionality	Survivability	Sustainability
Applicable	Monitoring of demographic pattern, peak flow, change in impervious area, storm sewer replacement, type of pricing structure, cost savings on infrastructure projects, savings on O&M cost, reduction in flooding reports, O&M activities with respect to service, cases of vector borne disease, water borne disease, involvement in research and innovative activities	Assessment of potential damage, assessment of reconstruction need, recovery plan, adaptation and mitigation strategy, emergency response, death or injury	E coli, toxicity (heavy metals), having updated data collection system, data sharing policy, actions undertaken to achieve sustainability goals are the focus
Applicable but assigned zero score because data was unavailable.	# of stormwater related complaints, and stormwater replacing the demand of potable water	# of property opting for source control	Having a water balance model, and energy used to convey stormwater
Recommended for monitoring, considered before but was never followed up	Water quality at the stormwater outfall		
Recommended for further	Continuous professional development for engineers	Provision for insurance	Cyanobacterial toxicity in

study/ monitoring, not considered before	and staffs		receiving water body, emerging virus strains and contaminants
Not applicable	The wet weather flow/ dry weather flow indicator, ISM specific water quality, swimming advisory, and beach closure advisory indicators		

It was found that despite the highest weightings provided on the R in both the weighting schemes, the performance of R was not as significant. It is clear from the assessment that for the long-term sustainability of stormwater infrastructure, only focusing on the resource aspect is not sufficient: public health and change management should also be prioritised. Change management is about ability of the system to deal with uncertain and unforeseen stressors, be able to survive any disastrous situation, and be resilient.

9. CONCLUSION AND RECOMENDATIONS

9.1 Conclusion

In the past, infrastructure systems were assessed on environmental, economic and social aspects, and in some cases, also institutional and technical aspects; however, the primary focus was almost always on resources. The fundamental principle of sustainability lies not only in safeguarding the resources but proactively reducing the use of resources, protecting public health, and being able to manage for changing circumstances: in other words, being able to address the variability of system due to existing and emerging stressors. The research proposes shifting from viewing sustainability from the conventional environmental, social and economic mindset to focusing on resources, public health, and change management. The aim of this research was to develop an innovative framework based on the functionality – survivability – sustainability (FSS) concept for assessing the sustainability of stormwater infrastructure and demonstrate its applicability in an example stormwater system.

At a time when stormwater infrastructure systems across multiple municipalities are facing challenges from the lack of funding, aging infrastructure, and institutional barriers, climate change related impacts further exacerbate public health and flooding hazards. Although there are a number of " to do" solutions to deal with the problem, unless the complex interaction between the functionality, survivability, and long term sustainability aspect is understood and addressed, solutions would hardly be considered truly sustainable.

A process based approach for sustainability assessment was developed. The process based approach underlines the fact that sustainability is a "moving target"; hence, the variability of the stressors will also affect the sustainability of the system, and to deal with this, interconnected and complex interactions need to be considered. As a result, monitoring indicators which were not considered before were emphasized. Moreover, not having data about some aspect of a system can jeopardize the sustainability of the system, despite its "acceptable" performance in other aspects. Therefore, having information and an effective data management system, as well as a data sharing policy, are emphasized. A survey of professionals working with stormwater infrastructure formed a significant aspect of this research development. Although the sample size was small and no statistical inference can be drawn from the survey, the respondents were knowledgeable and the responses represented the water management scenario in the respective city. As a result, the sample responses are highly illustrative of the types of issues that may be encountered.

Using an illustrative case study, this research demonstrated how the *Functionality-Survivability-Sustainability* (FSS) framework can be implemented to assess the sustainability condition of a representative stormwater infrastructure system. The framework incorporates the indicators that can address both the more understood issues as well as those that have higher degrees of uncertainty. Although worked through an example stormwater infrastructure, this research identified common indicators that can be applied to other infrastructure, in some cases with modifications.

9.2 Overall outcomes of this research

This research set out to develop a comprehensive framework for sustainability assessment that can encompass broader, long-term, and changing issues. Stormwater infrastructure system was used as an example. The outcomes of this research were achieved through the methodology adopted. The following section presents the overall outcomes of this research with respect to the objectives.

Objective 1: Identify and examine various issues in stormwater management, and efforts to address these issues.

Outcome:

Two sets of issues were identified: 1) Issues derived from physical factors: economic, health and safety, population, institutional matters, ecological and consumer related; and 2) Issues derived from climatic variations: uncertainties in climatic projection and data, and climate change and health aspects.

Objective 2: Examine whether existing approaches to sustainability and performance assessment can be utilized in assessing the sustainability of infrastructure.

Outcome:

The following three general assessment approaches were examined: 1) ranking, sustainability indicators (SIs), urban footprint, metabolism, extended metabolism, combination of metabolism and SIs, LCA, and notable mathematical models used in the past: 2) Canadian performance assessment criteria for municipal performance assessment program (MPMP) and national water wastewater benchmarking initiative (NWWBI); and 3) the PIEVC Protocol for infrastructure vulnerability assessment were examined.

The current approach to sustainability primarily focuses on minimizing the use of resource but does not necessarily consider public health issues and an effective change management strategy. The PIEVC Protocol is specifically used for assessing vulnerability of infrastructure for climate change, and does not include other sustainability aspects. Another important, missing aspect is that no matter whatever method of sustainability assessment is chosen, unless there is enough data and information about a system, the assessment may not be complete: the system might be unsustainable but would never identified as such.

Objective 3: Develop a new framework that can encompass broader and long-term issues in future as well as current issues.

Outcome:

The functionality-survivability-sustainability (FSS) framework was developed for assessing the infrastructure in the long term. The infrastructure decision making survey was used as a tool for a broader understanding of the system, common issues, and how such issues are managed. The survey provided an important basis for developing the framework. The framework is flexible, can be applied in part for F and S aspects individually. The framework is developed with stormwater system as an example; however, its approach and principles can be applied in other infrastructure arenas such as water, wastewater, transportation, energy, and buildings.

Objective 4: Identify the criteria and indicators for stormwater infrastructure.

Outcome:

Resource, public health and change management (R, P and C) criteria were established with a process based approach encompassing the dynamic nature of the sustainability and emphasizing that sustainability for infrastructure is a process, not an output, and can change in nature: it is important to understand this concept while assessing sustainability of infrastructure. Nineteen indicators for functionality, 8 for survivability and 7 for sustainability are identified. Some new and emerging indicators are identified which were not considered before. The framework in this research is primarily built for stormwater infrastrutucre, for other systems modifications are required. Common indicators that can be applied to other infrastructure such as water, wastewater, transportation, energy, buildings, etc. are also identified and listed in section 6.4.4, and a discussion on possible modification followed.

Objective 5: Apply the framework to a case study to demonstrate how the sustainability assessment can be carried out.

Outcome:

Stormwater system in area X in city A was used as the case study to demonstrate the FSS framework application as described in Chapter 8.

Objective 6: Apply multi criteria assessment method to come up with a final sustainability level of the system.

Outcome:

A detailed decision guide to apply the multi criteria method for assessing sustainability was mapped out for quantifiable and non-quantifiable indicators in Chapter 7. To compare how different ways of assigning weights can impact the assessment, two weighting schemes were used: 1) based on the expert' opinion and 2) derived from the literature. Both the weightings were utilized in the case study, and it was found that the outcomes vary little.

Objective 7: Propose a method to communicate the results of the assessment.

Outcome:

A general template to present the outcomes of the assessment was developed in Chapter 7. Three levels of trends for achieving sustainability are proposed: declining, steady and improving. A further sub level is proposed based on the combination of performances.

The functionality – survivability - sustainability assessment framework is unique because:

1) It captures all aspects, functionality, vulnerability and sustainability, in a comprehensive manner not previously seen. Emphasizing only one aspect does not make the system sustainable. Instead, a combined approach towards all - resource, public health and change management - is expected to yield more functional, resilient and sustainable infrastructure systems. Systems and its attributes are considered dynamic.
2) There are limited studies focusing on broad scale infrastructure sustainability. The majority of the previous studies focused on water and wastewater systems, and rarely on stormwater infrastructures. This research fills that gap by developing the FSS framework for assessing sustainability of infrastructure using stormwater system as an example.
3) In the case study, the assessment was done for all the FSS components, however the framework can be used as a tool by the concerned authorities to assess the performance of their system either individually for functionality, survivability or sustainability, or as a whole depending on need, priority and preferences. In this sense this tool is flexible and easier to utilize.

9.3 Recommendations

The following recommendations are made to facilitate more widespread applicability of this sustainability assessment framework, as well as for improving the framework itself:

1) For future surveys, it is recommended to sample a statistically significant size of respondents and establish key study parameters, such as the target participation rate. This would likely require approaching a higher number of potential survey

respondents, leveraging possibly professional forums as contact scenarios.

2) In the case study example, many indicators were estimated because of insufficient data, and some could not even be assessed because of data unavailability. In other instances, the data exist, but were not available for the study. This led to the system being assessed as "unsustainable". Therefore it is recommended for the municipalities to have: a) a timely and effective data collection, management and reporting system for infrastructure related data (e.g., an online database); and b) a transparent data sharing and partnering policy with all the stakeholders to facilitate informed decision making, and to further advance research and innovation. To share the data with other stakeholders, municipalities are recommended to have a cost sharing policy among stakeholders (e.g. regional and local municipality), and a well defined liability sharing policy. An *information management system* could be launched to enable the actual process of data transfer and distribution.
3) To increase the data collection, a sound and effective monitoring plan is essential. However, modelling approaches and tools can be utilized to gather data especially for those indicators for which monitoring may not be feasible.
4) A separate scoring that represents data availability/ unavailability can be included alongside the individual indicators.
5) More study in providing insurance for urban flooding is recommended for spreading the flooding risk.
6) More study is recommended in pricing structure for water services which would encourage conservation and discourage over consumption.
7) Professional development requirements for professional engineers and other staffs, and capacity building to deal with new and emerging stressors are recommended.
8) Monitoring emerging indicators such as cyanobacterial toxicity, emerging strains of viruses and chemicals of emerging concerns, as well as the possible interactions between source water and water, wastewater and stormwater infrastructure is recommended.
9) The frequency of monitoring receiving water quality indicators and public health indicators are seasonal. Instead, a sound and frequent monitoring plan is recommended to capture the trends of long term weather related stressors.

10) If the receiving water quality has been impaired, the stormwater outfall should be monitored in addition to the stormwater management feature specific parameters.
11) Performing the sustainability assessment on stormwater infrastructure on a periodic basis is recommended to establish trends in functionality, survivability and sustainability performance to establish if the system is moving away or towards a sustainable state.
12) To make the FSS framework more robust, applying it to various types of stormwater infrastructure is recommended; for example, systems having combined sewer system and innovative stormwater management features. The feedback from such an assessment should further be incorporated to improve the framework.
13) Additional testing is recommended by applying the framework to other infrastructure systems to determine applicability and facilitate development of new indicators to improve the robustness of the framework and refine the decision processes.
14) Indicators for public health relevant to other infrastructures systems can be included and adapted as needed. For example, indoor air quality related indicators for buildings, and outdoor air quality indicators for transportation infrastructure can be considered.
15) The Ontario Water Opportunities Act (OWA) 2010 encourages sustainable infrastructure to address water, wastewater and stormwater infrastructure challenges. The Act requires municipalities to have water sustainability plans and allows the Ministry of Environment (MoE) to establish indicators and targets for municipal water, wastewater and stormwater services. This sustainability assessment framework can also be a tool to facilitate the requirements of the WOA.

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APPENDIX A

Infrastructure Decision Making Survey

Page #1

Introduction

Greetings! Thank you in advance for participating in the University of Windsor Water Infrastructure Decision making Survey. The main purpose of this online survey is to gather information about the decision making process involved in the municipal water infrastructure. The survey is divided into two groups. Questions in Group A are for general information, and mostly focuses on how sustainability is tied into decision making process, and the focus of Group B questions is to identify the gaps in data management and how lack of information can influence decision making.

It will only take about 30 minutes to complete the survey. As a token of appreciation, a $10 gift card will be provided to all the participants. Upon the completion of this survey, you will be redirected to another page where we ask for your mailing information. Your contact information will not be tied back to the actual response which leads to the anonymity of the survey.

You may be in an identifiable group of people but we are asking for information in your official capacity. No individual name will be revealed, and we will maintain confidentiality. The survey has research ethics board approval. You can choose not to answer a question and can still participate in the survey. You can withdraw from this study anytime you want before the end of survey period (May 2011). The investigator may withdraw the participants from this research if circumstances arise which warrant doing so. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e‑mail: ethics@uwindsor.ca

By answering the questions in this survey, you are providing voluntary consent to participate in this survey. Please print this page for your record.

You can see the finding of this survey posted in group form on www.uwindsor.ca/reb website from May 2011. We will appreciate to have your feedback.

If you have any questions, concerns or comment about the research, please feel free to contact one of us. Ms. Jyoti Upadhyaya email: upadhyaj@uwindsor.ca, Dr. Edwin Tam email: edwintam@uwindsor.ca, Dr. Nihar Biswas email: biswas@uwindsor.ca.

Page #2

Group A- Decision Making Process

Question 1

Which municipality is served by the water infrastructure system of which you are an employee? Please specify.

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Question 2

In which category would you identify yourself? You can select more than one category.

Senior management.

Mid level management.

Engineer.

Technical and operational.

Other, please specify. __________________________

Question 3

What is the average age of water related infrastructure such as pipe lines, pumps, treatment plants etc. in your municipality? You may provide a
range, e.g. 20-40 years.

____

Question 4

What is the management arrangement for water/wastewater/stormwater systems in your municipality?

All the water, wastewater, stormwater systems are managed by general engineering/infrastructure division within the municipality.

All the water, wastewater, stormwater systems are managed by general environmental division within the municipality.

All the water, wastewater, stormwater systems including treatment and distribution are managed under one umbrella within the municipality.

We have separate body responsible for water. Wastewater and stormwater are under one separate group within the municipality.

Water system (conveyance, treatment and distribution) is privately operated while wastewater and stormwater are within municipality.

More than one private party is involved in water, wastewater, and stormwater management.

Any other arrangement, please specify. ___________________________

Question 5

In your opinion, which of the following groups has the most effect through their actions on decisions related to municipal infrastructure (e.g.,
planning, costs, implementation, maintenance, etc.)? Indicate up to the two most important groups.

Senior management.

Mid level management.

Engineers.

Technical and operational staff.

Consumers(Residents) through their elected representatives.

Other, please specify. ___________________________

Question 6

What are the most pressing issues in terms of water management in your municipality? Please rank them in order of 1 being most pressing to 5 being least.

Water supply security

Quality of the supplied water

Issues related to aging infrastructure

Funding deficit

Hazard associated with natural incidents e.g. flooding

Question 7

What do you think is the preferred way to deal with the most pressing issue identified in Question 6? Please specify and explain.

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Question 8

At the time when most of the infrastructure are reaching their end of design life, what are some of the issues related to aging water infrastructure

e.g. under capacity, breaks and leaks? Please specify.

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Question 9

Response to a natural hazard is done in three phases: pre incident planning, emergency response right after incident (within hours and days), and post incident recovery activity (within days, weeks and months). How does your organization respond to a natural incident over the long term (i.e., not an emergency response) that can affect the water related infrastructure (e.g., pipes, pumps etc.)?

We usually just react to the situations as they arise but do not follow through with any further analysis.

We try to determine the reasons for the issue so that we can improve our response should a similar situation arise in the future but we limit our analysis to only the situation specifics.

We undertake a systematic review of current processes to determine how to proactively handle future, similar scenarios from a comprehensive viewpoint by considering also elements outside of the situation specifics.

We wait for the province or other regulatory authority to provide us guidelines and frameworks to handle any emerging issues.

Other, please specify. ______________________________

Question 10

How frequently is the performance of the water system monitored and measured?

Once every month or more frequent.

Once a year.

Once every five years.

Whenever provice requires us to undertake such activities.

We do not measure the performance of our system.

Other, please specify. ___________________________

Question 11 A

Generally quality, cost and time are the fundamental criteria for engineering decision making. In your opinion what was the priority during initial decisions (planning/design)? Please rank the initial priority as 1 being the highest and 3 being the lowest.

Quality

Cost

Time

Question 11 B

How have these priorities changed over the time? Please rank the current priority of the following criteria against the initial priority as 1 being the highest and 3 being the lowest. If the priority has not changed, please move to Question 12.

Quality

Cost

Time

Question 11 C

Why do you think the weighting and priority has been changed over time? You can choose up to three answers.

Due to economic instability.

Due to aging infrastructure.

Due to consumers increased demand for improved services.

Due to regulatory requirements.

No change.

Any other reason, please specify. ___________________________

Question 12

If you are required to report the performance of your water systems to your province, what do you think about the parameters used to report to the province about the performance of the water system? You can choose more than one.

They truly represent the overall system performance.

They mostly give information on what outcomes were achieved.

They are mostly focused on financial performance.

They do not tell us whether the processes that we implemented to achieve the results were good.

They do not tell us whether we are going to be more sustainable or less.

Question 13 A

Does your organization consider sustainability in the infrastructure related decision making?

No, we do not consider sustainability at present.

No, but we are developing a sustainability plan.

Yes, we have a plan, but it is only in the early stages of implementation.

Yes, we are implementing a plan that has been previously developed.

Other, please specify. ___________________________

Question 13 B

At what stage of decision making do you think sustainability is/ should be implemented in the water sector in your municipality?

In long term policy formulation only.

Annual programs and goal settings.

Conceptualization of any program or project.

Design phase of any new or improvement project.

Ongoing operation and maintenance.

Other, please specify. ___________________________

Question 13 C

Do you think implementing sustainability will be helpful to deal with pressing issues such as natural hazards associated with climate change?

No, because sustainability and climate change are not tied together.

To some degree, because sustainability and climate change are somewhat tied.

This relationship between climate change and sustainability has not really been considered by many organization.

I do not know.

Other, please explain. ___________________________

Question 14

What indicators would be most effective for measuring sustainability of water systems? Please rank your choices as 1 being most effective to 5 being least effective.

Indicators reflecting the resource conservation

Indicators reflecting emissions or waste reduction

Indicators reflecting public health and ecosystem health

Indicators reflecting the cost reduction for treatment, operation and maintenance

Indicators reflecting ability of the system to manage any uncertainities asociated with the system e.g. comprehensiveness of the approach to prepare for potential flooding.

Question 15 A

How does your municipality approach resource usage and its conservation and efficiency for water system?

We do not currently have any formal approach (i.e., no policy, procedure or program).

We have a policy to improve resource usage but it is not implemented well in practice.

We have a policy and program to improve resource usage, but we cannot assess very well how effective they are.

We have a policy and program to improve resource usage and through monitoring, we have a good grasp on its effectiveness.

Others, please specify. ___________________________

Question 15 B

What are the main issues that interfere with your efforts to implement water resource management practices? Please rank your choices as 1 being most challenging to 5 being least challenging.

Lack of data and information readily available to make an informed choice

Lack of funds

Lack of mandatory requirement by law to enforce any initiative

Lack of staffing and manpower

Lack of awareness among consumers

Question 16 A

Has your municipality identified or implemented policies/ processes/ programs in relation to water system to improve upon public health?

We do not currently have any formal approach (i.e., no policy, procedure or program).

We have a policy to improve public health but it is not implemented well in practice.

We have a policy and program to improve public health, but we cannot assess very well how effective they are.

We have a policy and program to improve public health and through monitoring, we have a good grasp on its effectiveness.

Others, please specify. ___________________________

Question 16 B

What are the main issues that interfere with your efforts to implement public health improvement practices? Please rank your choices as 1 being most challenging to 5 being least challenging.

Lack of data and information readily available to make an informed

choice.

Lack of funds.

Lack of mandatory requirement by law to enforce any initiative.

Lack of staffing and manpower.

Lack of awareness among consumers.

Question 17

What does the term "Change Management" mean to you in an infrastructure context?

a) Managing physical changes in infrastructure to at least maintain the current level of service, but not necessarily to improve it.

b) Managing infrastructure to improve level of service provided.

c) Strategic change in policy to reduce future risk.

If you selected 16 (c), What should be done? Please specify.

____

Question 18

System approach is the process of understanding how things influence one another within a whole. Do you approach infrastructure managementfrom a systems perspective?

a) No, and we do not currently have any plans to implement a systems approach.

b) No, but we are considering some sort of systems approach.

c) Yes, and we are implementing (or will be in the near future) a systems approach.

d) Yes, we have been using a systems approach for some time now and continue to do so.

If you selected 17(a), why will a systems approach not be implemented? Please explain.

____

Question 19 A

For a system to be sustainable, it is important for it to be functional (to be able to fulfill its purpose) and be able to survive any perceived or unforeseen hazards (e.g. extreme natural event). Unless a system is functioning well, it is unlikely that it can survive an incident, and be sustainable in the long term. Therefore an interrelationship can be implied between all the three elements. Do you think this relationship is important for decision makers to understand in order for your system to be sustainable over long term? Please explain.

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Question 19 B

Do you think performance assessment of your water system should reflect the functionality, survivability and sustainability of your water system, as described above? Please explain.

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Question 20 A

Functionality is defined as the ability of the system to fulfill its purpose. What factors do you think affect functionality of your water system e.g. population dynamics, aging infrastructure, funding, water pricing etc.? Please specify.

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Question 20 B

What should be the main indicators for assessing the functionality of your water infrastructure? Please specify and explain.

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Question 21 A

Survivability is the ability of a system to continue to function during and after a natural or man- made incident, e.g. flood event. What factors do you think affect survivability of your water system? Please specify and explain.

____

Question 21 B

What should be the main indicators for assessing the survivability of your water infrastructure? Please specify and explain.

____

Question 22

Climate change is linked to the increased vulnerability of infrastructure to the extreme weather events. Is there a climate change management plan in your municipality?

No, we do not consider climate change at present nor is it an outstanding issue.

No, but are developing a climate change management plan.

Yes, we have a plan, but it is only in the early stages of implementation.

Yes, we are implementing a plan that has been previously developed.

Others, please specify. __________________________

Question 23

If you have a climate change management plan, which aspects of water management are addressed in the plan?

Water supply security.

Distribution system management.

Treatment process management.

Flood management.

All the above.

Other. Please specify. __________________________

Not applicable.

Question 24 A

Which of the following systems is most vulnerable to climate change?

Water supply system.

Wastewater system.

Stormwater system.

All the above.

Any other system. Please specify. ____________________________

Question 24 B

Please comment on why you think the system you chose above is most vulnerable for your municipality?

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Question 25 A

Which of the following systems poses greatest risk to the people because of effects from climate change within the municipality?

Water supply system.

Wastewater system.

Stormwater system.

All the above.

Any other system. Please specify. ____________________________

Question 25 B

Please comment on why you think the system you chose above poses greatest risk to the people within the municipality?

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Page #3

Group B- Information and Data Management

Question 26

Is there a data/information management system in your organization?

No, we do not have a data/information management system at present.

No, but are developing a data/information management system.

Yes, we have a data/information management system, but it is only in the early stages of implementation.

Yes, we have a data/information management system that has been implemented for decision making.

Other. Please specify. ____________________________

Question 27

If you have a data/ information management system, how effective it is in helping you or other decision makers to make a infrastructure related decision? Do you have additional comments about your data/ information management system? Please specify.

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Question 28

What is the most important piece of information to assist you or other decision makers in making a long term water infrastructure related decisions in your municipality?

Data and information kept within data/information management system of the municipality.

Budget availability.

Provincial government policy.

Regulatory requirement.

Residents outcry.

Others, please specify. ____________________________

Question 29 A

What time step data are usually used when a long term water infrastructure related decision is made in your municipality?

a) Five year data.

b) Annual data.

c) Monthly data.

d) Daily data.

e) Other, please specify. __________________________

Question 29 B

If you selected 29 A (a) or 29 A (b), do you think a more frequent time step data should be used for decision making?

Yes, because it can capture any seasonal variation.

Yes, because it can capture any patterns in terms of time.

No, because it would be cumbersome to work with.

No, because our system is already designed for higher capacity, we do not need to consider smaller time steps.

It would not make any difference.

Not applicable.

Please specify a time step that would be preffered __________________________

Question 30

Do you think that the future decisions made in absence of data can influence the water system's ability to deal with uncertainty?

Yes, because it can increase the vulnerability of the system.

No, because our system is robust enough to deal with vulnerability.

No, our system is newly built and safe.

Do not know, we have not considered uncertainty.

Other, please specify __________________________

Question 31

What type of data and information do you think are most effective for sustainability assessment?

Data reflecting the resource usage.

Data reflecting the public health measures (e.g. Boil Water Advisory).

Data reflecting financial issues.

All the above.

Other parameters, please specify. __________________________

Please comment on why you think your above choice is appropriate for your municipality.

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Question 32 A

In your opinion what is the preferred indicator of measuring the consumption of water?

Total water taken from the source.

Total water distributed.

Total water billed.

Other, please specify. ______________________________

Question 32 B

In your opinion what is the preffered indicator for interpretting how to minimize water consumption?

Water taken from source/ person

Water distributed/ person

Water used/ person

Water used/ category e.g. for industrial, commerial, institutional etc.

Other, please specify. ______________________________

Please comment on why you think your above choices seem appropriate for your municipality.

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Question 33

In your opinion what should be the key indicators for public health related to water supply?

Number of cases of water borne illnesses.

Number of Boil Water Advisory issued.

Number of swimming advisory issued downstream of the wastewater treatment plant efluent discharge point.

Number of beach closure issued downstream of the wastewater treatment plant effluent discharge point.

Number of times the wastewater treatment plant has to be bypassed.

All the above.

Other indicator, please specify. ___________________________

Question 34

In your opinion what kind of data are important to record and monitor for water infrastructure functionality? Please specify.

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Question 35 A

In your opinion what kind of data are important to record and monitor for water infrastructure survivability (ability of a system to continue to
function during and after a natural or man- made incident, e.g. flood event) in the short term? Please specify.

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Question 35 B

In your opinion what kind of data are important to record and monitor for water infrastructure survivability (ability of a system to continue to function during and after a natural or man- made incident, e.g. flood event) in long term? Please specify.

____

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Question 36

In your opinion what challenges exists in the data management in your organization?

Lack of knowledge sharing within organization.

Not knowing the exact importance of data and information.

Lack of people and resources to record, manage and assess data.

Lack of support from higher management.

Lack of clear directives from province.

All the above.

Others, please specify. ___________________________

Question 37

How do you think the barrier to data availability and management can be addressed?

By having more research to identify the data gap and finding a method to address it.

By having a central repository of all the municipal infrastructure data.

By making data management and sharing a mandatory requirement.

By increasing inter and intra organizational cooperation.

All the above.

Other, please specify. ___________________________

Question 38

Is there anything we have not asked you about that you think is important for us to know?

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Thank you very much for your participation!

VITA AUCTORIS

Jyoti Upadhyaya was born in Dumariya, Sarlahi, Nepal. She was graduated in civil engineering from Tribhuwan University, Nepal and worked in municipal water sector for over seven years. Jyoti was awarded the Australian International Development Agency (AusAID) Scholarship during 2003 to 2005. She completed her master degree in environmental engineering in 2005 from University of Melbourne, Australia. She immigrated to Canada in 2005. Her interest in environment and sustainability is based on her experience and she is looking forward to continue further work in this area.