Creation of a Dynamic Risk Ranking Methodology for Multiple Storm Events and its Application to the City of Edmonton

by

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Abstract

Globally, municipalities have been experiencing flooding events caused by riverine, coastal, or urban flooding and have applied both many and varied mitigation measures. In most flood mitigation cases, financial investment for mitigation improvements was approved post flooding. This reactive rather than proactive approach tended to focus mainly on financial consequences. This thesis is based on the risk ranking methodology that was part of EPCOR's Stormwater Integrated Resources Planning that was created for the City of Edmonton as part of their flood management plan. It utilizes a grid-based risk methodology of likelihood and consequence events to determine investment focus. This provides direction in order to mitigate flood damage before a severe weather event causing property loss and/or impacts in a community. Rather than flood mitigation projects initiated solely on a financial cost benefit basis, Health and Safety, Environment, and Social factors were also included in the grid to generate a multi-faceted consequence approach. Climate change is causing severity and frequency of storm events to increase, which are effects that are also considered within the risk determination. This is a disaggregated approach to assessing risk and has the ability to identify and implement incremental improvements as the study area changes. The risk assessment framework was formulated and applied to the City of Edmonton's watershed and sewershed basins and validated with past known flooding events. The results were then applied to a Geospatial map of the City of Edmonton to provide a mapping representation of the risk throughout the City. The visual representation provided users a tool to prioritize future areas for flood mitigation programs. The dynamic capability allows for the user to apply flood mitigation projects to the study area and see the risk difference it would provide before it is physically implemented. Through the dedication of regular updates and the ability to add new risk criteria the model is a continuously evolving risk model.

Preface

This thesis is the original work of Elizabeth Otto, who completed it as an employee of EPCOR between 2017 and 2019 under the supervision of Susan Ancel of EPCOR. The work for EPCOR was later used as the basis for this thesis. The creation of the SIRP risk ranking methodology was quite a success both as a new tool for engineers and municipalities, but also as a means to explain flooding risk to the public. This methodology has been presented at a number of Canadian conferences and has been positively received. The results of this thesis and accompanying application of flood mitigation, since its completion in 2018, have received an commendations including the Clean 50 award in celebration of innovative and sustainability in the community (Southey, 2021).

The results created as part of the SIRP and risk ranking methodology resulted in EPCOR being a successful recipient for the Disaster Mitigation and Adaptation Fund (DMAF) from the Government of Canada. This funding provided more than $53 million to flood mitigation measures in the City of Edmonton (Ramsay, 2019) which will be used to build 13 new dry ponds to collect storm water and reduce street flooding, as well as, mitigating flooding at the two water treatment plants which provide safe drinking water to the residents of Edmonton and surrounding area.

All this original work has been supported and reviewed by EPCOR Canada.

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First and foremost, I would like to thank EPCOR for providing me the opportunity not only to be part of the SIRP team but to apply my work on the risk ranking methodology to my thesis. Without their support and encouragement this thesis would not have been possible. Specifically, I would like to thank Susan Ancel for teaching me to question everything and to find different ways of looking at a problem. I would also like to thank Albert Kwan and his eye for detail, as well as, a vast knowledge of the city drainage network.

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Glossary of Terms

Consequence – a result or effect of an action based on the occurrence of a flooding event (Cardona et al., 2012)

Design Standards – generally accepted procedures as stated by the municipality or provincial government. Updated regularly to meet with new methods or designs.

Exposure – the natural element that has been evaluated as part of a hazard (Cardona, 2012)

Flood risk management - a pro-active planning, mitigation, or preparation activities to reduce or minimize the risk of flooding based on a risk-based framework (Vojtek & Vojteková, 2016)

Hazards – the possibility of a natural or human induced event, that can be predicted, which will have an adverse effect on people, buildings, or the environment. (Cardona, 2012)

Level of Service – describes the performance level of the sewer system, often defined in terms of the storm event that the pipe networks are designed to manage.

Likelihood – defined by Hopkin (2010) as “the chance of a risk materializing” and can also be defined as the probability of occurrence

Mike Urban – software used to model urban water networks in municipalities. These networks include the water distribution system, stormwater drainage system and sewer collection in both the separate and combined systems. (MikeUrban, 2020)

Public Perception – how the public views an action or event, usually determined through studies, questionnaires, or open forums

SWMF – Storm Water Management Facility – term used for both wet and dry ponds that are installed within the drainage network and provides additional capacity/storage during larger storm events

Vulnerability – the impact that a hazard has on people, livelihood or structures (Cardona, 2012). Vulnerability can be defined by which the specific amount of damage that would be caused during a flooding event (Pham et al., 2021).

Acronyms

CSO – Combined Sewer Overflows

CWFMS – City-Wide Flood Mitigation Strategy

CWN – Canadian Water Network

FMEA - Failure Model Effects Analysis

FOIP – Freedom of Information and Protection of Privacy Act

GIS – Geographic Information System

HAZOP - Hazard and Operability

IDF – Intensity Duration Frequency

IRP – Integrated Resources Planning

LID – Low Impact Development

LiDAR – Light Detection and Ranging

PESTLE - Political, economic, social, technological, legal, Environmental

SIRP – Stormwater Integrated Resources Planning

SWMF – Storm Water Management Facility

SWOT - Strengths, Weakness, Opportunities, Threats

TSS – Total Suspended Solids

TP – Total Phosphorus

1. Introduction

Flooding has caused damage to homes and businesses around the world (Zeng et al., 2019), which affects health, safety, social well-being, and various infrastructure. Numerous studies from around the world indicate that both current and future damage can be expected based on current or future climate change flooding models (Zhou et al., 2018, Al-Ami et al., 2019). In Canada, a growing number of communities and homeowners are feeling the effects of extreme weather events (IBC, 2018). Financial losses from extreme weather events between 1983 and 2008 were evaluated at $405 million per year, and increased between 2009 and 2017 to $1.8 Billion (*ibid*). The Insurance Bureau of Canada stated that the key driver of these costs was water damage (*ibid*). With the projected increases in extreme rainfall events, governments are attempting to determine the best way to minimize damage(s).

Current studies lack a critical element: determination of how to prioritize flood mitigation projects or determine if the risk of flooding to an area is acceptable. The work within this thesis focuses on the first stage of a two-part strategy for flood resilience called Stormwater Integrated Resources Planning (SIRP). The first stage was the creation of the risk ranking methodology. The second stage in the creation of SIRP focused on application of flood mitigation projects to at risk areas.

Climate change has added a complexity to flood risk by causing changes to what was traditionally seen as a typical storm event. Predicting the extent of flooding has become more complicated when trying to create a cohesive large municipal plan. Other drivers that have increased flooding damage in regards municipal infrastructure are rapidly expanding municipalities, as well as, ageing infrastructure. Rapid urban growth increases the impervious areas and new development is typically designed to the standards of the day, whereas previously installed infrastructure was designed to previous standards and could be falling into disrepair. These are the two key elements that this thesis reviews; however, there are many other aspects that can increase the complexity in regards to building a cohesive flood mitigation strategy.

In 2017 the City of Edmonton created a flood mitigation strategy that was built solely using hydraulic models. However, these hydraulic models do not take into account the changing storm patterns or the condition of drainage piping to handle a storm event. The City's strategy calculated reducing the damage caused by flooding to have a price tag of $4.2 billion over 80 years, but this price tag did not take into consideration future changes to rainfall patterns. If implemented, it would have applied the storm event patterns of today almost a century later than when the program would be completed. Concerns were raised that after completing this work, it may not have a visible impact due to the changing storm patterns. This occurred in Chicago in 2017 when they completed a 50 year project to mitigate flooding through tunnels. When it opened in 2017, it was made clear to the municipal leaders that it would not provide the benefit anticipated and flooding continued at the same rate (Grabar, 2019). Edmonton decided to avoid this situation.

Building flood mitigation programs that only focus on hydraulic models and cost benefit for prioritization are no longer acceptable to governments or to the public. If these types of programs continue, with no indication of long-term benefits, residents will be the ones facing the increasing cost. Upgrades to the municipal system are managed through utility fees. Insurance industries will continue to increase their fees to homeowners to recuperate their losses from repairs caused by flooding. These fees can reach an unattainable cost for residents in higher risk flood zones. Previously, the Canadian Federal and Provincial Government had disaster assistance for larger scale flooding events. This disaster assistance has been cut back since 2017, and the insurance industry has increased its offering with different flooding packages (Forrest, 2017). With the continued increase in insurance for homes in flood risk areas, residents will be faced with the tough choice of whether to move or to live with the risk of losing their home if a flood event occurs.

1.1. Problem Statement

To reduce costs of flood damage for homeowners, a new method of determining and prioritizing flood mitigation projects is required by municipal or utility drainage departments. This thesis therefore develops a novel method that can continuously validate flood mitigation projects and programs, and that can also incorporate effects of climate change and aging infrastructure. By expanding from only using hydraulic flood models, multiple storm events, and the current pipe network, flooding risk can be evaluated with a more holistic approach.

The work described in this thesis also serves public and private interests: the City of Edmonton & EPCOR Water Inc. (EPCOR) wanted a new methodology to prioritize investment into flood mitigation. The goal is to build a risk method that can visually demonstrate the risk of flooding throughout the City of Edmonton. This approach is different than the traditional approach of visually demonstrating the depth of flooding within a specific asset such as pipes or manholes.

1.2. Project Objectives

The main objective was to geospatially analyse and map the risk of flooding throughout the City of Edmonton to support the identification of flood risks and prioritize projects to reduce them. The flood risk visualization and prioritization system developed here had several necessary criteria: 1) it was necessary to use a Geospatial Information System (GIS) to allow planners and decision-makers to make decisions for individual watersheds and sewersheds, 2) the scale of analysis needed to have enough fine-resolution to locate specific flood mitigation measures but broad enough to compare to other climate hazards, and 3) the system had to be dynamic in its ability to identify neighbourhoods and watersheds/sewersheds for mitigation measures with changes in hydraulic and hydrological models.

The first step in creation of the risk ranking methodology was the disaggregation of the City of Edmonton into watersheds and sewersheds, which allowed the quantification of both the probability and extent of damage expected to occur during a flooding event. Within these watersheds and sewersheds (also called sub basins), evaluation of specific risks could than occur through the creation of likelihood and consequence scales.

To rank risks at the sub basin scale next required likelihood and consequence scale using key statements. Building a cohesive likelihood and consequence scale required multiple factors to be evaluated. For the likelihood component, multiple different storm events were utilized to create the scale based on the probability of occurrence and easily acquired hydraulic maps. Consequences were categorized as related to health and safety, environmental, social, and economic/financial consequences. These categories could utilize the same data sets to display the complexity of the consequences. For example, one hydraulic model would be applied to all four consequence categories which would focus on a result experienced by flooding. With the multiple consequence and likelihood methods, a weighting system was needed to combine the different consequence types. One of these weighting options was created through the public engagement survey that was completed through an external contractor. Finally, using a 0 through 5 scale for each, the total risk was calculated for each sub basin and then represented through a colour coordinated chart.

Having created the risk ranking methodology through likelihood and consequence scales the final risk can be mathematically calculated. The results of the risk were then applied to a colour scale which could then be uploaded into geospatial software to visually demonstrate the risk.

Because the thesis includes work completed for EPCOR by a larger team, it is important to clarify my individual role. As the technical expert for urban flooding within EPCOR Canada, I was responsible to review past flood mitigation and assessment projects and programs, and with assistance and oversight from colleagues, build a brand-new method of determining flooding risk that can now be applied to any municipality through either preferred storm or multiple storm events. Information and previous studies were required from other team members and colleagues. For example, the City of Edmonton/EPCOR graciously provided various data sets that included but were not limited to hydraulic modelling and asset conditions. I then analyzed and refined these data sets for the development of a novel risk ranking methodology. Furthermore, I developed and utilized a risk model to illustrate risk reduction by the implementation of a flood reduction application such as LID and/or dry pond construction.

1.3. Thesis Structure

Chapter 2, the literature review, focuses on what flooding is and how a risk ranking method is built. Since the focus in on building a new risk ranking methodology, Chapter 2 only reviews material relevant to this thesis. There are many other methods that have an impact on flooding that are not specifically mentioned, but were evaluated. This research will review causes of flooding and what is required to create a risk ranking methodology.

Chapter 3 focuses on what has occurred within the study area of the City of Edmonton. It also looks at two other municipalities that were evaluated, as creation of the risk ranking methodology was ongoing. The methodology of how risk ranking was built can be found in Chapter 4. This section will go into specifics regarding what data was utilised, created, or purchased. It outlines the consequence statements that were built and the method to utilizing multiple storms for likelihood. At the end of this chapter the final weighting methodology will be explained.

The final results can be found in Chapter 5. The results presented within this thesis are based on the results from 2018. It will demonstrate the grids that were built, as well as, the application of the risk onto a geospatial analysis of the City of Edmonton. This section will also review the results found as part of the survey that was conducted. Chapter 6 looks at the applicability regarding the dynamic updating capability. This Chapter will provide three examples and the utilization of the risk ranking mapping to create a flood mitigation project strategy. It will also provide high level detail as to the results from the work completed after the risk ranking was finalized, the creation of a flood mitigation strategy. The conclusions of this work can be found in Chapter 7.

2. Literature Review

Many papers, articles, and reports have been published to-date outlining methods determining where flooding will occur and how to mitigate flooding; however, there are very few citations regarding the decision-making process of prioritizing flood mitigation projects/programs. This literature review will explain the Integrated Resources Planning (IRP) methodology and its application to flooding. It will then cover a few drivers of flooding before explaining what risk is and how risk is calculated. Although IRP has been used for decades, its application to flooding is new.

2.1. Defining and Utilizing Integrated Resources Planning

An Integrated Resource Plan (IRP) outlines what resources are needed in order to meet expected demand over a long-term planning horizon (Baldwin & Hamstead, 2014). Key IRP items include planned asset resource additions and retirements, as well as cost and performance assumptions (Line, 2019, USEPA, 2019). IRP was first defined in regards to water management in 1997 in a report from the Water Research Foundation (Cista, 1997). EPCOR was part of the case study as part of this report and had proposed using the approach to the City of Edmonton in 1993. They defined Integrated Water Resources Management (similar to IRP) specifically as a method used to coordinate the development and management of water, land, and other resources in order to reach the best outcome for economic and social welfare without compromising the surrounding ecosystem (Baldwin & Hamstead, 2014). Their definition is applicable to the goals of this thesis.

IRP allows for an expanded toolbox of projects that can be applied to the same problem and looks outside of the traditional problem area. By examining integrations both upstream and downstream of the issues, it opens up to different scopes of works to manage the issue (Baldwin & Hamstead, 2014). IRP methodologies looks not only at economic efficiencies but as environmental sustainability and social equity within the study area. This is completed by reviewing the existing resources, codependence within the environment, future uncertainties, and possible conflicts (Baldwin & Hamstead, 2014).

Baldwin & Hamstead (2014) listed a number of principles that they used to guide their decision-making process that were also applied to this thesis. Although the principles presented by Baldwin & Hamstead

(2014) are in regards to drinking water management, the same principles can be applied to stormwater management. The principles of note include:

- Water management systems currently in place
- Supplement existing data with local knowledge
- Management of water within the whole basin
- Overland flows and qualities of waterways
- Contribution of knowledge from the community and stakeholders to the decision making process
- Frequency of extreme events and their risks
- The threat of flooding towards people and property

2.2. Flooding and Flooding Drivers

Flooding is a common natural disaster that threatens all regions around the world (Xing et al., 2021, Pham et al., 2021, Wang et al., 2021). Flooding has been defined as “high stages of water over land or coastal areas that are outside of the normal levels which result in damage to infrastructure and nature” (Ghosh, 2014, pg 1). There are multiple types of flooding events described in literature but the focus of this review is on three; riverine (fluvial), urban (pluvial), and combined sewer surcharge.

Fluvial or riverine flooding is caused when rising river level results in property, roadway, and bridge damage. This often occurs during spring melt but can also occur due to extreme rainfalls upstream. Fluvial flooding can wash out bridges and roadways due to the changes in flow volumes and flow rates. It is estimated that fluvial flooding has caused over a billion dollars in damage in Canada over the last decade (Candela & Aronica, 2016; Teufel & Sushama, 2021).

Urban flooding is classified as surface flooding due to heavy rainfall. This type of flooding has been experienced by many municipalities around Canada. Focusing on urban flooding, there is a detrimental effect on municipal services and infrastructure both at the surface and below ground (Zhou et al., 2018). Urban flooding can also be a predecessor to the third type of flooding called sewer surcharge (Candela & Aronica, 2016).

Sewer surcharge flooding is a result of excess water within the sewer (either as combined drainage and sanitary or just sanitary) networks that exceed the drainage capacity of the system. Sewer Surcharge flooding can be the result of extreme rainfall/hail events, or from blockages in the system that restrict discharge (often due to improper items being flushed down the pipes). When there is flow within a sewage pipe system that exceeds the design capacity, then the flow can back up into nearby homes. Surcharging can occur in the storm pipe network and can cause flooding at the surface.

The damage caused by flooding has been steadily increasing around the world (Zhou et al., 2018; Al-Amin et al., 2019). Managing and mitigating flooding has become a priority for many municipalities around the world (Rasmussen, 2016; City of Toronto, 2019; Region of Peel, 2019). Damage caused through these flooding events can severely cripple cities and towns and in extreme cases cause enough economic damage to force groups to move away (Al-Amin et al., 2019). Focusing on flooding seen within Alberta, Canada, Edmonton was hit by two major urban flooding events in 2004 and 2012 (Edmonton, 2004; Edmonton, 2012). Riverine flooding also affected Calgary in 2013 and Fort McMurray in 2020 (Hetherington et al., 2021; Red Cross, 2021). Each of these flooding events caused millions of dollars in damage (IBC, 2019; Jha et al., 2012).

There are a number of factors that can increase the severity of flooding. Not all of the drivers can be managed through human action. The two key factors that impacted building the flooding IRP as part of this thesis include municipal infrastructure and climate change. Municipalities has underground pipe infrastructure that had begun to age and/or had undergone changes in design standards. Climate change is changing weather patterns that bring about larger and more intense flooding events.

2.2.1. Municipal Pipe Infrastructure

Underground pipe and storage infrastructure within municipalities impacts how stormwater can be managed. Underground infrastructure can pose a challenge to determine the risk of flooding due to the variability within the network (Dawson et al., 2008). Municipal pipe networks can include a mix of original combined system, and the newer separate system that includes storm pipes and sanitary pipes. Traditionally, all the sewage from homes and exterior stormwater from streets would enter one pipe called a combined pipe. Through changing design standards, this network was separated into sanitary pipes which collect waste and stormwater pipes which can be attached both to the streets and homes and only collect rainwater or groundwater discharges. Not only should the changes to the underground pipe system be taken into account, but the age of the infrastructure can impact the extent of flooding.

Historical design standards also impact the extent of flooding within an area. In these cases, areas that were designed for the standard of the day, can be at risk due to larger infill homes being built in the area or additions to upstream pipes that result in the existing pipes being undersized. These undersized pipe, do not have the capacity to remove stormwater from the streets, causing deep pools of water to form with heavy precipitation.

Homes within municipalities are also at risk due to their connection to the underground system and age (EPCOR, 2019). The image below (Figure 2-1) demonstrates the multiple ways that stormwater can enter an average home. This image provides an example of a separate underground system for a mature neighbourhood home that has settled resulting in a negative grading towards the home. The longer stormwater remains on the streets the higher the risk of stormwater entering the sanitary system. Stormwater that enters the sanitary system will equalize between the storm pipe and from the roadway which will drain in to the home. The mix of stormwater and sewer entering a home is called sanitary surcharge and can cause health risk to the residents. This is seen most often in the combined sewer areas but can also occur in separate systems. Focus for mitigating sanitary surcharge should not just rely on underground infrastructure but on a holistic approach that looks at the home and grading of streets, and public/private property (EPCOR, 2019).

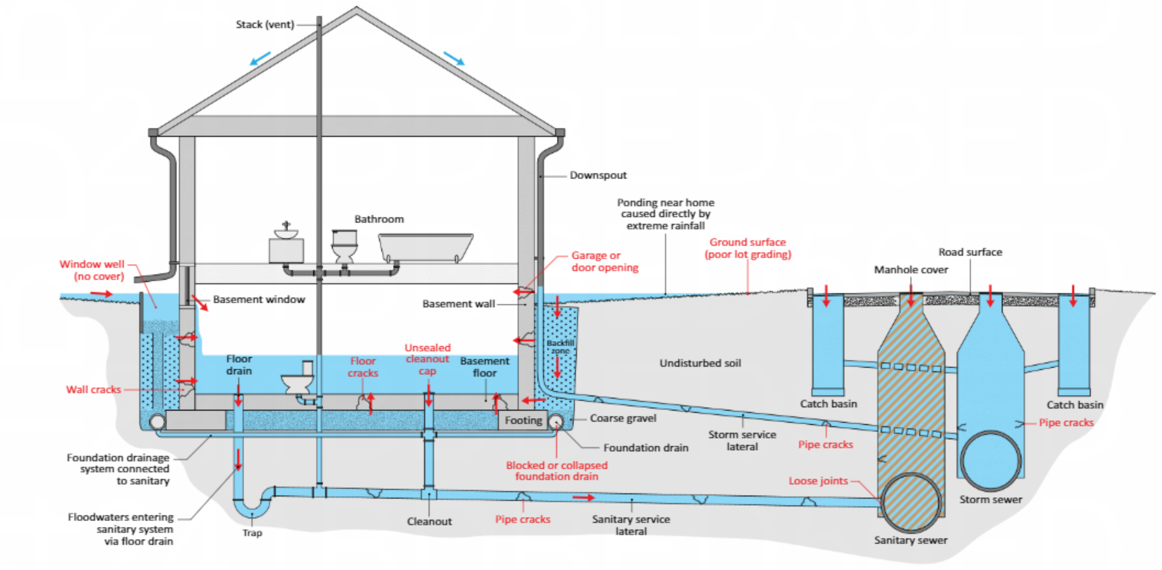


Figure 2-1: CSA Standards Z800-18 Guideline on Basement Flood Protection and Risk Reduction

Along with changes to the design standards as to how the system is built, the underground infrastructure itself ages and can experience failure. Cracks within drainage piping can allow wastewater to be released untreated into groundwater and in some extreme cases cause sink holes. These cracks take place in the pipe network and also attract tree roots due to the nutrients and liquids. Tree roots within the system can cause blockages that result in sanitary sewer flooding within a home. Other impacts that can cause sewer backups include fats, oils, greases, and most recently "flushable" wipes (Michael, 2020). The underground pipe network was not built to manage all of the non-degradable solids that cause major damage to drainage systems (Michael, 2020).

Damage to underground infrastructure can be difficult to detect and costly to repair. Aging infrastructure is key when evaluating flooding concerns brought forward by the public. Anni et al. (2020) experimented using MikeUrban hydraulic modeling software by comparing an area with underground infrastructure and the lack thereof. The conclusion was that there is a significant difference in flooding depth and volumes when there was no underground pipe network specifically for smaller events but also with larger events. If the pipe network is damaged due to age this would indicate similar results and cause an increase in flooding that may not be seen when hydraulic modeling takes place to determine flooding areas.

2.2.2. Climate Change in regards to flooding

Climate change models have been created to show projections of future climatic conditions on both a global and regional scale (Zhou et al., 2018, Al-Amin et al., 2019). A number of the scenarios for global models indicate an increase in high intensity storm events (Masson-Delmotte et al., 2021). These increases in storm events will result in increased frequency and volume of rainfall and snow in Canada (Masson-Delmotte et al., 2021; Jeong et al., 2020; Teufel & Sushama, 2021).

There are a number of climate models that were created through multi-year collaborations (Bush & Lemmen, 2019; CCCR, 2019; Teufel & Sushama, 2021). The results of these collaborations indicate that, specifically within the Canadian prairies, it is expected that the largest increase in precipitation would be during the spring by up to 26% by the later 21st Century (Stewart et al., 2019; Bush & Lemmen, 2019). This is followed closely by an increase in rainfall during the fall by up to 10% (Stewart et al., 2019). These increases have already been seen to cause damage within Alberta since the beginning of the 21st Century (Bourdeau-Goulet & Hassanzadeh, 2021).

Climate change has been researched and is thought to be the leading cause related to increased natural disasters (Masson-Delmotte et al., 2021). Adapting today's infrastructure to the expected results of climate change has only recently been reviewed (Jha et al., 2012). Proactive work should look at investing in municipal infrastructure early to prevent expensive upgrades when assets fail.

2.2.3. Other drivers of flooding

There are many different drivers of flooding that have been researched throughout the world. A small sample of other drivers includes:

- Rapid urbanization (Mahmoud & Gan, 2018)
- Soil content (Berghuijs et al., 2019)
- Increased peak rainfall (Berghuijs et al., 2019)
- Utilization of green infrastructure (Low Impact Development or Stormwater Management Ponds)

There are many studies that review these flooding drivers but for consistency within this thesis, no other studies will be discussed.

2.3. Risk Management – What it is and how to build a Risk Methodology

Risk management can be defined by three questions: What can be done? What options are available and what are their trade-offs? and What are the impacts of current decision on future options? (Blais et al., 2009; Wilcox & Ayyub, 2003). Blais et al. (2009) and Wilcox et al. (2003) also define the goals of risk management: to reduce risk to an acceptable level, and to prioritize resources based on a comparative analysis of alternatives. To meet these goals the requirements are, 1) Definition of acceptable risk 2) Comparative evaluation of alternatives, and 3) Optimal allocation of resources to meet institutional goals.

A flood risk methodology can be built using many different key elements: hazards, exposure, vulnerability, and public perception (Pham et al., 2021, Al-Amin et al., 2019). Pham et al. (2021) defined flooding hazard in regards to human life and property damage. Risk can be undertaken through passive or reactive activities (Hopkin, 2013). Passive risk management can be identified through long term monitoring and data collection (Hopkin, 2013). Reactive risk management is identified through seeking to influence the level of risk that is being faced (Hopkin, 2013). The focus of this thesis is on proactive risk management. Determination of flood risk can improve the creation of successful strategies for flood mitigation.

Proactive drivers for risk management identify the potential impacts through a combination of likelihoods (Hopkin, 2013). Hopkin (2013) defines the impacts as "The size and nature of the consequence of a risk materializing" and will be used in parallel with consequence in this thesis (Hopkin, 2013, Chapter 1). Likelihood is also defined by Hopkin (2010) as "the chance of a risk materializing" and can also be defined as the probability of occurrence.

Some of the impacts that Hopkin (2013) indicates as part of a proactive risk management include either damage or benefits through financial, infrastructure, reputation, or marketplace. The number of impacts can change based on the business or use of the risk management framework. Consequences have also been known to change based on the length of occurrence (Hopkin, 2013). Once the consequence and likelihood of risk are evaluated as part of the risk assessment then strategies, tactics, operations, or compliances can be evaluated to reduce the consequence of the risk.

Hopkin (2010; 2013) indicated that there are many techniques that can be used to evaluate the risk. These include but are not limited to workshops, brainstorming sessions, inspections, audits, checklists, questionnaires, HAZOP (Hazard and Operability), FMEA (Failure Model Effects Analysis), SWOT (Strengths, Weakness, Opportunities, Threats), and PESTLE (Political, Economic, Social, Technological, Legal, Environmental) analysis. Public questionnaires will be evaluated in more detail in section 2.4.3. Of these techniques, workshops are the most common and can provide multiple opinions on different risks (Hopkin, 2013).

Developing a risk methodology can either be completed by an individual or a team but should be updated regularly (Hopkin, 2013). As measures are put in place the risk assessment would also change.

The methodology could be applied to an action or be used to determine a long term plan. Learning from actions taken can determine if the risk is robust or if changes are required (Hopkin, 2013).

There are different levels or criteria of risk that can be analysed. Hopkins (2010; 2013) indicated that for different business there are four types of risk that may or may not be applicable. They are:

- Financial risk
- Infrastructure risk
- Reputation risk
- Marketplace risk

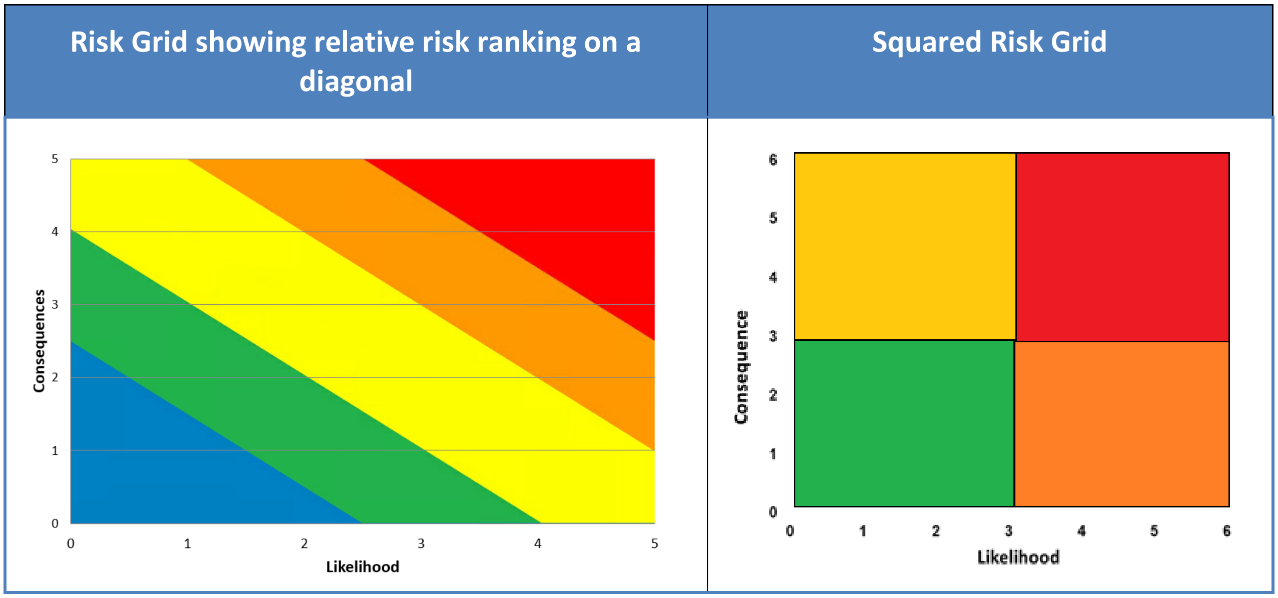
Risk criteria can focus on one aspect of business portfolio, or they can be combined to present multiple risks. There are also new or unknown risks that need to be evaluated when creating a risk assessment. Existing risks, already known by organizations, are fairly straight forward to incorporate into the system. New risk would be something that could occur or might be created by external environmental changes. Unknown risks are classified as risks that have not been experienced to date because they are connected to new actions, strategies, or operational changes (Hopkin, 2013).

The easiest method of demonstrating risk is to use a risk map or grid (Hopkin, 2010). There are many formats that this can take and each type of organization will have a different method of both demonstrating the risk and determining the level of acceptance. Hopkin (2010) created a standardized format that can be viewed in the figure below.

Magnitude / Consequence	Low Likelihood High Magnitude	High Likelihood High Magnitude
	Low Likelihood Low Magnitude	High Likelihood Low Magnitude
	Likelihood	

Figure 2-2: Hopkin standardization of a Risk Grid (2010)

Consideration of all pending projects within certain zones has been found to assist in prioritizing projects according to risk. There are multiple ways of colour coordinating the likelihood and consequence graphs to indicate the highest risk. Figure 2-3 shows two methods of displaying risk grids.


Risk Grid showing relative risk ranking on a diagonal

Squared Risk Grid

Figure 2-3: Examples of Risk Ranking Grids

Using colours and patterns different project classifications can be explained, as shown in Table 2-1.

Colour	Consequence	Likelihood	Action
RED	High	High	Intolerable requiring immediate intervention
ORANGE	Low	High	Increased monitoring required
YELLOW	High	Low	Increased contingency planning required
GREEN	Low	Low	Annual review to confirm risk ranking

Table 2-1: Colour, Consequence, Likelihood Classifications

Since the focus of this thesis is on the flooding risk for the City of Edmonton, a review of risk methods was completed to determine if there were any methodologies already utilized within the City. The closest risk ranking methodology that was available and could be compared against long term was the climate change risk ranking created by the City of Edmonton. See section 3.2.1 for more information regarding the Climate Change risk ranking within the City of Edmonton.

2.3.1. Creating Likelihood

Likelihood is expected to be different for each entity when calculating risk (Hopkin, 2013). Each entity will create a series of definitions, with details as to the classification of the likelihood. Some examples of definitions that Hopkins (2013) provides include:

- Very likely; it is expected to occur with high frequency
- Likely; there is a persistent issues , or it has happened in the past or elsewhere
- Unlikely; it has occurred at some time in the past but not likely in all circumstances
- Very unlikely ; has not been known to happen in the recent past

Rainfall events have already been classified into likelihood scenarios based on the probability of occurrence. The common understanding by civil engineers and hydrologists is that a "100-year storm event" has a 1% probability of occurring in any given year. Using Hopkins (2013) definition this would be classified as a very unlikely scenario. The more likely storm events would be classified as the 1 in 1 which has a 100% probability of occurrence every year.

Intensity-Duration-Frequency (IDF) curves model rainfall events for a specific part of the world and utilize historical rainfall data to determine the IDF curves. These curves would indicate 1 in 100 year rainfall events, and is used as the basis for city planners to build/maintain infrastructure.

For the City of Edmonton, the 100-year storm event is the design standard (EPCOR, 2020). Standard practice for defining storm events is to calculate the probability of a storm occurrence in one year. Utilizing the probability of occurrence for storm events can be and is used as the method of determining likelihood for the SIRP risk ranking methodology. Storm events and other information is utilized for determine the other half of determining risk, the consequence.

Review of how insurance companies apply flooding risk to determine their insurance rates indicated that insurance companies do not look at one individual storm event. During an Insurance conference in Edmonton it was stated that insurance companies determine the risk of flooding based on a range of storm events (Šárka, 2018). JBA Risk Management is one of three companies that provide flood maps to insurance companies utilize a range of flooding events from 20 years to 1,500 years.

2.3.2. Constructing Consequence

Similar to likelihood, consequence or impacts have a number of methods of calculating the risk. Some examples of definitions that Hopkins (2013) provides include:

- Major; major loss of services for an extended period of time
- Significant; complete loss of services for short period or significant effects on services
- Moderate; moderate effect on services for a short period of time
- Minor; short disruption of major service or minor effects on non-critical services

Risk is determined through the designation of likelihood and consequence scales. Different fields would have different levels of impact. For example, the highest level of impact for a financial business could be loss of funds, whereas for natural disasters it would be loss of life (Hopkin, 2013).

There are many different data/information sources that can be used to determine the different levels of damage. For this risk ranking methodology, determining consequence was built using a number of previously completed data sets. The one that provided the greatest impact was the use of previous hydraulic models. These hydraulic models were built using Mike Urban.

There are different types of urban flood models. The most common are 1D-1D or 1D-2D models. A 1D-1D model is created based on the underground piping system and level of surcharge at one point, through the manhole. A 1D-2D model can either be top down or bottom up. The bottom up approach is more common in past hydraulic models and demonstrates the pipes that are over capacity and the distance that pooling water would extend beyond a manhole. A top down approach requires greater computer processing power and more computing time (Kourtis et al., 2017).

The top-down approach would look at rain falling over an entire network, where it migrates and pools in lower points and at which location it would enter the sewer system. Hydraulic model calculations are applied using surface flow based on a 3-D terrain model, most commonly produced using a Light Detection and Ranging (LiDAR) survey. When using 3-D terrain models, it is possible to model both the depth of flooding at a location and the extent of flooding (EPCOR, 2018). All three types of surface flooding models were initially considered valid for the risk grid evaluation. However for the 1st SIRP iteration, only the 1D-2D models were used since they provided better understanding of the surface flooding extent.

2.3.3. Using Public Surveys to build Risk Models

Another aspect of building risk ranking framework can include the use of public surveys. Questionnaires or surveys have an advantage when evaluating risk due to the shorter timeframe to complete and the ability to simplify the questions (Hopkin, 2013). Although the advantage is collecting a number of opinions quickly, the disadvantage is that the questions may not leave room to explore or learn about different risk (Hopkin, 2013). Public Engagement can be a helpful tool when creating risk-analysis or decision-making processes (Penning-Rowsell & Becker, 2019). This methodology can assist with building trust and open communication during emergencies (Penning-Rowsell & Becker, 2019) but if used incorrectly can deteriorate trust within the community (Penning-Rowsell & Becker, 2019).

According to Penning-Rowsell & Becket (2019), it is important when utilizing public engagement or surveys to be able to answer the following questions: Who within the public is required to participate? How should engagement within the participants be managed? And when should they be engaged (Penning-Rowsell & Becker, 2019)?

Statistics Canada has a full report on survey methods and practices that include how to determine the sample size, data analysis, and more (Statistics Canada, 2010). For the purpose of this thesis, the focus will be on questionnaire design and data analysis. The survey completed was built with the assistance of ThinkHQ a survey company within Canada who provided assistance in creating the design of the survey and the survey questions, and then provided the completed data analysis.

According to Statistics Canada (2010) there are two kinds of surveys: sample and census. A census requires collection of data from everyone within the population, whereas a sample collects information from only a fraction of the population. Sample surveys are then broken down into non-probability and probability samples (OMB, 2006). Non-probability samples can usually be completed quickly but assume that the sample reflects the thoughts of the population as a whole (Statistic Canada, 2010). Probability sample takes more time but there is confirmation that the survey is completed by specific groups within the population. This usually takes longer but is considered more reliable by statistical agencies (Statistics Canada, 2010). A Probability sample was created for this study.

Statistics Canada (2010) outlines a method to determine the number of participants for a survey through past experience. They have determined that there is a margin of error based on the sample size, where a sample size of 50 would have a larger margin of error then a sample size consisting of 1,000 individuals. The sample size should also be compared to the total population that would be affected by the survey (Statistics Canada, 2010).

Once the sample size has been determined, the survey questions method can be evaluated. The manner and method that questions are asked has to be constructed so as not to lead the survey participant to a conclusion. Survey questions will change based on the method of data collection, the same question would be asked differently depending on whether the survey was completed on paper, online, phone, or interview style (Statistics Canada, 2010). Instructions can be included if the questions are considered complex (Statistics Canada, 2010, OMB, 2006). Before releasing the survey questions to the target audience, a test of the questioner should be completed to identify any problems such as spelling or awkward wording (Statistics Canada, 2010).

Types of survey questions can include two choice, multiple choice, checklist, ranking or rating (Statistics Canada, 2010). For this thesis a ranking method called a Maximum Difference or MaxDiff (Chrzan & Patterson, 2006) chosen. A MaxDiff survey poses a question and then provides a subset of factors statements for the survey participant to choose their most and least important statement (Wang et al., 2011). The questions are asked a number of times with the response statements changing. This allows the analysis at the end to compare the different statements against each other on a most to least importance scale (Wang et al., 2011). This creates a matrix questionnaire to balance the statements (Wang et al., 2011).

Analysis of the MaxDiff survey can be completed a number of ways. Wang et al. (2011) used a scoring system for each time a statement was chosen as most important. EPCOR (2018) used a conjoint analysis methodology to determine the preference of statements.

2.4. Summary of the Literature Review

Understanding types of flooding and the extent of damage that result from these events can be applied to developing a methodology to prioritize flood mitigation projects that are key for municipalities. Utilizing known drivers of flooding can assist in building a methodology that is specific to an area. The risk ranking is built using storm events to determine likelihood and hydraulic models and other data sets (i.e. social) are used to determine the consequence.

3. Flood Management Styles Around the World

The Stormwater Integrated Resources Management plan was created by EPCOR for the City of Edmonton, Alberta in October 2018. The goal was to build a risk ranking methodology so that the City of Edmonton and EPCOR could understand the risk of flooding within the municipality. During the creation of SIRP, a review of learnings from other municipalities within Canada and around the world helped to shape some of the risk criteria. As mentioned previously, this was the first time an IRP was applied to stormwater in the form of a risk ranking methodology. The first part of the EPCOR Stormwater IRP was the creation of the risk ranking methodology which is explained within this thesis. A brief description of the second part of the EPCOR SIRP creation is included in Appendix A.

3.1. Edmonton Previous Flood Mitigation Works

Edmonton has experienced a number of major flooding events. The most severe riverine flooding event in Edmonton occurred in 1915 and was ranked as a 1 in 142-year flooding event (Sameng, 2015). This flood caused 2,000 people to be displaced, destroyed 50 buildings and submerged over 700 homes. During this river flooding event, some homes were literally lifted off their foundations and floated down the river; however no lives were lost (Edmonton Historical Board, 2019; City of Edmonton, 2020). There were no records found relating to flood mitigation programs that were implemented to mitigate the outcome of this type of event from re-occurring. And, although no records have been found, it is believed that the City of Edmonton purchased many of the properties within the flooded neighbourhood Rossedale, located on the city flood plain, and the City has prevented homes from being rebuilt on these sites.

In 2004, heavy rain accompanied by hail and high winds caused flooding of over 2,000 homes. Hail mixed with rain caused many of the catch basins and lateral pipes to plug, causing extensive basement and street flooding throughout communities of West Edmonton, and the community of Mill Woods in South East Edmonton. As well, hail blockages to storm drains caused a number of underpasses to flood along Whitemud Drive (a major arterial transportation route spanning the city). This storm event caused over $10 million damage to the famous West Edmonton Mall (Mahoney, 2004). Insurance underwriters estimated the cost of homeowner damage to be in the range of $87 million (Canadian Underwriter, 2004). This flood was registered as a 1 in 200-year rainfall event (City of Edmonton, 2004). Following this event, the Neighbourhood Flood Prevention Program was created (City of Edmonton, 2006). This would be classified as a reactive program that focused only on the neighbourhoods that had experienced flooding.

Eight years later, in 2012, over 200 mm of rain mixed with hail fell within a few hours causing storm drain blockages and significant street flooding (CBC, 2012). Again, during this event, several underpasses were flooded causing City fire and rescue to use boats to get to residents stuck in their vehicles to these underpass locations (Shaw & Hoang, 2012). The 2012 event caused flooding to over 2,000 homes and extensive damage to City infrastructure through manhole blow outs: pump station flooding, washed out park trails, and erosion of bridge abutments. A recreation center was forced to shut down when overland flows caused a breach in one of the security doors and flooded out the basement electrical room (CBC, 2012). Environment Canada predicted that over 100 mm of rainfall fell through parts of Edmonton in under a half hour (CBC, 2012). Due to the extreme precipitation rate, this storm event was classified as a 1 in 200-year rainfall event (City of Edmonton, 2012). After this event, another program, the Expanded Flood Mitigation Program, was created (Sameng, 2014). Again, a reactive program, as it only focused on the flooded neighbourhoods.

Four years later, in 2016, a series of storm events occurred within the same week and flooded a major underpass in south Edmonton. The fire department was again required to use the rescue boat to save people from their flooded vehicles (Theobald, 2016). The only reported damage from these storm events was to vehicles caught in flooded underpasses. This began a more focused proactive study looking specifically at all of the underpasses throughout the City of Edmonton. This study resulted in a risk ranking of the city's underpasses based on the probability of flooding and the expected depth of the flood water. Sites that would flood over the allowable design standards (0.35 m) during smaller storm events were considered the highest risk (EPCOR, 2020).

After the 2012 storm event, Edmonton's Utility Committee made a request to the City's drainage planning team to provide a list of all of the neighbourhoods that were at risk. This was the first proactive flood mitigation strategy, determining which areas of the City were at greater risk and suggesting solutions to mitigate future flooding. The City-Wide Flood Mitigation Strategy (CWFMS) began its study in 2014 and completed in 2017. It focused mostly on the creation of a City-Wide Mike Urban Hydraulic 1D-2D model. The model results were then utilized to determine flood mitigation projects. Based on the project cost-benefit results, a prioritized neighbourhood mitigation list was created. This strategy covered three quarters of the developed City as part of their study. Its focus was on residential neighbourhoods that had not already experienced flooding, and were built before 1980's based on the design standards of that era and the existing underground piping networks. When this project was brought forward to the City of Edmonton Utility Council there was some concern at the high cost of the proposed projects and the timeline to complete the work. Shortly after proposing this project to Utility Committee, the City of Edmonton Drainage team was transferred to EPCOR. The results from the study were still considered useful as hydraulic models which were then included in the SIRP risk ranking methodology.

Based on the number of flooding events between 2004 and 2016, there was an increased public awareness of storm events to flooding of private property. The Flood Mitigation Strategy of 2016, outlined the flood mitigation strategies based on the flood potential of the city, as well the requirement of flood mitigation infrastructure. The Public Engagements sessions, which were part of the City-Wide Flood Mitigation Strategy, demonstrated that flood mitigation had reached the forefront of people's minds.

3.1.1. Municipal Infrastructure Management

There are two issues that the City of Edmonton experiences in regards to infrastructure management. The first is that the City of Edmonton has grown through annexation since 1892 (Laliberte, 2014). The City of Edmonton was incorporated as town in 1892 and then as a city in 1904. Over the next one-hundred year, after the first incorporation, there were 31 areas that were annexed into the city. This growth through annexation created distinctly different areas of underground infrastructure with differing levels of infrastructure and services. Many of these annexations included smaller municipalities that had their own design standards and pipe network system. These pipe networks were left as is until maintenance required changes to the system. This means that there are pockets of pipe network can be the same age within a neighbourhood or can have a difference of a decade either older or younger, with effects on the risk based on the age of the pipes and the probability of failure.

As annexation has taken place, it has not been a normal practice for municipalities to upgrade the different infrastructure standards. This resulted in a mixture of infrastructure built under different design standards. Due to this, and even though there have been some legacy upgrades, each neighbourhood within the City of Edmonton has a unique risk for flooding. As a result, City councils have made decisions on which neighbourhood should undergo flood mitigation using a simple comparison of the number of properties that would be positively impacted by any flood mitigation project.

The City of Edmonton had a major change in the design standards in the 1980's when they switched from a combined sanitary-stormwater system to a separated system with the inclusion of major and minor storm systems. The sewer network can be viewed on the City of Edmonton Open Data portal (https://data.edmonton.ca/) that demonstrates the transition from the combined system to the separate system within the city. Since a separate sanitary system flow can eventually enter a combined system, this can prove challenging to determining the cause of flooding during a storm event. Internal studies within the City of Edmonton took place to determining the reason neighbourhoods flooded when they were on the edge of the transition from combined to separate system. The speculation was that sanitary surcharge flooding within these separate systems is due to the surcharging within the downstream combined system which backs up into the sanitary system.

3.1.2. Climate Change Adaptation Strategy

The City of Edmonton has identified a number of climate hazards and created the Climate Change Adaptation Plan (City of Edmonton, 2018) to mitigate climate hazards based on climate modeling.

In 2018, as SIRP was being developed, the City of Edmonton also began their "*Climate Resilient Edmonton: Adaptation Strategy and Action Plan"* (City of Edmonton, 2020), rebranded Climate Change Adaptation Plan. Synergies were found between the two strategies regarding the expected weather events and specifically with storm events. SIRP adapted to emulate the "*Climate Resilient Edmonton: Adaptation Strategy and Action Plan"* as the basis for funding future flood mitigation projects.

During the information collection period of SIRP, the team began meeting with the City of Edmonton's Climate Change Adaptation Team. Frequent discussion took place to discuss SIRP's proposed ranking methodology, and explore connections between the two projects (Climate Adaptation vs. SIRP). Part of the discussions were the major extreme weather events that the City believed were of the highest risk to the Edmonton Area (City of Edmonton, 2018).

Table 3-1: Extreme Weather Events from the City of Edmonton Climate Change Adaptation Team

Extreme Weather Event	Trend in Frequency of Event
Wildfire	Increasing
High Flow in River	Increasing
Low Flow in River	Increasing
Rain on Snow	Increasing
Freezing Rain	Increasing
High Wind	Increasing
Heavy Snow	Unknown
Blizzard	Unchanged
Hail	Unknown
Lighting	Increasing
Tornado	Unknown
Days Over 30C	Increasing
Heavy Rainfall	Increasing

Of the extreme weather events, listed in Table 3-1, two weather related consequences are contained within the drainage infrastructure: high flow in rivers (caused by increase rainfall or increased snow fall or fast-spring melt), and heavy rainfall. EPCOR decided to include these climate hazard risks in the SIRP risk ranking criteria and proposed mitigation measures. The Edmonton climate change team had already created a risk ranking methodology that matched what EPCOR had initially envisioned (Edmonton 2020)

The climate change adaptation team already had a Consequence and Likelihood table that outlined their different levels of risk, with Likelihood based on the probability of occurrence and Consequence based on the four different criteria of consequence (Edmonton 2020). The four consequence criteria that were selected and approved by the City of Edmonton are,

- Health and Safety
- Environment
- Social
- Economy/Financial

These categories were selected as they clearly convey the critical risk themes that are of the utmost importance to the City of Edmonton government and citizen's.

3.1.3. Availability of Data Utilized

Being part of the team that created SIRP, all of the historical flooding data from past storm/flood events were available while creating the SIRP program. SIRP was created by EPCOR for the City of Edmonton and after creation was approved for use in this thesis. All of the past decades of hydraulic modeling results were available along with many others sets of data from the City, were made available to EPCOR and were critical during the build the risk ranking methodology and resulted in the detailed product that resulted.

3.2. Municipalities from around the World

Since the IRP methodology had not been widely applied to stormwater when the study began, the SIRP team mostly focused on known information within EPCOR. During a brief review and discussion with other municipalities at conferences it was determined that only one municipality, Copenhagen, had a similar program to what EPCOR wanted to create with SIRP. Ongoing discussions with the City of Toronto provided some insight into the new methods of managing flooding.

3.2.1. Copenhagen

Copenhagen, the capital of Denmark, is situated along the coast of the Baltic Sea. This city is at risk of flooding from rising sea levels and extreme rainstorms (Rasmussen, 2016). To mitigate flooding, the municipality has implemented the “Cloudburst Strategy”, which focuses on flood mitigation and weather pattern changes.

Copenhagen focused on building a blue-green (similar to green infrastructure with the inclusion of sea level changes) approach through the cloudburst toolkit (Rasmussen, 2016). The results of the toolkit and cost analysis between the blue-green solution and pipe infrastructure resulted in a potential 50% savings for the blue-green strategy while providing the same benefit as a traditional grey infrastructure solution.

Copenhagen’s Cloud Burst strategy separated the city into catchment areas which were then used to determine the level of importance. Each catchment area was assessed using the following four categories; Risk, Implementation, Coherence with Urban Development Project, and Synergistic Effect

(City of Copenhagen, 2012). Based on these four categories the following map was created. This map indicates the areas of concern to mitigate flooding.

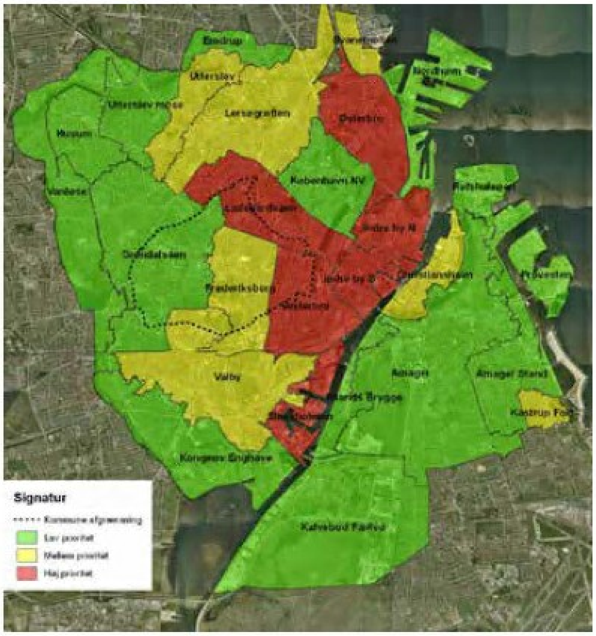


Figure 3-1: Copenhagen's Prioritising Adaptive Measures (City of Copenhagen 2012)

Copenhagen provided a touch point when building the SIRP risk ranking. They separated their city into understandable areas. Instead of the traditional method of looking at neighbourhoods, this method looked at the flow patterns of the drainage system both at the surface and through the underground pipe network. Also, their use of this multi criteria system allowed for prioritization of areas of concern.

3.2.2. Toronto

The City of Toronto has been working on a Flood Resilient Plan, which focuses on understanding the limitations of flooding data and climate hazards (City of Toronto, 2019; Office of Resilience, 2019). Their working group was created to look at four topics:

- Understanding the limitations of flood mapping/data
- Determining changes in climate with regard to their effect on urban flooding
- Identifying critical services/infrastructure and their flood risk requirements
- Allowing for data sharing between planning and development purposes

Similar to Copenhagen, Toronto created a methodology of looking at multiple data sets and how each affected the same area. The ability to evaluate multiple data sets to learn as much as possible about an area was key to building the new SIRP risk ranking methodology. Toronto also experienced a number of flooding events during the creation of SIRP, which prompted a few additional risk criteria to be included in the SIRP risk ranking methodology, including parkades and LID.

4. Methodology to Create SIRP Risk Ranking

The creation of SIRP started in October 2017 with the risk ranking results available for approval October 2018 at a City of Edmonton Utility Committee. The full report provided to the Utility Committee in October 2018 can be found in on the EPCOR website (EPCOR, 2018). An additional year was then used to automate much of the process. All of the results provided are from the 2018 demonstration to the City of Edmonton. Due to the short timeline, much of the creation of the risk ranking methodology was completed concurrently, which is typical of IRP methodology.

An overview of the steps taken for the creation of this thesis can be found in Figure 4-1, on the following page, which outlines the overall steps that were completed. Due to tight timelines many steps were completed concurrently. Within each step the sections were completed (concurrently except for step 3 in which development took place before geospatial analysis.

Step 1 consisted of evaluating known data and the format of its availability. Much of the data available was in a geospatial format which was the springboard to determining the software required that could produce a geospatial analysis of the final product. Undertaking this investigation resulted in an early choice of the final geospatial software for the project.

After completing Step 1, the focus turned to building the risk ranking methodology through likelihood and consequence scales, Step 2 in Figure 4-1. Using storm events and mortgage rates allowed for a brand-new method of applying for multi event likelihood. The likelihood scale was constructed with the use of multiple storm events, quite differently than traditional methods. The creation of the consequence scale followed a more traditional method, with the creation of key statements. These key statements were built to be easily transferable to other municipalities. One of the final focuses during the creation of the risk ranking methodology was to employ the use of a number of modifiers to assist with prioritization of watersheds and sewersheds (also known in this document as sub basins). From there focus was reviewing methods of weighting the consequence (based on the multiple storm events). A final action within Step 2, before moving to Step 3, was to build the risk grid using a non-traditional focus learned through the results of a public engagement survey, which was completed by ThinkHQ on EPCOR's behalf.

Step 3 involved building the map to showcase the risk ranking methodology. The first iteration was to use a grid with different coloured points for each storm event. This then transitioned to determining the maximum risk ranking and uploading the results onto a map of the City. The creation of this aspect of the project can be found in Chapter 5.

The final aspect of Step 3 can be found in Chapter 6 which reviews the dynamic capability of the model, as well as the application of the risk to create a flood mitigation strategy. The new risk grid was then tested for its dynamic capability with new hydraulic models and test sites. The work to this point as well as the validation was my own; EPCOR then used these results to build their overall Stormwater Integrated Resource Strategy.

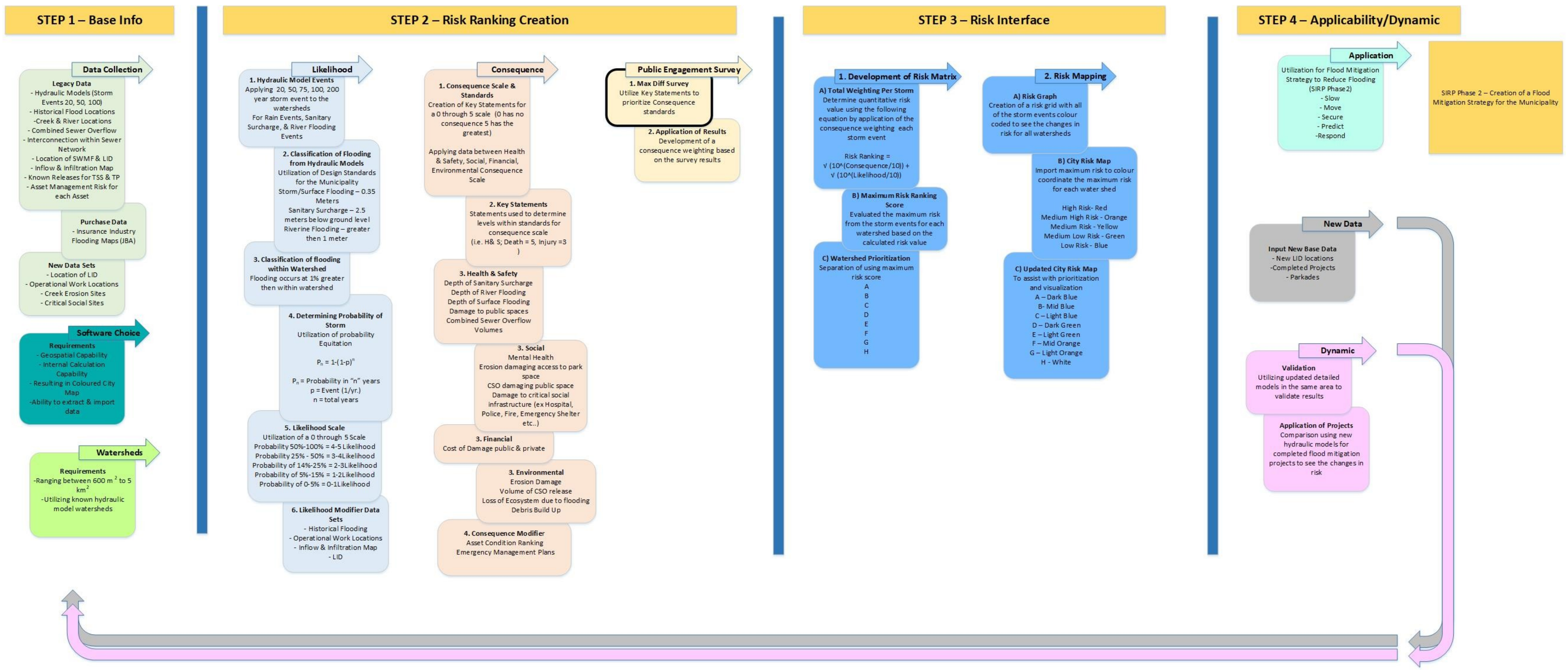


Figure 4-1: Diagram of steps of work completed as part of the creation of the SIRP risk ranking methodology. The black bolded box indicates work completed by others and the blue blocks indicate the separation between each step.

4.1. Selecting a Geospatial Software

There are many types of software that can be used to determining flooding risk within an urban area. Although modeling is important, the focus of this thesis is the utilization of a Geographic Information System (GIS) to evaluate the results from multiple past modeling results. GIS software allows the users to visualize, analyse, and interpret information through geo-coding the data sets, which helps to determine relationships, patterns, or trends (Harder & Brown, 2017). GIS can be utilized in multiple fields and can be displayed through purchased or public software or via the cloud.

There is a number of different software packages that could have been utilized with GIS capabilities such as BatchGeo, MapInfo, Citymapper, to name a few. For this thesis, the focus was on the ESRI ArcGIS suite of programs with the use of ArcMAP. ArcMAP was chosen due to the time constraints on building the risk ranking methodology and licensing had been previously purchased and available.

ArcMap is a part of a suit of programs from ArcGIS. ArcMap is a software that can geographically represent data on a map. This software allows the user evaluate/compare different data sets both visually on the map and based on proximity (Harder & Brown, 2017). ArcGIS also works as a display method for Mike Urban which is the software of choice for modeling within EPCOR, as well as, many hydraulic modeling consultants within Canada. The ability to open and evaluated modeling results after the fact is important for future updates within the risk ranking methodology. ArcMap also allows for geographical evaluation of the data sets directly in the software (Harder & Brown, 2017).

ArcMap has a tool called Model Builder which allows the user to create, edit, and manage models. Model Builder is a working window that converts Python code into easily understandable actions. The actions provide a visual programming tool so that the user does not have to learn Python script (ArcMap, 2016).

The results of hydraulic modeling can be used to determine the number of properties affected, the depth of flooding seen, and in some cases the length of time flooding will occur. These results can then be input into ArcMap to be viewed geographically with other factors (Harder & Brown, 2017). Through the use of both a geographical coordinate system with past hydraulic models and other data sets, the model builder provided a safe environment to trial the SIRP Risk Ranking methodology, allowing for "what if" scenarios to be developed, analysed, and rerun under different inputs.

An added feature of ESRI's ArcGIS software, there are a number of partners which provide additional licensing to software that are designed to expand the potential of ArcGIS. These partners include Innovyze, CityWirks, ConTerra, AED-SICAD, and Ericsson (ESRI, 2021). For a full list of partners visit the ESRI partners website.

InfoAsset Planner, created by Innovyze, is a partner software that utilizes the GIS data in ArcMap to assess risk and determine project costs (Innovyze, 2021) and has incorporated a likelihood and consequence risk builder. This system can be utilized to classify the likelihood and consequence based on the field within the files and then calculate the risk based on the likelihood and consequence built into the system.

Since EPCOR already owned the ArcMap and InfoAsset Planner software license, they were used to map and geographically compare data sets. These two software packages were chosen because of their compatibility with hydraulic modeling results, and personal understanding of the system due to the short timeline for building the methodology.

4.2. Information Collected and Utilization

The focus of SIRP was to find a method to utilize the model results, operational locations, and known asset conditions to create the risk ranking. The collected information was classified into four categories:

1. **Legacy Data**: Data already collected within the City of Edmonton and EPCOR and in a format that could be used for the risk grid approach 'as is' or required only mild reformatting.
2. **Purchased Data**: Required information that could be transferred or purchased from outside sources.
3. **New Data Sets**: Information that was considered important but needed to be built from scratch.
4. **Future Information**: Due to the timeline of project development future information was NOT

considered for the initial SIRP development, but may be identified as beneficial in subsequent risk grid updates/iterations.

All of the data that was collected and utilized can be found in Table 4-1, on the next page.

Table 4-1: List of Information files that were utilized to build the SIRP risk ranking

Title of Data	Category	Model/ GIS/ Other	Area Covered	Year Data Created	Storm Event Covered	Initially Used for 2018 Risk Release or Added Later	Publically Available/ Internal Documents*
City Wide Flood Mitigation	Legacy	Model	¾ of City of Edmonton	2015-2017	50 and 100	Initial	Edmonton's Open Data Portable
Mill Woods	Legacy	Model	1/6 of City	2012	100	Initial	FOIP office
JBA Flood Risk Maps	Purchased	Model	Everywhere	2018	20, 50, 75, 100, 200, 500, 1500	Initial	Available for purchase
Tawa Dry Pond	Legacy	Model	2 Neighbourhood*	2017	50, 100	Later	FOIP office
Parkallen Dry Pond	Legacy	Model	1 Neighbourhood	2018	50, 100	Later	FOIP office
Downtown Intensification	Legacy	Model	6 Neighbourhood	2015	20	Later	FOIP office
Steinhaure & Erminskin Dry Pond	Legacy	Model	2 Neighbourhood	2018	50, 100	Later	FOIP office
Hurstwood Wet Pond	Legacy	Model	1 Neighbourhood	2018	100	Later	FOIP office
Historical 311 Calls	Legacy	GIS	Everywhere	2014-2017	N/A	Initial	FOIP protected
Creek Locations	Legacy	GIS	Everywhere	2018	N/A	Initial	Edmonton's Open Data Portable
Combines Sewer Overflow	Legacy	GIS	Everywhere	2017	N/A	Initial	FOIP office
Interconnections	Legacy	GIS	Everywhere	2017	N/A	Initial	FOIP office
Low Impact Development (LID) Locations	New	GIS	Everywhere	2017	N/A	Initial	Edmonton's Open Data Portable

Title of Data	Category	Model/ GIS/ Other	Area Covered	Year Data Created	Storm Event Covered	Initially Used for 2018 Risk Release or Added Later	Publically Available/ Internal Documents*
Operational Data	New	GIS	Everywhere	2009-2017	N/A	Initial	FOIP office
Location of Stormwater Management Locations	Legacy	GIS	Everywhere	2017	N/A	Initial	Edmonton's Open Data Portable
Inflow and Infiltration Study	Legacy	Other	Everywhere	2015	N/A	Initial	FOIP office
Discharge Improvement Zones	Legacy	Other	Everywhere	2016	N/A	Initial	FOIP office
Creek Erosion Sites	New	Other	Everywhere	2012-2016	N/A	Initial	FOIP office
Critical Social Sites	New	GIS	Everywhere	2017-2018	N/A	Initial	FOIP office or through Alberta Health Services Website

* For access to data sets from the FOIP office, contact the City's FOIP department with the name of the report and the date it was published. https://www.edmonton.ca/city_government/city_organization/freedom-of-information-and-privacy.aspx

4.2.1. Legacy Data

Due to numerous flood mitigation programs undertaken by the City of Edmonton, the legacy flood data were considered applicable and the starting point of the legacy data collection. The importance of these legacy data sets included hydraulic models of the affected area which were transferred into ArcMap files, or easily transferable. Historical hydraulic models focused on only two of the three types of flooding under evaluation, sanitary surcharge and urban flooding. Many of the files were chosen due to their importance in demonstrating the current risk of flooding.

A review of the historical hydraulic models revealed a patchwork of coverage with many newer areas or industrial areas of the City with no past hydraulic modeling results. Since one of the measures of success for SIRP was that the risk ranking was to be dynamic and updated regularly, gaps in the available data were not considered to be critical for the first iteration of risk grid analysis. In some cases, other options were available. For example, the sanitary surcharge and urban flood maps were unavailable for areas built after the 1980's, which was the year that major and minor sewer separation became the design standard. Based on this, it was decided that as long as a neighbourhood was built after 1980's it would be considered protected from a 100-year storm event, due to updated design standards, and so acceptable for the first pass of SIRP's risk ranking methodology.

The next data set collected, since the 2004 flood event, were addresses of Edmonton Residents who had experienced flooding in their home. This data has proven important as it assisted in trending neighbourhood vulnerability for smaller storm events. However, this information did not have a qualification as to whether the basement flooding was due to sanitary sewer backups, overland rain flooding, snowmelt, water main breaks, leaking water hoses, etc, as possible causes.

City Operational Data was collected by Engineering within an Oracle database system. Included in this database were root clearing, grease collector cleaning, blockages, and sewer main flushing (EPCOR, 2018). These datasets not only included location of maintenance but also provided asset conditions and permitted a better overview indication of what network systems were experiencing.

Environmental data sets included reports outlining locations of all erosion found within creeks throughout the city and combined sewer overflow (CSO). Flood models were used to determine areas of environmental sensitivity and if these areas were affected by flooding events. Another Environmental risk was identified during the 2016 Study, called Discharge Improvement Zones study (*Matrix, 2016*). This study identified locations within the City of Edmonton that had high releases of total suspended solids (TSS), and total phosphorus (TP). TSS and TP are important environmental factors that can impair oxygen intake which effect the feeding of aquatic species, as well as polluting creeks, ponds, and rivers. TP can cause algae blooms if it enters a water body in high concentrations which can cause decreases in the diversity of the ecosystem. TSS not only includes sand and grit but can also transport other contaminants such as oils or aqueous cations/anions of heavy metals, pesticides or organic poisons which also have environmental impacts. The volume of TSS and TP entering the North Saskatchewan River is monitored by Alberta Environment and there have been requests to reduce the volume of TSS and TP entering the river (*Matrix, 2016*).

The EPCOR Asset Condition Team has risk ranked all of the drainage assets within the City of Edmonton. They provided maps of the asset risk which were than evaluated and included into the risk ranking methodology. The Drainage asset risk was based on a program of scheduled inspections (including video surveys), and extrapolation of past failures, and update these condition ratings annually. These models tend to assume that the pipes are all clear and have no reduction in passage at all flow rates, so the drainage team would then estimate, based on the condition of a drainage pipe, especially unpressurized concrete and steel pipes, effects on flow rates during extreme events. However, the asset ranking records clearly indicated to the SIRP team that this was not the case, and that historic flood records showed surface and sanitary surcharge flooding in areas that had an excess of theoretical drainage capacity. Neighbourhoods with underground drainage systems with actual flow rates less than theoretical, for example from the presence of grease and roots in a portion of the pipe network there would be less capacity within the pipe thus resulting in higher consequences of flooding or would experience flooding during smaller storm events. The drainage infrastructure condition data sets were used to identify areas within the City with a higher flood risk than would otherwise be modeled. Review of the data provided thousands of geo-tagged asset locations. Using geospatial analysis software allowed operational condition rating and asset risk ranking data to be included in data collection, and a preliminary review was done to identify areas where higher risk of flooding could be anticipated, or at least partially explain why flooding had already occurred. The asset risk ranking based the condition of the assets for likelihood of failure and consequence of failure. Assets were given a higher risk ranking when failure would have a disproportionate impact on the drainage system.

4.2.2. Purchased Data

For areas within the City that were outside of hydraulic modeling zones, it was initially thought that a surrogate should be used. The risk would be based on the age of the storm infrastructure in the sub basin. This was eventually removed in favor of the JBA Risk Management (JBA) Flood Risk Maps which covered all of the City of Edmonton and external boundaries.

While attending a meeting in May 2018, hosted by the Canadian Water Network for the leaders of the major Cities in Canada and the senior leaders from multiple insurance company the SIRP team learned that it is standard practice for insurance companies to purchase flooding risk maps from one of three companies that complete flood risk analysis. The SIRP project team determined that there were three companies around the world that specialize in Risk Analysis and production of flood maps for commercial sale. JBA Risk Management were successful in providing flood maps, for both urban (surface) and riverine, to EPCOR. JBA's standard product, for every flood risk in a geographic area, includes maps of the following extreme rainfall events (format - 1 event over x years); 1:20, 1:50, 1:75, 1:100, 1:200, 1:500, and 1:1,500.

The SIRP team proofed Insurance JBA flood maps against previously developed City hydraulic models. Figure 4-2, below, provides a visual comparison of the extent of flooding between the maps purchased from JBA and EPCOR internal model for the 1 in 100-year storm event. When the visual comparison is done for at large scale, there is little difference between the two predictions. This indicates that the initial removal of surface ponding that JBA removed to account for city infrastructure is comparable. Comparison on a neighbourhood scale, there are significant differences between the two predictive models. There is one major difference between the insurance models and city models, the LiDAR grid system used. Examination of the inputs used by the two models identified two sources of difference:

1. JBA models uses a 3-D terrain model based on a 30 metre grid resolution, a product of the Federal Government (Alexandre, 2019). The EPCOR hydrologic models use a 3-D terrain model based on a 0.5 metre grid resolution (City of Edmonton, 2017) producing small-scale differences in overland flow.

2. Insurance JBA model system does not include the effects of the drainage pipe network on overland flooding.

The SIRP team had previously determined that multiple flood models would be used as inputs as long as both sanitary and storm models were used (EPCOR, 2018). Although these models had limitations noted above, the SIRP team included JBA flood maps as an input to the risk grid, providing a baseline of large-scale resolution for sub basins within the City.

Comparison of Insurance Maps to Engineering Analysis – 1:100 Year storm	
Insurance Flood Maps River and Urban Flooding	**City Wide Flood Mitigation**
	

Figure 4-2: Visual comparison of the extent of flooding between JBA and City of Edmonton models. The coloured sections indicates flooding between 0 to over 9 meters in depth. The JBA map demonstrates blue as the river flooding extent and the green is the surface flooding.

Figure 4-3, below, demonstrates something that had never been seen in such detail before, the range of storm events over the same area. Municipalities and utilities tend to focus on one storm event and aim to provide mitigation for that one event to meet the design standard, 1 in 100-year storm event. Since the JBA maps include the range of seven different events they could be superimposed over one another to demonstrate the difference between events. Figure 4-3 shows that when the storms are superimposed on one another the location of flooding remains relatively the same which was expected.

The conclusion that resulted from this visualization was that damage due to flooding remains within the low areas. There is limited geographic difference between a 1:20 year and a 1:200-year event for the properties that are most at risk.

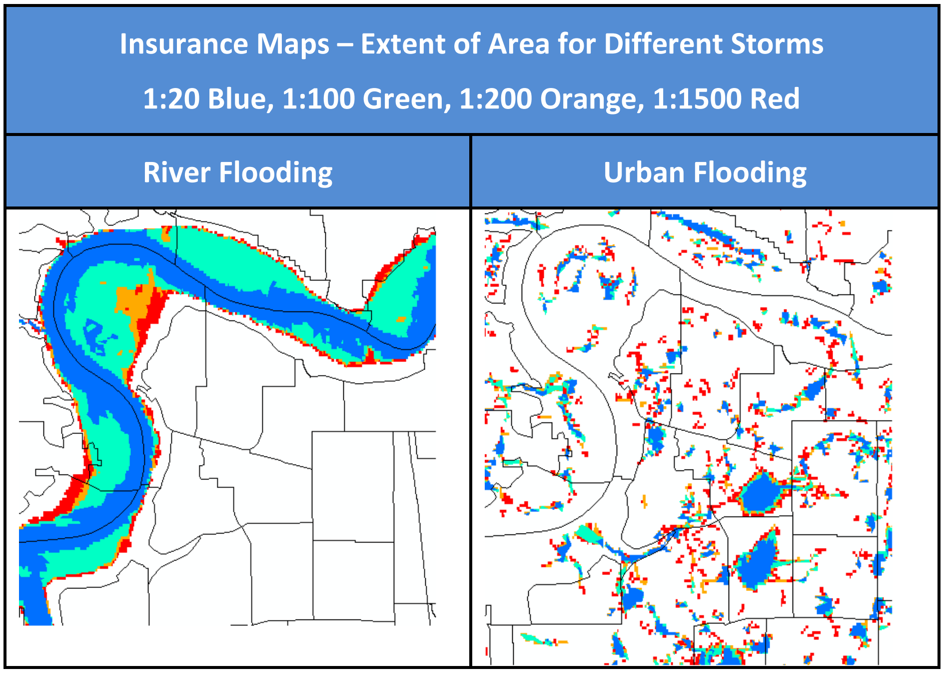


Figure 4-3: Different in flooding extents for JBA flood maps based on return frequency

4.2.3. New Data Sets

One of the data sets that was built, specifically for the SIRP risk assessment, was a map of the location of the Low Impact Development (LID) sites. Hydraulic models to date have not taken into consideration the retention of storm water at the LID sites, which prevent storm water entering the pipe network. It was considered important to start taking LID's into account at the beginning of the risk ranking creation since long term changes to the system would in all likelihood include a significant increase in LID's.

As mentioned previously, Edmonton's Climate Change team had focused on the consequence categories of Health & Safety, Environmental, Social, and Financial. Social was a dataset that had not previously been considered as part of the past flood mitigation programs. The SIRP team had to build a new geospatial shapefile for the location of the identified Social factors. This map included consideration of the impact of flooding on public and private properties that provide public services (Hospitals, Police

Stations, Fire Stations, Schools, Senior Homes, Underpasses, Medi Centers, Shopping Centers, etc.). Inclusion of these specific properties was corroborated by the results of Public Consultations.

4.2.4. Information to be added in the Future

Due to the limited timeline for the risk grid development and approval, some information, which was considered important, but could not be collected expediently, was delayed for a future iteration. A few of the items not included in the initial development include Parkades, Alberta Health Services Buildings, above & below ground LRT Lines, and warehouses for food storage. It is expected that as the risk ranking system is updated on a bi-yearly basis these items will be included.

However, some specific properties were added to the data set as a result of data collected from reported flood events in other jurisdictions. For example, parkades in depressed topography were planned to be added following a flood event in the City of Toronto in 2018 (Canadian Press, 2018).

4.2.5. Utilization of Sub-Basins

Different boundaries can create different risk when building the risk ranking methodology. There were three options that were reviewed before the final decision of sub basins was made. These options were: neighbourhoods, hexagons, and basins.

Traditionally, within the City of Edmonton, neighbourhood boundaries were used. However, the local neighbourhood focus limited the ability to compare flood mitigation benefits between different areas of the city, especially when different parts of a neighbourhood being studied were serviced by different storm basins. It was determined that the traditional of using neighbourhoods as the boundary for flood models were not sufficient to form the basis for a city-wide flood risk model.

The hexagon option was available from EPCOR Water, which was used to validate fire hydrant pressures, which split the City into over 6,000 hexagons. This hexagon network offered finer resolution than the City’s neighbourhood model, however, the disadvantage was the minimization of extreme examples of flooding applications when compared to Climate Change Risk over large sections of the City of Edmonton.

Existing hydraulic models of the City had been broken up into Drainage Basins, also called Catchment Areas or Watersheds and Sewersheds. Drainage Basins are defined as an area that would drain directly into the North Saskatchewan River or any of the surrounding creeks (which eventually drain into the North Saskatchewan River) through the city's storm trunk drainage network with one separate outfall for each of these basins. Figure 4-4 below demonstrates the major basin system within Edmonton. The storm trunk network is superimposed on this image to indicate that these basins are for the most part independent.

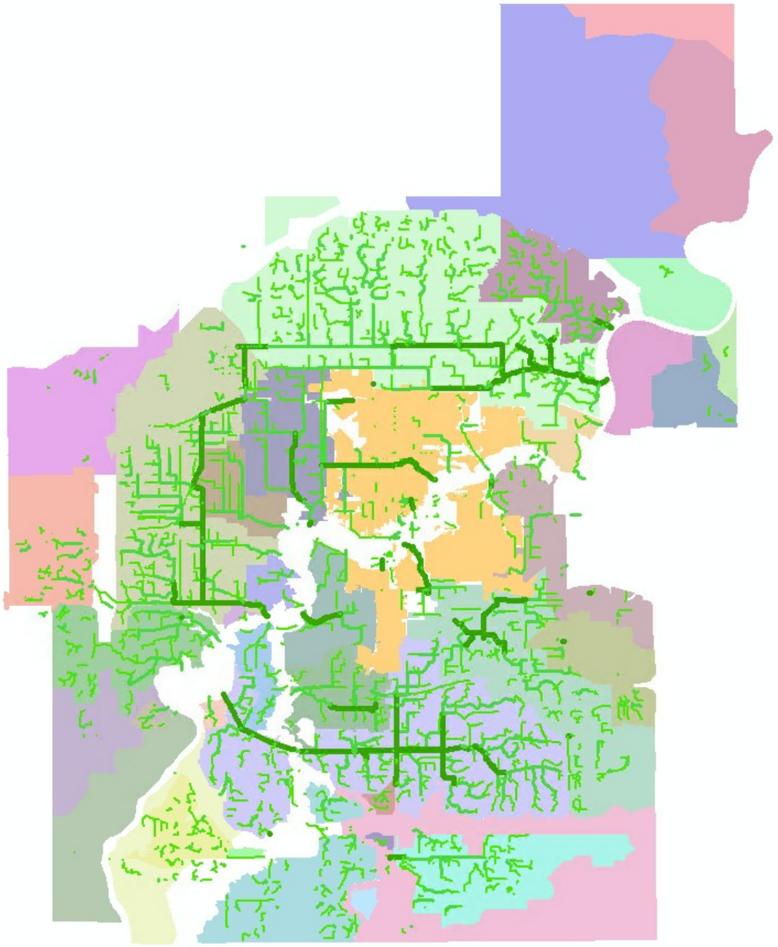


Figure 4-4: Major Basins within the City of Edmonton including the Storm Trunk/Major Pipe Network

Finally, after consultation with EPCOR's hydraulic modeling team on the potential for the division of the major drainage basin system into smaller scale areas. This work had been completed by the modeling team for defining sub-basins within the existing City-defined Drainage Basins. Sub-basins exist within major basin or connect major basin flow. Sub-basins created as part of the hydraulic modeling network took into consideration the surface topology and the underground pipe network. With only minor changes, this method was adopted the system of dividing the 41 major drainage basins into 1,310 sub-basins for the project area.

Using the hydraulic methodology to separate the city into sub basins created a system to evaluate the risk ranking. This initial break down was built using the sub basins from the City Wide Flood Mitigation Strategy hydraulic model that EPCOR owned. This series of sub basins was evaluated using consultant hydraulic models and proved to be exceptionally similar. After a thorough evaluation, 1,310 sub basins were defined for the City for the 2018 review. With 401 neighbourhoods within Edmonton (City of Edmonton, 2021), this meant that the average neighbourhood contained three sub basins.

To reflect how development affected flood consequences, the criteria for identifying sub-basins were amended in and near new neighbourhoods after it was noted that these areas were still zoned for agricultural use and as a result had a risk ranking of zero. This reduction also causes the focus to be on the higher risk areas in the core and mature neighbourhoods. It is also expected that the sub basins can be expected to change for future updates as infrastructure ages, land use zoning changes, or the neighbourhood becomes developed.

The use of sub-basins allows for evaluation of a smaller area which will determine its specific risk of flooding. With focus on where stormwater moves it allows for a real review of the highest risk that can be found within a basin. Allowing for differentiation between the low points within neighbourhoods and higher elevation as different sub basins allow for appropriate sub basins risk.

4.3. Building the Risk Grid

Since flooding is considered a climate change hazard it was decided that for ease of discussion with the City Council Members the two ranking system, SIRP and the City's Climate Change Adaptation Program should be similar.

Although the initial risk criteria had been built by the Climate Change Adaptation Team, to facilitate risk ranking specifically to flooding, for this thesis a new set of key statements were created. These new key statements retained the same risk levels as to be comparable to the other Climate Change Hazards.

4.3.1. Likelihood through Multiple Scenarios

Likelihood, when associated with flooding, traditionally looked at the probability of occurrence of a storm event per year (EPCOR, 2018). The standard for calculating long-term risk using the period of 30 years, based on the maximum length of time for a standard residential mortgage was evaluated and adopted. The 30-year likelihood for a storm event at a property was then ranked on a scale from 0 to 5 for use in the risk grid approach for each sub basin. The following equation from Hamming (1991) was used to determine the probability of a storm occurrence per year over a specific time frame.

$$P_n = 1 - (1 - p)^n$$

P_n = *Probability in n years*

p = *event (1/yr)*

n = *total years*

Equation 4-1: Probability Calculation

Using the hydraulic models, ArcGIS was used to determine if there was any flooding registered within a sub basin. The multiple models covered urban, riverine, and sanitary overflow flooding. If flooding was indicated at any point within the sub basin, it was determined that the whole sub basin had a risk of flooding at the specific storm likelihood.

The likelihood of a flood event would be affected by the general condition of infrastructure assets servicing the sub-basin. To simplify the initial risk ranking, the decision was made to create a surrogate measure of the change in likelihood of flooding, based on the asset condition, using a simple addition of a modifying factor applied to the likelihood. Since social interactions have no effect on the likelihood of a flood occurring, they were not considered when calculating the likelihood of flooding.

To determine if a sub basin had a risk of flooding, the results from past hydraulic models were used, as well as, the newly purchased JBA flood forecasting maps. There were a number of hydraulic models available to the team, but focus was on models that had been built and run within the last five years. This 5-year timeline was chosen to minimize having sub basins register as high risk when flood mitigation projects had already been completed. These project focused on improvements to the storm and sanitary systems, following the two major storm events of 2004 and 2012, and these flood mitigation measures drastically reduced the risk of flooding.

The hydraulic model results indicated the depth of flooding from the storm or sanitary system either to grade or within the underground pipe network. Standardizing what consists as flooding within a sub basin was required since urban flooding models and sanitary surcharge models provide different level results.

Indications of flooding that were used to determine the likelihood risk focused on the EPCOR Design Standards for surface flooding over 0.35 meters on the street. EPCOR's design standard chose 0.35 meters for two reasons: 1) the average height of the road curb and, 2) the average height to cause cars to be flooded. This definition is at any point along the roadway. Hydraulic models utilizing a 2D grid system look at the average elevation of the ground. The internal EPCOR models utilize a 5-meter grid pattern and the purchased JBA flood maps utilize a 30-meter grid system, as well as, providing a range of depths. This range of elevations can cause some differentiation of where flooding actually occurs. Evaluating the likelihood of flooding, using depth of flooding, resulted in a scenario where ALL sub basins reach the 0.35-meter flood level and so there was no basin differentiation due to different storm events. To avoid this blanket flooding scenario a minimum area requirement for the flood was used. The minimum requirement was that 1% of the area of the sub basin needed a flooding depth over 0.35 meters to register as flooding within the sub basins. This method allows for the limiting of minor or acceptable flooding within low risk sub basins which assists in focusing future prioritization.

When reviewing the sanitary surcharge models, the results provided the depth of flooding within the underground pipe network as meters below ground level. The EPCOR Design Standards stated that there is a high risk of sewer surcharge flooding when pipe surcharging reaches between 1.5 to 2.5 meters below ground level. This flooding is based on the probability of sanitary surcharge into the surrounding basements. Since depth below ground of basements can vary, so does the risk of flooding. The depth of basement floors is not a known data set. Since the basement depth of Edmonton residential/commercial properties is not a known data set, EPCOR leadership asked the SIRP team to determine if there was a difference in damage based on the depth of water that entered a basement. Results for this question were provided in a recent 2015 study by the Government of Alberta (IBI Group, 2015). For both commercial and residential properties there was an initial cost as soon as any water entered the site, and then there was only a slight increase in cost until the water level reached the main floor. This indicated that any flooding in the basement needed to be mitigated (IBI Group, 2015). With this knowledge, the team decided that the depth of flooding of 2.5 meters would be utilized to calculate the likelihood. The same application of a 1% area requirement was applied to the sanitary system, within each sub-basin, to manage the risk.

Using the minimum of 1% area standard to determine flooding within the sub basins provides a binary decision as to if the sub basins would be included on the likelihood scale. If the flooding extent was less than 1% then it was marked as zero. If the flooding exceeded 1% then it was marked as the EPCOR Likelihood of Flooding within the sub basin based on its storm event.

Since multiple storm events were available to be reviewed, a final decision had to be made as to which events were to be used for the SIRP risk grid. The final storm event choices were:

- 20 year
- 50 year
- 75 year
- 100 year
- 200 year.

The JBA's Flood Map included storm events for the 20, 50, 75, 100, 200, 500, and 1,500 storms. Utilizing the 100-year event was critical since it represents EPCOR design standard for storm protection (*EPCOR, 2020*). Additionally, expanding into the more frequent events was also deemed critical since it would provide the differentiation regarding likelihood.

The hydraulic models that were owned by EPCOR that were available included the 50 year and the 100 year 4 hour storm events. These two storm events could then easily be included in the risk ranking.

Since there is significant difference in the volume of rain that falls during the 20 year and the 50 year events 4 hour event. It was decided that a 20 year storm event should be included in the evaluation of risk, with a JBA flood model available for this event period. The 20 year period was also the smallest storm event to be evaluated for the SIRP likelihood gird to be compatible with the Climate Change team. Storm events less than the 20 year period were below the range that was used on the Climate Change team's likelihood scale, due to the fact that smaller events had a higher frequency of occurrence. From discussions with the EPCOR modeling team and external modeling consultants the use of the smaller 5 year 4 hour storm event have a number of concerns due to stability and reliability. Due to these concerns the 5 year storm event was not included as part of the risk ranking methodology.

There were some concerns with only utilizing three storm events, the 20, 50, and 100 year 4 hour storm even, the existing hydraulic model data, but there were limited hydraulic modeling results for any other storm event time frame. Future updates to the SIRP model should include new hydraulic models for updated flood mitigation project to include all of the storm events, this would adequately display the new risks.

JBA flood maps were available for a 75 year 4 hour storm event and was considered a perfect addition to the risk grid evaluation since it would provide appropriate spacing within the likelihood of the 50 and 100 year 4 hour events. This would allow four equally spaced probability storm events for the likelihood evolutions when flooding occurs within a sub basin. This would also permit future capital projects to be evaluating for both cost benefit and risk reduction. Working within mature areas, where the sewer systems were installed to different design standards and there is limited surface space for green infrastructure to mitigate flooding, adaptability is required for evaluation between the 50 year and the 100 year storm events.

Based on the positioning of the four storm events, likelihoods sat on the higher end of the scale. Addition of a fifth event would permit for a range of likelihoods of mid to low risk. Initially a 500-year storm event was considered and evaluated. But early results indicated that there were a high number of sub basins at risk within the smaller 20 and 50 year events. The largest storm events that would provide a good description of the risk was determined to be the 200 year storm events. The 200 year storm event would still provide validity when reviewing expected changing climates. There are some internal expectations that in the long term, as the SIRP completes capital project to reduce the risk, the 500-year event would be re-evaluated and added to the risk ranking.

Utilizing Equation 4-1 to determine the likelihood of occurrence over 30 years, Table 4-2 was created to summarize the calculation results for probability of the 5 storm events considered over a 30 year period. For these calculations, a mortgage time reference of 30 years was used of that the SIRP team could explain to Edmontonians that during a 30 year period a resident would have a 26% chance of their home flooding if it was not protected to the 100 year rainfall level. This 26% probability of flooding remains the same during the 30 year window until flood mitigation work is completed for the area. To determine the event which causes flooding within the sub basin the hydraulic models were used.

Using the 5 storm events, calculation of the probability was the next step which determined the likelihood of flooding for each sub basin, which would then be placed on a scale from 0 through 5, the same scale used by the Climate Change Adaptation Strategy and EPCOR on their risk grid. The Climate Change Adaptation Strategy already had a defined likelihood scale which allowed the team to directly determine the likelihood. Table 4-2 also quantifies the risk of each storm event using 1 through 5 likelihood scale. The choice for the difference in breaks for the likelihood was directly related to Edmonton's Climate Change Risk ranking to allow for ease of explanation at City Council Meetings. Although the risk ranking scale extended to 5 it was decided that the maximum used would be 4.5 for the 20 year storm event. This allows for the addition of modifiers to bring the likelihood up to a 5 to separate out and prioritize sub basins.

Table 4-2: Likelihood of Flooding Table

Storm Scenario	Percent Likelihood Over 30 years	EPCOR Likelihood Risk
1:20	78.54%	4.5
1:50	45.45%	4
1:75	33.15%	3.5
1:100	26.03%	3
1:200	13.96%	2

4.3.2. Creating Four Consequence Categories

Once the key statements were expanded from the Climate Change Hazard risk statements, the next step was to apply them to the legacy and new data sets. The list of key statements that were used as part of the SIRP program can be found in Section 4.3.2.5. The key statements were organized based on their ranking within the risk grid. Key statements are descriptions that were written for easy conversion of the raw data within the sub basins to specific consequence rankings. These assisted in creating consistency when evaluating multiple data sets.

The greatest discussion regarding the different categories was whether each data set should be applied in one category or many. The SIRP team's final decision was to apply the data sets to all applicable consequence categories. The following section expands on how the data sets were utilized.

The final metric that was built referenced how the data was used to calculate a consequence ranking. This metric is considered proprietary knowledge by EPCOR. The specifics will not be discussed but general explanations of how data created the consequence will be reviewed.

4.3.2.1 Health & Safety

Health and Safety consequence rating examined the impact of flood events on public life. This consequence consisted of a deep dive into specific flooding events and how flooding affected the public. Health and Safety was a legacy data sets, as a lot of information was known due to the volume of models available, the insurance flood maps, and past studies. These discussions resulted in the following drivers that describe the risk ranking for Health and Safety:

- **Sanitary Surcharge**: Physical contact with raw sewage can cause health risk to the public as a whole. The available data sets were evaluated based on the 50 year and 100 year storm models.

- **Riverine Flooding**: Higher flows can cause increase in erosion in both known and unknown locations. Edmontonians that use the river valley trails and/or have residences on the top of river banks could be at physical risk and/or have property damage due to destabilization of trails and/or banks. The JBA Flood Maps were the basis for these consequence results with using 20, 50, 75, 100, and 200 year storm events.

- **Urban Flooding**: Flooding in low lying areas can cause storm water to enter homes or underpasses quickly and can trap residents either in their cars or homes, which again causes a risk to life and property. The available models included storms at the 50 and 100 year level, as well as the JBA Flood Maps at 20, 50, 75, 100, and 200 year storm events

- **Creeks/Erosion**: If walking paths or foot bridges are near creeks or erosion sites and the bank collapsed while being using, then there is a risk of loss of life. The focus for this consequence was on the possible effect of structure while in use. Erosion study results were geographically input into the gird and ranked based on medium, moderate, or extreme erosion risk at each site.

- **CSO**: Combined Sewer Overflow is similar to sanitary surcharge with regard to bacterial contamination within the storm water. This release is connected to surcharging of the combined sanitary/drainage system where the flow is expelled through outfalls into the creeks and river where there is a risk of contamination to humans. CSO locations have level or sensor monitors which allows EPCOR to track how many times a site has a CSO release. This data is completely dependent on the types of storms that occur within the catchment area each year. Samples are also taken during storm events to predict the total fecal coli form count that was released at different sites.

4.3.2.2 Environment

Environment was an item that the Climate Change team had added that was initially considered difficult to calculate as a risk and consequence ranking based solely on a flooding event. Following the description provided by the Climate Change risk statement, the team managed to determine four drivers within the legacy data set.

- **Erosion Concerns**: With the increase in urbanization and subsequence increase in non-porous surface areas in the City, the volume and speed of storm water entering the rivers and creeks has increased substantially. Even though mitigating factors are in place, there is an increase in erosion risk at all creek outflow locations. Past studies provided the exact locations of these erosion concerns.

- **Combined Sewer Overflow**: Edmonton has nineteen designated CSO locations that release combined sewer/drainage into the North Saskatchewan River. These releases increase the amount of *E. Coli* into the river, as well as, other toxins (AEP, 2015). Release volumes were calculated over the last five years and a volume release range was determined for each CSO location. Expectations are that with future flood mitigation measures these CSO releases will be diminished.

- **Loss of Ecosystems**: Based on the depth of flooding and length of flood water retention within a green space and Storm Water Management Facilities (SWMF), it was determined that there could be a loss of vegetation/ecosystem for local wildlife. This review looked specifically at the depth of flooding at SWMF, since these areas would retain the storm water for longer periods of time.

- **Debris Build Up:** Basement Floods create debris that enters the City's waste facilities. Another concern after flooding includes the trash build up along streets and back alleys which can create a breeding ground for bacteria. This increase in items reaching the landfill also creates increased environmental concerns.

When using the risk grid, it was determined that there were no locations that ranked as High Risk for Environmental impact. This was considered acceptable since storm events are short in duration and historically have only affected a small part of the City per incident. The SIRP program also had to remain comparable to the City of Edmonton's Climate Change Risk. The Climate Change Hazard statements were focused on loss of ecosystem. Although flooding can cause localized damage to the environment, it will not cause the total loss of the ecosystem within an area.

4.3.2.3 Social

Social impact was also a new consideration for areas of risk. Many of the standards used in the past focused solely on preventing damage to private property. When reviewing the data sets and the results from the public engagement survey, it turned out that there was a significant difference in what was originally expected to be the areas of highest concern.

Since Social Risk was new method of calculating risk, the initially focus was on a recent study regarding mental health. From there, it expanded out to focus on public perception of the effects of flooding.

- **Long Term Flooding Concerns**: Concerns of flooding in the long term applied to all types of flooding events, sanitary overflow, storm, and riverine. Long term mental health has been shown to be at risk after a flooding event, as many homeowners experience anxiety during rainstorms (University of Waterloo, 2018). Based in part on this finding, the City of Edmonton Utility Committee requested that risks to mental health be considered as part of the SIRP risk ranking. Knowing that mental health affects everyone differently, the consequences of risk were placed on the causal trigger, flooding. This was calculated based on the percent of houses within a sub basin that were affected by flooding.

- **Erosion Concerns**: With the increase in urbanization and impermeable surfaces, the volume and subsequent velocity of storm water entering rivers and creeks has increased substantially. Even though mitigating factors have been put in place there was an increase in erosion risk locations in all of the creeks. The North Saskatchewan River and creeks within Edmonton are part of an extensive multipurpose pathway system. These pathways would be closed off if due to erosion damage. The River Valley Alliance and along with other non-profit programs are working at creating a continuous trail system throughout the City, which is an indication of the importance of the Edmonton River Valley to its citizens (Alliance, 2020).

- **Combined Sewer Overflow**: The North Saskatchewan River is used by other municipalities downstream and is a recreational location for Edmontonians. Edmonton has nineteen designated CSO locations that could release combined sewer/drainage waste into the North Saskatchewan River during and following severe storm events. Occurrence of these releases result in a temporary loss of recreational sites in the affected areas and are therefore considered a loss to the community from a Health and Safety concern perspective. The volume of release and the *E.Coli* count was used to calculate this metric.

The Intergovernmental Panel on Climate Change recommends that the location of critical/emergency infrastructure should be prioritized over private residential or commercial property. This was a new major data set that was created and called Critical Infrastructure. Once these locations were known, the risk of flooding at these specific site's were calculated using the Urban and Sanitary flood model results and JBA flood maps. During emergency event's hospitals, police stations, fire stations/ambulance, medical-centers etc. are required to assist others. The consequences of flood events on the ability to provide services at these critical health and safely infrastructures had not been previously reviewed by the City of Edmonton. The final list of critical social infrastructure included:

- Hospitals
- Fire Halls, Police, and Ambulance Stations
- Emergency Relief Shelters, Homeless and Addiction centers
- Seniors Homes / Long-term Care Facilities
- Schools – Elementary through to University
- Shopping Malls
- Recreation / Leisure Centers (also used to support emergency response)
- Transit Centers and LRT Rail corridors
- Water and Wastewater plants, reservoirs and pump stations
- Electrical Sub-stations

Based on the results from the Public Engagement Survey, critical social properties at high risk of flooding were ranked higher for a social consequence. The consequence of this high social ranking was sufficient to increase the priority for upgrade/mitigation project funding.

Rating of social consequences was based on the importance of the service provided at the property (i.e. hospitals ranked higher than transit centres) using a scale of 1 to 5. The maximum risk of the critical sites was utilized to determine the social risk within a sub basin.

4.3.2.4 Financial

Financial risk has been evaluated many times in the past through various City of Edmonton Flood Mitigation Programs. The SIRP team rated financial consequences on predicted number of homes in the sub-basin that would be affected due to flood events, rather than a monetary cost to individual property owners. The primary purpose of choosing this method for rating financial consequence was to minimize the difference of ranking that could result from the disproportional value of property damage for the same number of affected properties, when comparing more affluent and less affluent sub-basins. A lesser benefit, from using this method, was that it was a more transparent calculation and easier to explain to non-technical stakeholders. The number of homes affected by sanitary overflow, urban, and riverine flooding was calculated to determine the risk within a sub basin. Properties already ranked as critical infrastructures were also included in this calculation but only as another building that was damaged.

4.3.2.5 Building Key Statement

To build the risk grid, key statements had to be created so that there was consistent understanding as to what qualified for each level of likelihood and consequence. With greater understanding of the consequence profiles, the team created Impact Scenarios to determine what would be classified under each of the consequence risks. These Impact Scenarios were created with the assistance of the Customer Advisory panel and validated with by the City's Climate Change Adaptation teams.

Table 4-3 through Table 4-5, shown below, outline the Impact Scenarios statements which were utilized for the Public Engagement Survey (ThinkHQ, 2018), and are reflective of the Climate Change Risk Ranking for Consequences (published in the October 2018 Utility Committee Meeting). Although the Consequence scale ranges from 0 through 5, the key statements were only created for the ranges 3 through 5.

Table 4-3: Consequence Statements for Moderate Risk

Consequence Risk 3 - Key Statements for Flood Impact

Health and Safety

- **Illness**: For a few weeks, residents and contractors in your neighbourhood are at risk of illness (e.g., respiratory and digestive issues) through contact with sewage and mold while clean-up and repairs are made.
- **Drowning**: Basement flooding puts residents at risk of injuries (e.g. tripping, pulled muscles, sprains, etc.).
- **Emergency Care**: Due to flooding impacting the building, wait-times increase at a local hospital or urgent care centre overflowing with patients who become ill or injured during flooding.
- **Road Access**: Storm water floods part of the street in front of your home. Flooding is contained to the road between the curbs until it recedes/drains away.
- **Drowning in Vehicle**: An underpass or parking lot floods at a high rate of speed, causing vehicles to stall and be abandoned by owners, and some minor injuries are incurred.

Environment

- **Vegetation Loss**: Vegetation in neighbourhood yards, parks, playgrounds and green spaces is seriously damaged by flooding and requires some restoration.
- **Ecosystem**: Some vegetation, insects and wildlife are all killed in a localized area due to a small amount of chemical pollutant or sewage spilling.
- **Transportation**: Neighbourhood parks, trails, creeks and sidewalks are damaged due to soil erosion, making them inaccessible for several weeks while being repaired.
- **Spills**: Some vegetation, insects and wildlife are all killed in the immediate vicinity of a flood-related accident involving a truck/train derailment spilling the chemicals, oil or gases they are carrying.
- **Garbage**: Garbage clean-up in your neighbourhood is delayed for several weeks due to large amounts of garbage (e.g., discarded furniture, household items and damaged drywall) piling up in yards, sidewalks and roadways.

Social

- **High Rises**: A high-rise building with offices and residential condos loses power. The building is accessible but for several weeks, people must take the stairs to their floor.
- **Family Disruption**: Family members or close family friends are temporarily displaced from their home, requiring you to care for them or support them for several weeks.
- **Transportation**: Major roadways, bridges or transit infrastructure are damaged, doubling your commute to and from your home for several weeks.
- **Support Agencies**: Agencies that support homeless or vulnerable citizens are temporarily displaced for several weeks and unable to get enough essential services they need such as food, shelter or addiction/mental health support.
- **Loss of Utilities**: Your neighbourhood loses an essential utility (such as power, natural gas or drinking water) for several weeks. Access to your home could be restricted until service is restored.
- **Mental Health**: The impacts of flooding cause personal stress for several weeks as you worry about home repairs and finances.
- **Emergency Care**: Emergency services buildings (police, fire, EMS) are damaged, limiting access to services for several weeks for repairs and response times are delayed.

Financial

- **Business**: Local businesses and services (e.g. local mall, recreation centre, businesses you frequent, etc.) are forced to close for several weeks.
- **Work Space**: Your employer's building (or a family member's employer) is temporarily inaccessible until repairs are completed, causing lost wages for a few weeks.
- **Exterior Property**: Homes and properties in your neighbourhood experience serious outdoor damage (e.g. damage to fencing, vehicles, gardens, etc. outside the home). Home-owners are out of pocket thousands of dollars to replace or fix.
- **Homes**: Residential properties in your neighbourhood are damaged and require repairs. Single family homes have up to 6-inches of water in the basement and condos/apartment buildings have up to 6-inches of water in the basement or lower-level suites.
- **Vehicles**: Vehicles in parkades, garages and parking lots in your neighbourhood are damaged due to storm water around the wheels/floorboards/brakes. Vehicles require repairs taking several weeks.
- **Homes:** Low income individuals are unable to afford repairs to their homes without assistance, forcing them to live in a damaged home for several weeks.

Table 4-4: Consequence Statements for Major Risk

Consequence Risk 4 - Key Statements for Flood Impact

Health and Safety

- **Illness:** For a few months, residents and contractors in your neighbourhood are at risk of illness (e.g., respiratory and digestive issues) through contact with sewage and mold while clean-up and repairs are made.
- **Drowning:** Basement flooding puts residents at risk of injuries requiring medical attention (e.g. falls, back injuries, electric shock, etc.).
- **Emergency Care:** Due to flooding impacting the building, a local hospital or urgent care centre is forced to close, turning away all patients.
- **Road Access**: Storm water floods streets in your neighbourhood and extends onto your property or lawn. Access to your location is restricted until the area can be cleaned and sanitized.
- **Drowning In Vehicle:** An underpass or parking lot floods at a high rate of speed, causing vehicles to stall or collide, and people need to be rescued from their vehicles and taken to the hospital.

Environment

- **Vegetation Loss**: The ecosystem (vegetation, insects and wildlife) in your yard, neighbourhood parks, playgrounds and greenspaces is destroyed and vegetation needs to be replanted.
- **Ecosystem**: The ecosystem (vegetation, insects and wildlife) in a large natural area is killed due to a large amount of chemical pollutant or sewage spilling into it.
- **Transportation**: Neighbourhood parks, trails, creeks and sidewalks are damaged due to soil erosion, making them inaccessible for several months while being repaired.
- **Spills**: The ecosystem (vegetation, insects and wildlife) in a large area (e.g., area the size of a pond or a neighbourhood) is killed as a result of a flood-related accident involving a truck/train derailment spilling the chemicals, oil or gases it is carrying
- **Garbage**: Garbage clean-up in your neighbourhood is delayed for several months due to large amounts of garbage (e.g., discarded furniture, household items and damaged drywall) piling up in yards, sidewalks and roadways).

Social

- **High Rises**: A high-rise building with offices and residential condos loses power. The building is inaccessible for several months.
- **Family Disruption**: Family members or close family friends are temporarily displaced from their home, requiring you to care for them or support them for several months.
- **Transportation**: Major roadways, bridges or transit infrastructure are damaged, doubling your commute to and from your home for several months.
- **Support Agencies**: Agencies that support homeless or vulnerable citizens are temporarily displaced for several months and unable to get enough essential services they need such as food, shelter or addiction/mental health support.
- **Loss of Utilities**: Your neighbourhood loses an essential utility (such as power, natural gas or drinking water) for several months. Access to your home could be restricted until service is restored.
- **Mental Health**: The impacts of flooding cause extensive personal stress (e.g., depression, anxiety, sleep disorders, etc.) for several months as you worry about home repairs, finances and accommodations.
- **Emergency Care**: Emergency services buildings (police, fire, EMS) are damaged limiting access to services for several months for repairs. Services are limited during repairs.

Financial

- **Business**: Local businesses and services (e.g. local mall, recreation centre, businesses you frequent, etc.) are forced to close for several months.
- **Work Space**: Your employer's building (or a family member's employer) is temporarily inaccessible until repairs are completed, causing lost wages for a few months.
- **Exterior Property**: Homes and properties in your neighbourhood experience serious outdoor damage (e.g. damage to fencing, vehicles, gardens, etc. outside the home). Home-owners are out-of-pocket tens of thousands of dollars to replace or fix.
- **Homes**: Residential properties in your neighbourhood are damaged and require repairs. Single family homes have up to 4-feet of water in the basement and condos/apartment buildings have up to 4-feet of water in the basement or lower-level suites.
- **Vehicles**: Vehicles in parkades, garages and parking lots in your neighbourhood are damaged due to storm water getting into the engine. Vehicles and parking areas require repairs taking several months.
- **Homes**: Low income individuals are unable to afford repairs to their homes without assistance, forcing them to live in a damaged home for several months.

Table 4-5: Consequence Statements for Extreme Risk

Consequence Risk 5 – Key Statements for Flood Impact

Health and Safety

- **Illness**: The health authority intervenes after increased reports of residents and contractors in your neighbourhood falling illness (e.g., respiratory and digestive issues) through prolonged contact with sewage and mold. Homes/dwellings are condemned.
- **Drowning**: Basement flooding to ground-level puts residents at risk of drowning/death from not being able to escape to higher ground.
- **Emergency Care**: Due to flooding impacting the building, a local hospital with specialized services is forced to close, and surgeries and other critical procedures need to be canceled, resulting in patient deaths or worsened conditions.
- **Road Access**: Storm water floods streets in your neighbourhood and completely covers your property or lawn, touching the lower walls of your home/building. Access to your location is restricted until the area can be cleaned and sanitized.
- **Drowning in Vehicle**: An underpass or parking lot floods at a high rate of speed, increasing risk of drowning deaths of people unable to escape their vehicles.

Environment

- **Vegetation Loss**: A large natural area is permanently damaged and not able to be replanted, including vegetation in your yard neighbourhood parks, playgrounds and greenspaces
- **Ecosystem**: The ecosystem (vegetation, insects and wildlife) in the North Saskatchewan River is killed due to a large amount of chemical pollutant or sewage spilling into it.
- **Transportation**: Neighbourhood parks, trails, creeks and sidewalks are damaged due to soil erosion, making them inaccessible for upwards of a year while being repaired.
- **Spills:** The ecosystem (vegetation, insects and wildlife) in a major natural area/whole watershed/drainage basin is killed as a result of a flood-related accident involving a truck/train derailment spilling the chemicals, oil or gases it is carrying.
- **Garbage:** Garbage clean-up in your neighbourhood is delayed for upwards of a year due to large amounts of garbage (e.g., discarded furniture, household items and damaged drywall) piling up in yards, sidewalks and roadways.

Social

- **High Rises:** A high-rise building with offices and residential condos experiences extensive damage, and utilities are unavailable. The building is inaccessible for upwards of a year.
- **Family**: Family members or close family friends are temporarily displaced from their home, requiring you to care for them or support them for upwards of a year.
- **Transportation**: Major roadways, bridges or transit infrastructure are damaged, doubling your commute to and from your home for upwards of a year.
- **Support Agencies**: Agencies that support homeless or vulnerable citizens are temporarily displaced for upwards of a year and unable to get enough essential services they need such as food, shelter or addiction/mental health support.
- **Loss of Utilities:** Your neighbourhood loses an essential utility (such as power, natural gas or drinking water) for upwards of a year. Your neighbourhood is evacuated – at the time of the flood.
- **Mental Health**: The impacts of flooding cause life-long chronic mental and physical health issues. Some may go on long-term disability as a result of the impacts.
- **Emergency Care**: Emergency services buildings (police, fire, EMS) are destroyed, staff and services are relocated, and response times may be impacted. Services from the destroyed building are unavailable for months.

Financial

- **Business:** Local businesses and services (e.g. local mall, recreation centre, businesses you frequent, etc.) are forced to close for upwards of a year.
- **Work Space**: Your employer's building (or a family member's employer) is temporarily inaccessible until repairs are completed, causing lost wages for upwards of a year.
- **Exterior Property**: Homes and properties in your neighbourhood experience serious outdoor damage (e.g. damage to fencing, vehicles, gardens, etc. outside the home). Home-owners are out-of-pocket hundreds of thousands of dollars to replace or fix.
- **Homes**: Residential properties in your neighbourhood are so damaged they require demolition (single family homes and condos/apartment buildings).
- **Vehicles**: Vehicles in parkades, garages and parking lots in your neighbourhood are completely damaged because vehicles are entirely submerged in storm water. Vehicles are written-off and parking areas require repairs taking upwards of a year.
- **Homes**: Low income individuals are unable to afford repairs to their homes without assistance, forcing them to leave their homes permanently.

4.3.3. Modifiers, Requirement and Types

Once the likelihood and consequence had been calculated and plotted on the risk grid, only a few points were visible as shown in Figure 4-5. This was due to whole and half numbers that were used within the consequence and likelihood matrix. To create differentiation between sub-basins, modifiers were created and applied to spread the likelihood and consequence risk. This also assisted in providing some additional differentiation as to which sub basins required immediately attention. All of the data sets were originally calculated and ranked according to standard likelihood/consequence risk statements. Modifiers were then applied to the likelihood and final weighted consequence for each storm event. There were two methods that would then be utilized to indicate the risk on the consequence grid. As seen in Figure 4-5, the graph on the left would indicate the maximum risk for each sub basin. This graph would have the same number of points indicated on the graph as there were sub-basins. The grid on the right indicates the risk of each sub basin in each of the five storm events. This means that each sub basin could be on the grid up to a maximum of five times.

Based on the data sets that were available the following criteria were separated out as likelihood and consequence modifiers.

4.3.3.1 Likelihood Modifiers

The criteria for choosing a likelihood modifier was based on whether the modifier would change the likelihood of an event occurrence and therefore be a predictor, regardless of flood depth.

- **Historical Basement Flooding Reports:** The City of Edmonton 311 information and services number has been collecting information from residents who have called to report a flooded basement, since 2005. Initially it was anticipated that this criterion would provide a strong data set for SIRP, it was discovered that the reasons for the flooding was not collected. A number of flooded homes were identified in a separate EPCOR database to have flooded due to a water main break. However, flooding could also have occurred during normal use, such as leaving an outside hose running, and not a storm event. The unqualified basement flood data tended to increase a positive likelihood, since the number of homes within the sub basin that experienced flooding increase the likelihood. The basement flood data required an increase in likelihood modifier, based on the 311 basement flood data.

- **Operational Data:** As mentioned earlier, hydraulic models assume that the pipes are in good condition when running the model. Since this is not always the case, there is an increased risk that the sub basin will experience a higher level of flooding during design level storms. It was decided that this would also be a positive likelihood modifier based on the fact that if pipes are in poor condition, then they will begin to flood earlier than the model would predict.

- **Inflow and Infiltration:** Unlike Operational Data, there are some considerations for inflow and infiltration built into hydraulic models. There was some discussion around removing this data set but it was eventually decided that removal might allow for other unknowns, such as cross connections, into the system. Inclusion of inflow and infiltration would also allow for reduction or removal of this modifier when flood mitigation projects that look specifically at Inflow or Infiltration were completed. The flow of storm water into the sanitary system, under normal circumstances, based on design standard, should be zero to quite low. But based on historical flow monitors, certain areas of the City have a higher calculated inflow and infiltration than would have been included in the hydraulic model, based on design. It was decided to include the calculated increase in inflow into the system as a positive likelihood modifier.

- **Low Impact Development (LID):** At the onset of the risk ranking model development, there were only a few dozen LID's within the City of Edmonton. These were not included in the hydraulic models that were available at the time. However, since LID's reduce the initial flow of water into the storm system, it was included as a negative likelihood modifier.

4.3.3.2 Consequence Modifiers

There were only two considerations for consequence modifiers. These were determined based on the increase or reduction in the risk based on known parameters.

- **Asset Condition:** Although there was some debate as to whether an asset condition would represent increases similar to the likelihood in operations data, it was decided that asset condition would affect the consequence instead of the likelihood.

For example, if a trestle (a pipe that runs over a creek through its own bridge) had to be shut down unexpectedly and no bypasses were available, then all of the upstream homes would experience a significant increase in flooding since there is no downstream outlet. The condition of trestle increased the flood consequence in the affect area.

All of the assets within the City of Edmonton are risk ranked and updated every year for their likelihood and consequence of failure. Utilizing the percentage of major assets with the high risk ranking in each sub-basin, a modifier for increase in consequence was developed.

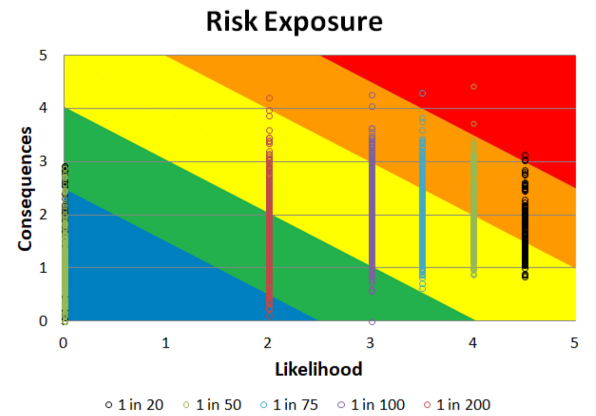
- **Emergency Management Changes:** At the time of this report, there were no data sets that were included as a negative consequence modifier. This modifier was created for sub basins that are considered to be at high risk of flooding but do not require capital upgrades due to their location or lack of infrastructure that would be affected. For areas that have a high probability of flooding and may be cost prohibitive to mitigate for permanent asset installation, an emergency management plan might include temporary measures which would reduce the consequence of the flooding event.

  An example would be the dog/recreational park in the Terwillegar neighborhood of the City of Edmonton. This large park is within the river valley and during increased river level events would be underwater very quickly. There is a high risk to human life if the park is in use while the river is rising. But short of building a large flood barrier which would anger the users of the space it would be a high-cost project to protect a green space. Instead once an emergency management plan is created, and tested, then this sub basin would no longer be at risk to the public, even though it could still experience flooding events. This modifier would be used to validate that there is still a risk of flooding but it is an accepted risk.

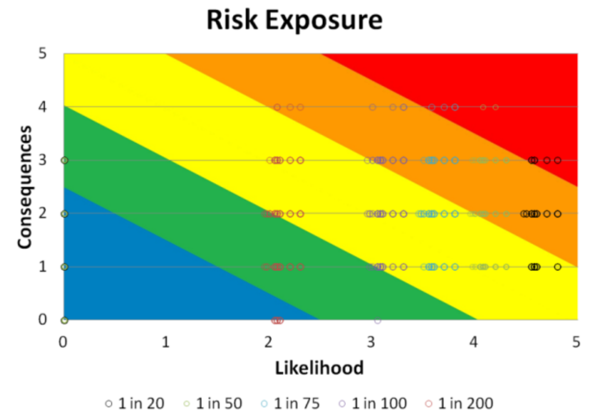
4.3.3.2 Application of Likelihood and Consequence Modifiers

The likelihood and consequence modifiers were included in all of the graphs below. Figure 4-5 graphically explains how the modifiers affected the likelihood and consequences for the 100-year storm event risk ranking with the application of the preferred weighting scale.

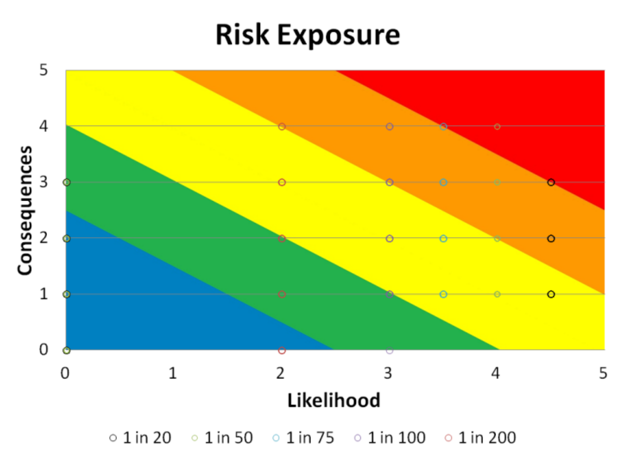
Removed the Likelihood Modifier but kept the Consequence modifier



Removed the Consequence Modifier but kept the Likelihood modifier



Neither Likelihood or Consequence Modifier



Utilizing all Modifier

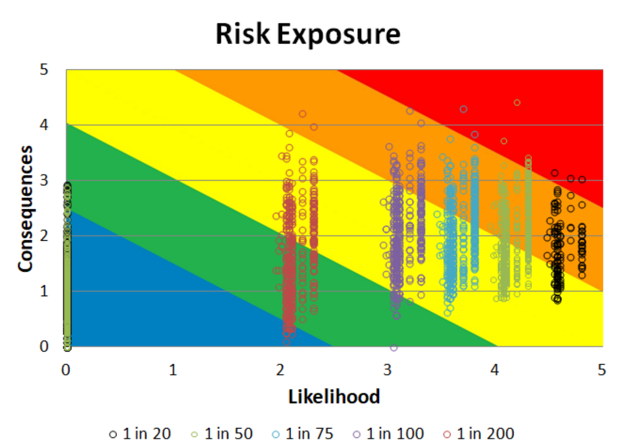


Figure 4-5: Modifier effect on risk ranking for all five storm events

Without any modifiers, as shown in the bottom left graph, it is impossible to tell the difference between the different sub basins at the same risk. Some differentiation can be seen when either the consequence modifier (top left) or likelihood modifier (top right) were applied to the risk score. These begin to separate out the clumps of sub basins which then allow for targeted prioritization. When all of the modifiers are applied, as shown in the bottom right graph, the sub basin indicators are spreads out, which makes it easier to see the difference and begins to determine which areas should become the focus of future flood mitigation projects.

It should be noted that the maximum a modifier could change the likelihood or consequence was by increasing or decreasing the final risk ranking by one. This is due to the cumulative effect that the modifiers had, specifically on the consequence. All of the sub basins have experienced a shift within the risk.

As seen in Figure 4-5 there is some sensitivity with the addition of modifiers. Looking at each type of consequence individually, the differences can be quite large. If there were no likelihood modifiers, then each of the sub basins remains within their appointed whole number (4.5, 4, 3.5, 3, 2) as was determined for each storm. When the likelihood is included, then one can see up to a 0.3 increase or a 0.15 decrease for each sub basin. Although this is only a small differentiation between the sub basins, there is a larger gradient between the consequence scoring. The average difference is an increase in 0.3, with the maximum consequence modifier of 0.5. Since many of the increases for consequence were half points, this can increase a risk quite substantially. Utilizing these consequences to get an accurate assessment of the sub basin risk had the greatest measure of success.

4.3.4. Risk Rank Weighting

Once the likelihood, consequences, and modifiers are calculated for each storm event and each data set, the next step was to calculate the risk ranking. The initial test was to determine the risk for each consequence factor and for each storm event.

Using a risk ranking equation that was already being used within EPCOR Water provided early abilities to calculate risk. Further research was completed to determine if there were other methods of calculating risk but they did not provide the usable result that this one did.

$$\text{Risk Ranking} = \sqrt{10^{\frac{Consequence+Sum(Modifier)}{10}}} \times \sqrt{10^{\frac{Likelihood+Sum(Modifier)}{10}}}$$

Equation 4-2: Calculation for total Risk within a sub basin

Equation 4-2 was used to calculate the risk within the grid. The risk grid that SIRP and the Climate Change Adaptation Strategy use is shown in Table 4-6. The table indicates that the risk score calculation can be converted into a verbal description. The description also aligns with the installation of the angular colours that were applied to the risk grid. Using the above equation, an angled line could be made on the risk grid which has the same value. For example, the risk scores of exactly 560, which is the separation of the red and orange colour in Figure 4-6, can be made using different likelihood and consequence scores. Two examples would be; a sub basin with a consequence of 5 and a likelihood of 3 or a sub basin with a consequence of 2.5 and a likelihood of 5, both make 560 using Equation 4-2 which would mean that both sub basins were at high risk. This allows for the risk description to be known without having to find each sub basins risk on the risk grid. Knowing the Risk Ranking score, the risk could can then be described using Table 4-6 below.

Table 4-6: Climate Change Adaptation Strategy

Risk Description	Colour Description	Risk Score
High Risk	Red	>560
Medium High Risk	Orange	560-100
Medium risk	Yellow	100-10
Medium Low Risk	Green	10-0.1
Low Risk	Blue	<0.1

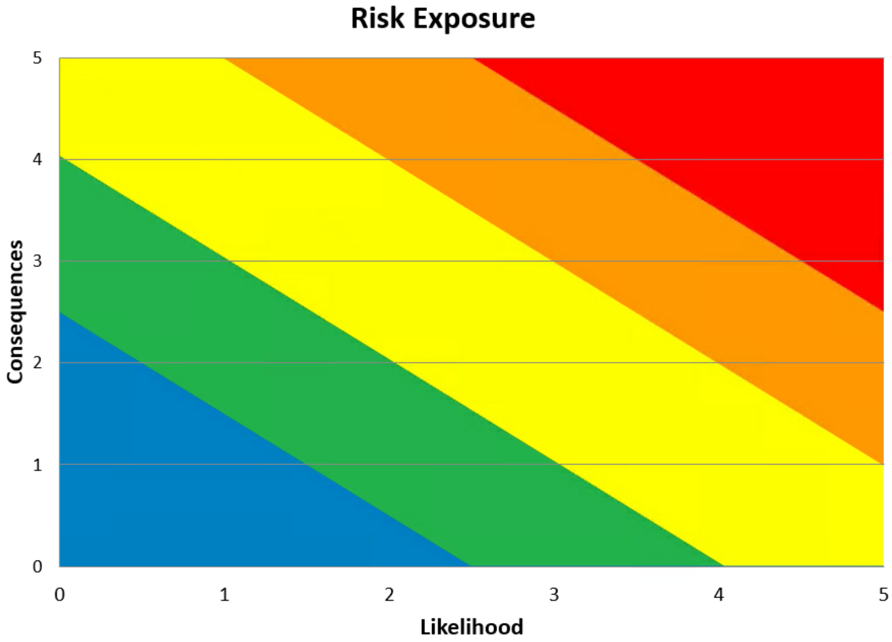


Figure 4-6: SIRP Risk Grid

This still left the consequence separated into the four categories for each storm event. Internally, SIRP decided to use a weighting system to consolidate the results for the four categories. Three consolidation methods were proposed and the results were presented to Edmonton's Utility Committee to make the final decision.

The three risk ranking methods, shown in Table 4-7, are as follows:

Method 1: An equal weighting of all four consequences resulting in 25% for each.

Method 2: Based on the results from the Public Engagement survey of August 2018, see Section 4.3.5 for details.

Method 3: Focused on utilizing the same principals as previous flood mitigation; emphasizing the highest damage cost areas, resulting in a weighting where Financial was 40% and the other three consequences were 20%.

Method 1 and 3 were proposed by EPCOR's management. The final decision was made by City of Edmonton Utility Committee in October 2018 to utilize Method 2.

Table 4-7: Risk Weighting Methods

Consequence Factors	Method 1 – Equal Weighting	Method 2 – Public Engagement	Method 3 – Traditional Weighting
Health & Safety	25%	30%	20%
Environmental	25%	15%	20%
Social	25%	30%	20%
Financial	25%	25%	40%

4.3.4.1 Mapping & Visualizing Risk Ranking

Once the weighting methods were created, the next step was to show the risks visually. The two visualization methods previously discussed were presenting the risk using 1) colours on a map or 2) through a risk grid. Visually representing the maximum risk on the map using ArcMap quickly provided the coloured risk. This geospatial software also allowed for further visualization with the ability to change colours based on the results. The coloured results were chosen based on previous EPCOR risk grid for high to low scale and then the letter scale was overlayed using Equation 4-2. For the risk grid there were two options reviewed: (1) presenting multiple storm events risks for each sub basin, and (2) presenting only the maximum risk per sub basin (a subset of the first option).

To better visualize risk grid graphs, the following example of three sub basins within Edmonton were chosen based on the total risk results for differentiation. The three sub basins, as shown in Table 4-8, have a total risk ranking of high (H), medium high (MH), and medium (M) based on different storm events. Sub basin M also does not indicate any surface, riverine, or sewer surcharge flooding likelihood until the 100 year storm event, while there is still a consequence of flooding within the sub basin at the smaller events due to the proximity of a creek. This consequence is due to the proximity of a bridge and walking paths that could be damaged if there was flooding. This consequence remains constant even though there is no likelihood of flooding.

Using Equation 4-2, the total risk for each storm event can be calculated and the maximum risk determined for the storm event. Each of these sub basins has a different storm event that is ranked as the maximum.

Table 4-8: Examples of sub basins to be placed on the risk grid

	Consequence					Likelihood						Consequence	Likelihood
	1:20	1:50	1:75	1:100	1:200	1:20	1:50	1:75	1:100	1:200	Max Storm Risk	Maximum	
H	2.6	3.2	3.8	4.0	4.0	4.8	4.3	3.8	3.3	2.3	75	3.8	3.8
MH	1.3	1.8	1.8	1.8	1.6	4.6	4.1	3.6	3.1	2.1	50	1.8	4.1
M	1.2	1.3	1.5	1.6	1.4	0	0	0	3.1	2.1	100	1.6	3.1

Application of the data in Table 4-8 is presented in Figure 4-7 for the two risk grid options. The first option (on the left of Figure 4-7) was to place each of the storm events for all three sub basins onto one grid. Since there are five storm events for the three sub basins, there are 15 points on the graph, with each colour representing a different storm event. The 20 year storm is represented in black, the 50 year storm in green, the 75 year storm in blue, the 100 year storm in purple and the 200 year storm in red. The second option as seen on the right of Figure 4-7 only demonstrates the maximum risk for each sub basins. This means that there are only three points within the risk grid.

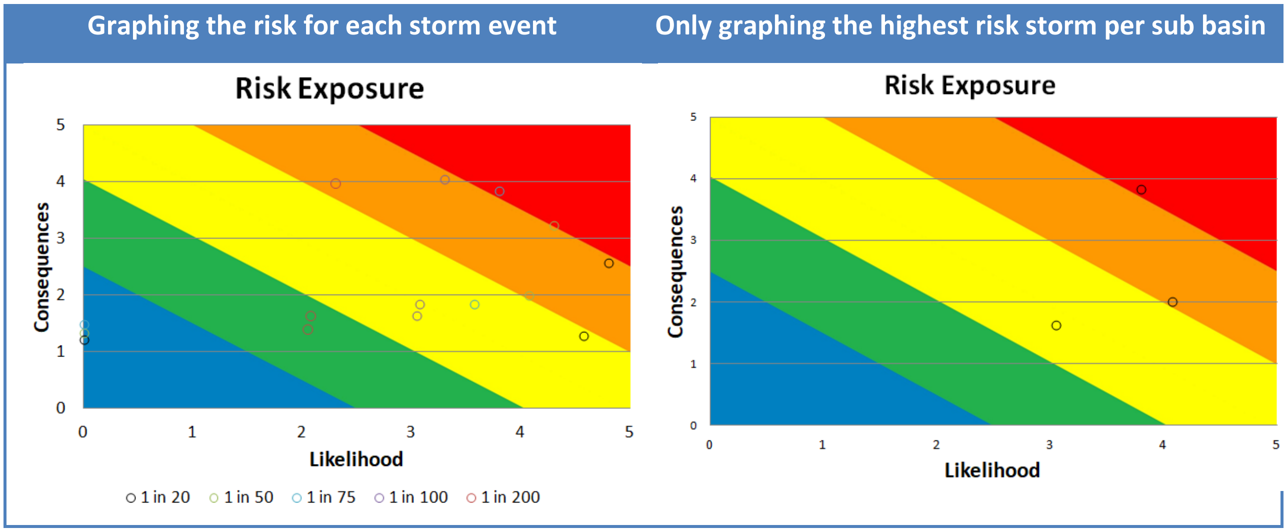


Figure 4-7: Methodology to creating the risk grid

Utilizing the information for option 1, which shows all storm event risks for each sub basin, allows evaluation of incremental flood mitigation projects that reduce the risk of flooding. For example, at the 20 year storm event, if a number of LID projects were completed in all three of the sub basins to mitigate surface flooding, all 20 year storm events would be removed and the risk grid would easily demonstrate the change by a reduction in the number of points.

Application of the same analysis to option 2, which shows only the maximum risk per sub basin, would mean that the LID project improvements would not be demonstrated, unless the highest risk was for the 20 year storm event, in which all the points would move to the next maximum risk event.

The decision was made to place each of the storm events onto the graph to allow planners to see how the flood mitigation projects affect each of the storm events. This would also keep the sub basins that would flood during smaller events in the forefront.

4.3.5. Public Engagement Survey Methods

During the creation of the SIRP risk grid, a single public survey session was conducted by an external company called ThinkHQ, with the analysis of results completed in August 2018. The results were then utilized to create the 2nd Method of Weighting as described in Table 4-7.

A list of impacts statements, provided in Section 4.3.2.5, based on SIRP's key risk tolerance statements was developed for the survey using MaxDiff survey questioning approach (Wang et al., 2011). A MaxDiff survey consists of respondents choosing which of five statements they consider their top priority and the lowest priority. A series of five statements were provided ten to fifteen times to the respondents. The MaxDiff response survey provides a clear indication as to what is the highest priority out of a number of bad scenarios and allows for a more realistic view of what will cause issues with residents after a flooding event.

The survey analysis method was conjoint analysis, which determines the public's preference value towards a topic/item. The survey tested the impact of three different flood events; Moderate, Major, and Extreme. Most of questions focused on the major and extreme flooding statements and it took, on average, 30 minutes to complete the survey.

4.4. Dynamic Updating Capability

A method to update the risk grid as flood mitigation projects were completed, as well as, to demonstrate risk reduction had been proposed, but had not been put into practice before the 2018 Committee of SIRP deadline. The proposed method has since been used twice, in different sub-basins, as previously planned mitigation projects moved from their design to pre-construction phases.

Hydraulic models have been updated based on anticipated improvements to the asset improvement, replacing older models. Validation of the update model and the process will be possible when these projects are completed. See Chapter 6 for samples of dynamic updating with different flood mitigation projects.

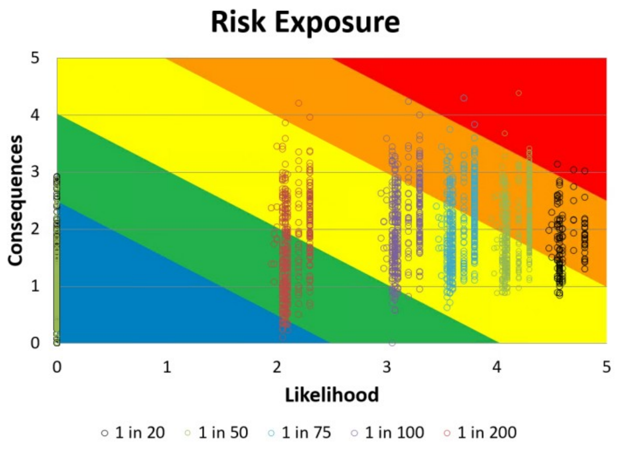
5. Results of the SIRP Risk Ranking Methodology

This section is organized in a sequence similar to Section 4 Methodology, with a review of project success at the end. The results focus on the risk grid, beginning with results of the likelihood and consequence statements, followed by modifiers, weighting, and public engagement.

5.1. Likelihood Results

Likelihood evaluates probability using multiple storm events, each sub basin risk ranking can be shown multiple times. If a sub basin is at risk of flooding during a 20 year event (demonstrated in black) it was included as multiple dots demonstrating the larger storm events as well. This method was chosen to evaluate the highest risk to each sub basin. Since the total risk for each storm event is different, the decision was that each storm event would be displayed on the risk grid. This means that some sub basins can be on the grid up to five times and others may not be on the grid at all. Figure 5-1 below demonstrates the risk for sub basins for each storm event placed on the risk grid.

Risk Grid



Risk Exposure Levels

High Risk	Red
Medium High Risk	Orange
Medium risk	Yellow
Medium Low Risk	Green
Low Risk	Blue

1 in 20 storm	Black Dots
1 in 50 storm	Green Dots
1 in 75 storm	Blue Dots
1 in 100 storm	Purple Dots
1 in 200 storm	Red Dots

Figure 5-1: Example of the Risk Grid

Applying the methodology of multiple storm events to the graph allows for dynamic comparison from year to year as flood mitigation projects are applied (see Section **Error! Reference source not found.** for xamples on how capital project change the risk of flooding).

As the likelihood of flooding decreases (i.e. from 20 to 200 year storm events) the consequence increases. Since all flooding events causing damage to private and public property is considered unacceptable, the focus then turns to managing the more frequent events that result in flooding. By managing the smaller flooding events it also reduces the overall stormwater volume that will require management during larger events. This focus will allow for quick win projects to be completed for the smaller storm events, while the larger mitigation projects are begin evaluated and constructed.

5.2.Consequence Results

5.2.1. Health and Safety Consequence Category

When the information sets were evaluated and the results focused only on Health and Safety Risk, as described in Section 4.4.2.1, Figure 5-2 was created. The figure on the left indicates the risk for each storm event for each sub basin. The figure on the right was created to be able to see the areas of risk within the City of Edmonton, by highlighting the sub basins and utilizing the total number of times the sub basins register at the Mid-High or High Risk. The focus is to reduce the risk of flooding within the High and Mid-High risk sub basins before working on any other risk category. The darker the sub basin colour the greater the number of storms the sub basin is predicted to flood with the addition of likelihood.

A number of the sub basins register under a risk of flooding based the mid-high and high level criteria for all five storm events. These are the sub basins considered to have the highest Health and Safety Risk.

Figure 5-2 also indicates that many of the sites that contain creeks are susceptible to flooding at lower events and remain within a high-risk category throughout the storm events. This can be explained through the release of high concentrations of *E.Coli* during storm events or through the depth of flooding due to high river levels. With careful review, through visual inspection, sub basins with underpasses are also seen to flood during multiple events which cause the sub basin to be at high risk in the map on the right of Figure 5-2. The Consequence scale has a larger spread which was created due to the difference in types of data applied to this consequence category and the addition of modifiers. Health and Safety had a number of half increases in risk depending on the depth for each flooding event.

As expected, the 20 year storm event (black dots) only had two consequence rankings greater than 4.5 whereas the 200 year storm event (red dots) have 19 sub basins at a consequence of 5 because of the increase in flooding on the ground.

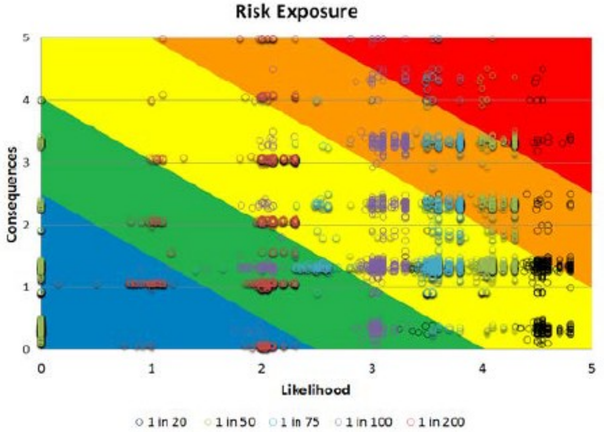
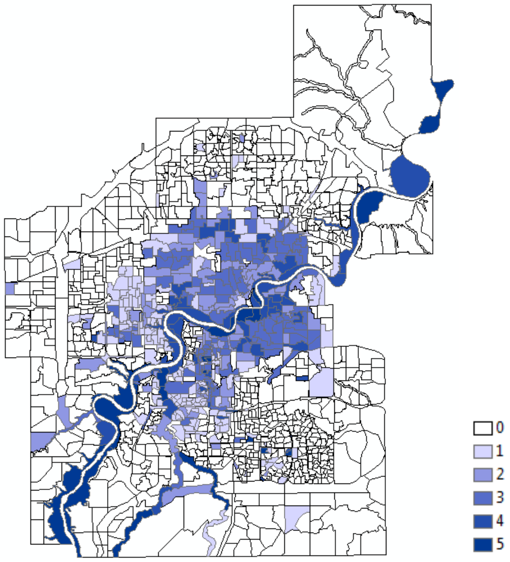
Risk Grid – Health and Safety	Priority Basins from Health and Safety Risk Perspective
	

Figure 5-2: Health and Safety Risk Grid, created in 2018

Table 5-1 indicates the number of sub basins within each of the risk descriptions. As expected, there was a higher number of sub basins within the high risk at the lower storm events since there is a lower likelihood of occurrence for the larger storm events.

Table 5-1: Number of sub basins within the High and Mid-High-Risk Ranking using only the Health & Safety Consequence Category

Storm Events	20 year	50 year	75 year	100 year	200 year
# of Sub Basins within the High Ranking	25	75	32	32	2
# of Sub Basins within the Medium High Ranking	52	169	155	121	39

5.2.2. Environmental Consequence Category

Figure 5-3 below focuses only on the Environmental consequence category, as described in Section 4.3.2.2. Figure 5-3 represents the increase in consequence, represented as creek erosion sites, during the higher storm events even as the likelihood decreases. As the storm event becomes less frequent (i.e. larger storm events) there is an increase in storm water being directed to the creeks. This increase in storm water within the creeks creates a higher risk of creek erosion causing slope failure in areas that are already experiencing erosion.

During a detailed review of this consequence, before the methodology was finalized, it was found that a number of sites that were considered high risk, due to surface flooding, were actually at locations that were designated as Storm Water Management Facilities (SWMF). SWMF are designed to store storm water during rainfall events and during the initial method of determining areas of high volumes of stormwater these basins with SWMF were flagged as areas of high flood risk. After this analysis, a quick change to the ArcGIS calculation tool box was able to remove flooding reports within the footprint of the SWMF. If flooding at the SWMF was included within the sub basin total, it would disproportionally increase the total risk and would create an error since flooding within the SWMF is part of the design. Additionally, SWMF inclusion would prevent any decrease in the sub basin risk since flooding would never be removed. The new calculation which removed any flooding within a designated flood zone provided a more realistic flood risk calculation for those sub basins.

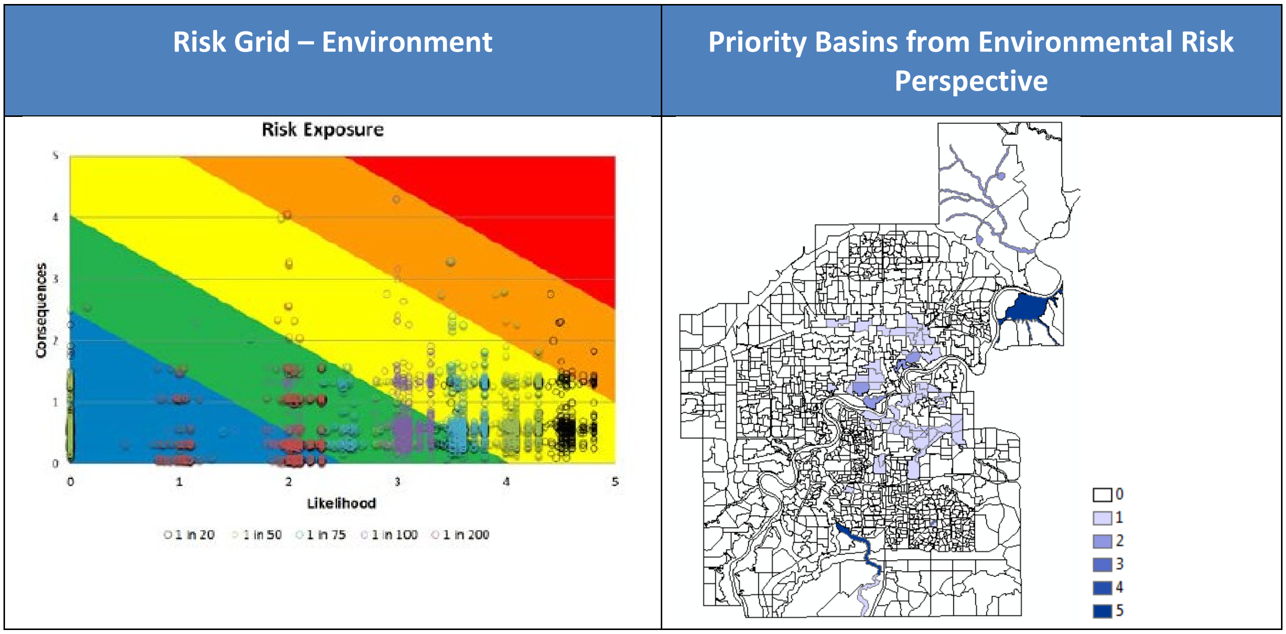


Figure 5-3: Environmental Risk Grid, Updated 2018

The environmental risk grid, shown below in Table 5.2, demonstrates that there are only 10 sub basins that have a consequence of greater than 3. This table shows that there is a greater number of sub basins that have a risk of medium high with only one site at High Risk. These results of a higher number of sub basins at risk during the smaller event was expected since it was theorized that after a certain point erosion and damage to the environment would no longer increase in large increments.

Table 5-2: Number of sub basins within the High and Mid-High-Risk Ranking using only the Environmental Consequence Category

Storm Events	20 year	50 year	75 year	100 year	200 year
# of Sub Basins within the High Ranking	0	0	0	1	0
# of Sub Basins within the Medium High Ranking	29	74	17	8	7

5.2.3. Social Consequence Category

The public engagement survey (EPCOR, 2018) (see section 5.3.1) clarified preferences for the prioritization of critical infrastructure and services for future flood mitigation investment. The highest risk locations were then evaluated in more detail and a communication plan was put in place to work directly with the infrastructure teams to mitigate disruption to their services. Table 5-3 below outlines locations of the highest importance and how many of these locations are at risk. The number of assets outlines the number of buildings that are within the City of Edmonton for each critical infrastructure. Table 5-3 indicates the number of sites that were at risk using the final version of the risk ranking methodology and applying the highest risk ranking score for the sub basin in which the critical infrastructure is situated. Utilizing this type of table as a means of communication facilitates the discussion of facilities risk with the owners of the infrastructure.

Table 5-3: Highest Critical Social Infrastructures and their maximum Risk Score based on the final sub basin evaluation

Sub-basin Risk Exposure Ranking Summary for Locations with Critical Infrastructure Risk based on high risk seen in any Storm Scenarios						
Critical Infrastructure	**Number of Assets**	**Low Risk**	**Medium-Low Risk**	**Medium Risk**	**Medium-High Risk**	**High Risk**
Hospitals and Urgent Care Facilities	8	2		1	2	3
Police Stations	35	1	2	20	7	5
Fire Halls	29	3	6	10	6	2
Ambulance Stations	13	1	2	6	2	2
Water and Wastewater Plants	3					3
Electrical Substations	16	1		8	6	1

Figure 5-4 below is the risk grid and map that focuses on the Social Risk. The map indicates the number of times the sub basins registered at Mid High or High Risk.

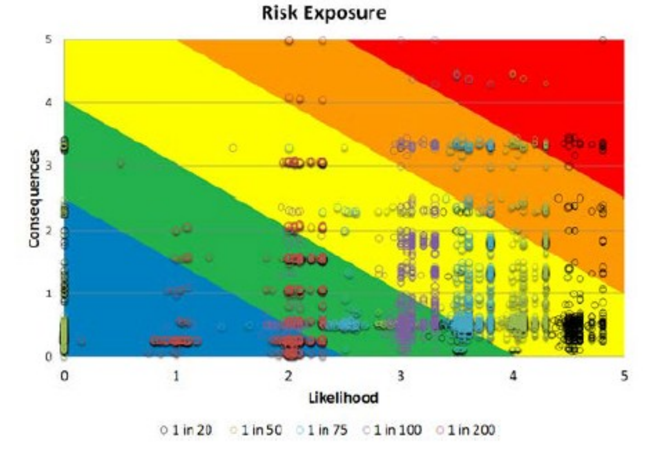
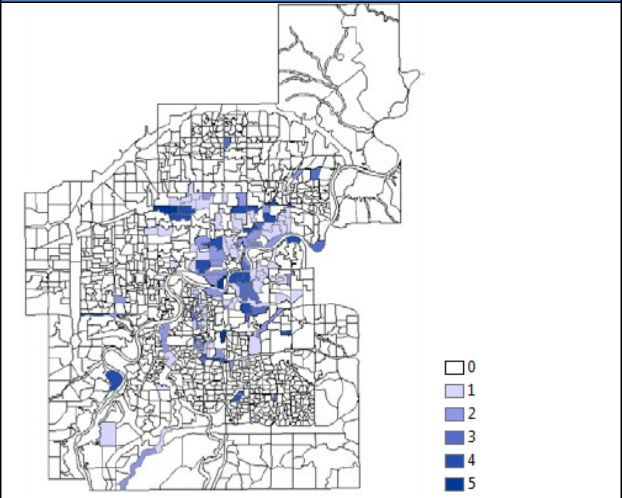
Risk Grid – Social	Priority Basins from Social Risk Perspective
	

Figure 5-4: Social Risk Grid, updated 2018

Critical social infrastructure sites had a similar increase in consequence as were observed for the environmental creek erosion analysis. As the site experienced higher flooding events, it was expected that the cost and time to complete required repairs would also increase, causing disruption to the facility's use. The cost of replacing required equipment at each critical site, to keep the facility operational during a disruption was also taken into consideration. For example, if a fire truck was damaged beyond repair due to its position in a flooded depression, replacement time is not the same as a resident being able to purchase another vehicle at a car lot the same day. This increased the consequence due to the depth and intensity of the storm event that affected the building envelope.

Table 5-4 indicates the number of sub basins that are at a high or medium high-risk ranking. As expected, there was a sharp increase in the number of sub basins from the 20 to 50-year risk ranking for High and Mid-High. There was then a reduction in the number of high-risk sites due to the lowering of the likelihood for the 75 and 100 year storm event.

Table 5-4: Number of sub basins within the High and Mid-High Risk Ranking using only the Social Consequence Category

Storm Events	20 year	50 year	75 year	100 year	200 year
# of Sub Basins within the High Ranking	34	46	19	12	1
# of Sub Basins within the Medium High Ranking	31	128	88	65	18

5.2.4. Financial Consequence Category

Figure 5-5 below, is the risk grid and map for Financial Risk, as described in Section 4.3.2.4. The Financial Risk also demonstrated an increase in consequence as likelihood decreased, as the storms increased in intensity. This increase in consequence, which relates to cost or number of homes affected, is directly related to the increase in volume of water that is released during larger storm events. As seen in Table 5-5, the 20 year storm event affects only a small number of sub basins since it has a lower flooding depth. There is an immediate spike at the 50 and 75 year storm event for the number of sub basins at High and Mid-High risk. The 200 year storm event would have a much greater depth of flooding and affects more areas.

The map on the right in Figure 5-5 indicates the areas of highest concern, which provided proof that the at-risk areas tend to be in the areas of oldest infrastructure, such as downtown Edmonton. Newer areas, seen on the edged of the city map below, had low flooding risk and thus had little to no financial risk

Figure 5-5: Financial Risk Grid, updated 2018

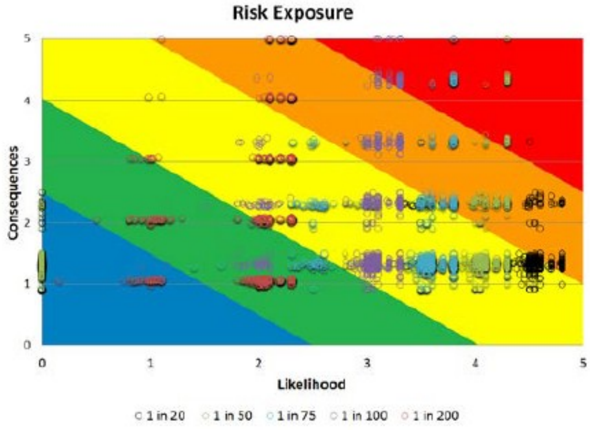
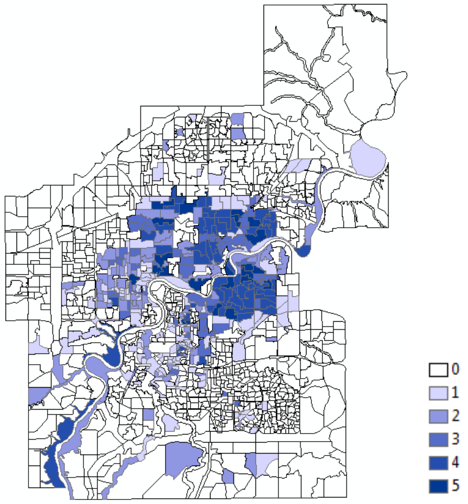
Risk Grid – Financial	Priority Basins from Financial Risk Perspective
	

Table 5-5: Number of sub basins within the High and Mid-High Risk Ranking using only the Financial Consequence Category

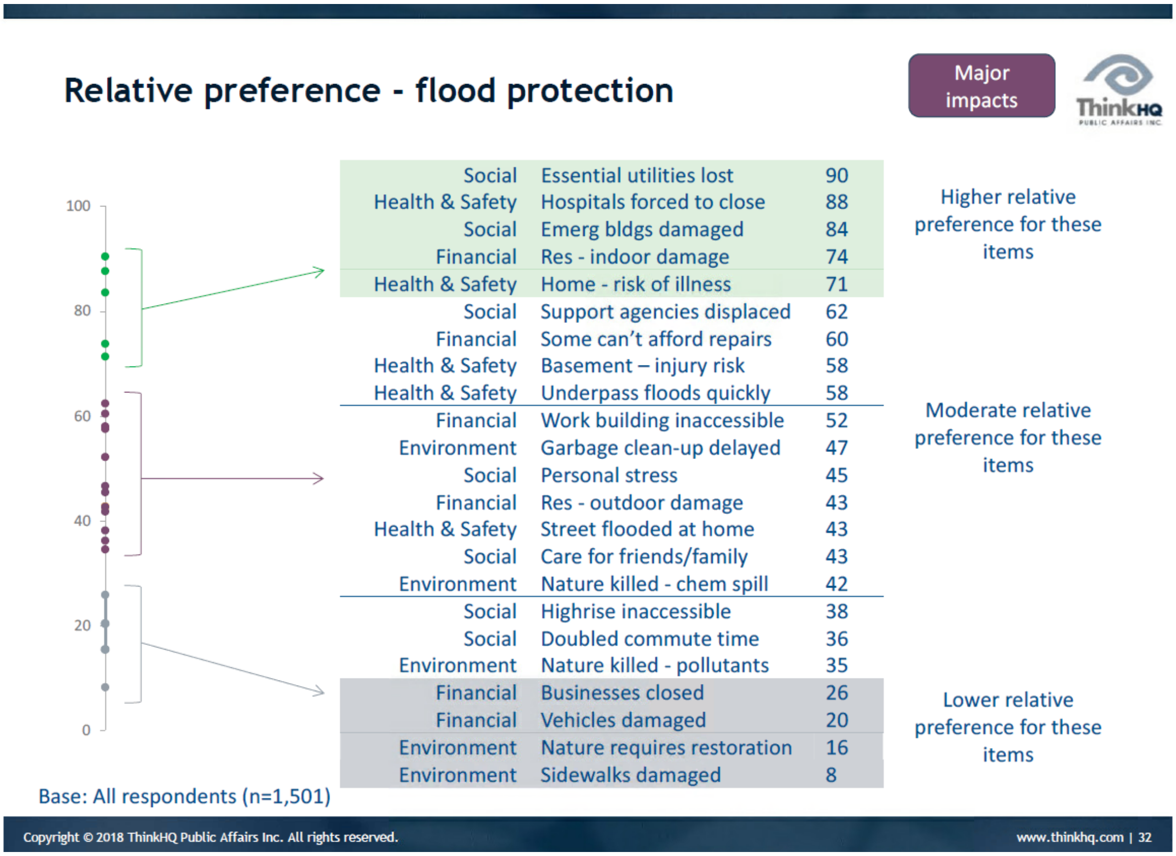
Storm Events	20 year	50 year	75 year	100 year	200 year
# of Sub Basins within the High Ranking	1	117	72	33	2
# of Sub Basins within the Medium High Ranking	63	213	156	85	40

5.3. Three Risk Ranking Weighting Options

5.3.1. Public Engagement

The results of the Public Engagement Survey completed by Think HQ (ThinkHQ, 2018) as described in Section 4.3.5, provided proof that traditional flood mitigation methods were no longer acceptable. In the past, the Drainage team created flood mitigation programs that focused on the importance of private homes requiring protection from future flooding events. Results from the Max-Diff survey indicated that critical infrastructure was the first priority and can be seen in Figure 5-6, below.

Following the review and classification of essential services, the next immediate focus for flood protection was residential homes. Commercial worksite(s) such as citizen's workplaces were also identified; however, were identified with a moderate importance level.



Relative preference - flood protection

Major impacts

ThinkHQ PUBLIC AFFAIRS INC.

Social	Essential utilities lost	90
Health & Safety	Hospitals forced to close	88
Social	Emerg bldgs damaged	84
Financial	Res - indoor damage	74
Health & Safety	Home - risk of illness	71
Social	Support agencies displaced	62
Financial	Some can't afford repairs	60
Health & Safety	Basement – injury risk	58
Health & Safety	Underpass floods quickly	58
Financial	Work building inaccessible	52
Environment	Garbage clean-up delayed	47
Social	Personal stress	45
Financial	Res - outdoor damage	43
Health & Safety	Street flooded at home	43
Social	Care for friends/family	43
Environment	Nature killed - chem spill	42
Social	Highrise inaccessible	38
Social	Doubled commute time	36
Environment	Nature killed - pollutants	35
Financial	Businesses closed	26
Financial	Vehicles damaged	20
Environment	Nature requires restoration	16
Environment	Sidewalks damaged	8

Higher relative preference for these items

Moderate relative preference for these items

Lower relative preference for these items

Base: All respondents (n=1,501)

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Figure 5-6: Results of the Pubic Engagement MaxDiff Survey

5.3.1.1 Hospitals, Utilities and Emergency Services

The highest ranked key statements from the Public Engagement survey were in regards to the impact regarding Hospitals, Essential Utilities, and Emergency Services. As seen in Figure 5-6, these three critical services were ranked between 80 and 90. This shows that residents consider essential services critical to their safety after a flooding event. These results were consistent throughout different demographics: age, gender, income, and education.

The results caused a shift in the application of consequence to sites reviewed in Social Risk and indicated that not all critical services locations should be given the same prioritization. Hospitals, Urgent Care facilities, Police Stations, Fire Stations, Water and Wastewater Treatment Plants, and Electrical Utilities are now deemed to be of most importance and should receive the first actions to mitigate against flooding. The results also indicated that these locations, just listed, should have a higher consequence than locations such as schools, day homes, and transit centers, for the same risk of flooding.

5.3.1.2 Prioritization of Human Life

Only slightly behind access to critical infrastructure, ranking between 58 and 74, was the protection of human life, with the next tier of critical issues being fast rising water levels at underpasses and basement flooding reaching the main floor.

The health and safety of people both during and after a storm event is considered of top importance to the public. It is to be noted that with extreme flooding, where physical impacts are seen, there are also hidden impacts such as mental health due to trauma. Mental health effects, resulting from experiencing a flooding event, have been known to have long lasting effects (ICCC, 2018). This information resulted in increasing the consequence key statement in regards to depth of flooding seen throughout the sub basin within the social consequence category as it would affect resident mental health.

5.3.1.3 Households, Support Agencies, and Businesses

The final major impact, as a result of the Public Engagement sessions, was focused on Social Service Agencies and their clients, as well as, Local Businesses that support these services. Social Services were defined as businesses that assist with homelessness and addiction. It was determined, that sub basins with Social Services would be provided a higher importance within the social grouping of critical infrastructures.

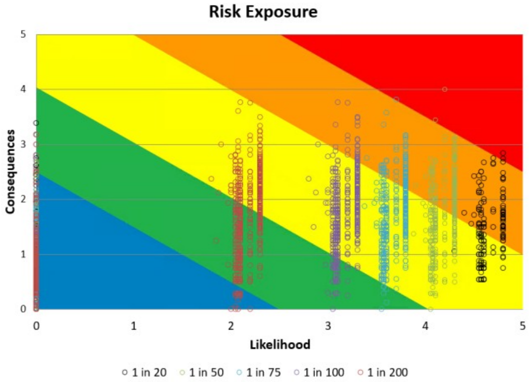
5.3.2. Final Weighting Analysis Decision

As described in Section 4.3.4**,** three methods of weighting the consequences were evaluated; re-presented in Table 4-7. SIRP and EPCOR leaderships preferred Method 2 based on the results of the public engagement survey. The final decision for selection of Weighting Method was made by the Edmonton's Utility Committee and Method 2 was approved in October 25, 2018. The final weighting method was 30% for both Health & Safety and Social, 25% Financial, and 15% Environmental.

Figure 5-7 to Figure 5-9 below, demonstrates the risk grid and geospatial analysis for each of the Weighting Methods 1, 2 and 3. For all Weighting Methods, much of the City is within the higher risk zones, indicated by the orange and red areas. On all three Method Maps, the majority of these mid-high and high risk sub basins are within the central part of the city. This was expected as these areas were built to currently outdated design standards and many of these areas are serviced with combined sewer/drainage networks.

It should be noted that the maps show very little difference between all three Weighting Methods. Using the risk grid approach developed thus far, without finer resolution, would make prioritizing mitigation strategy proposals difficult. Section 5.3.3 addresses this problem through the use of Additional Separation within the Risk score.

<table>
<tr><th>Method</th><th>Risk Grid</th><th>Risk Map</th></tr>
<tr><td>1</td><td>



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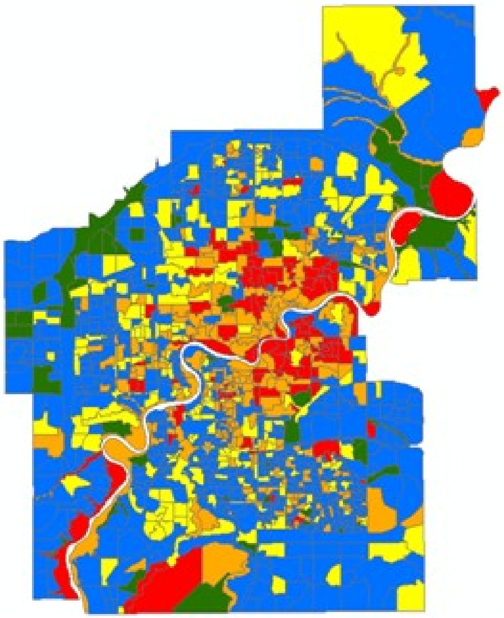

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Figure 5-7: Evaluation of the Weighting Method 1

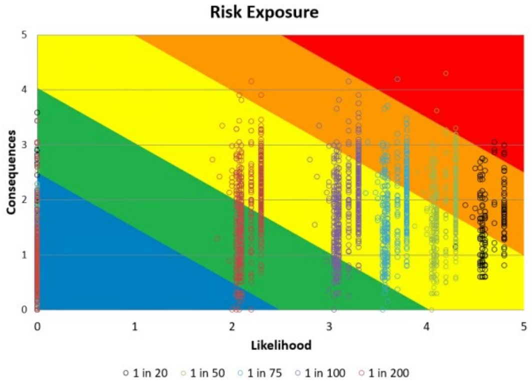
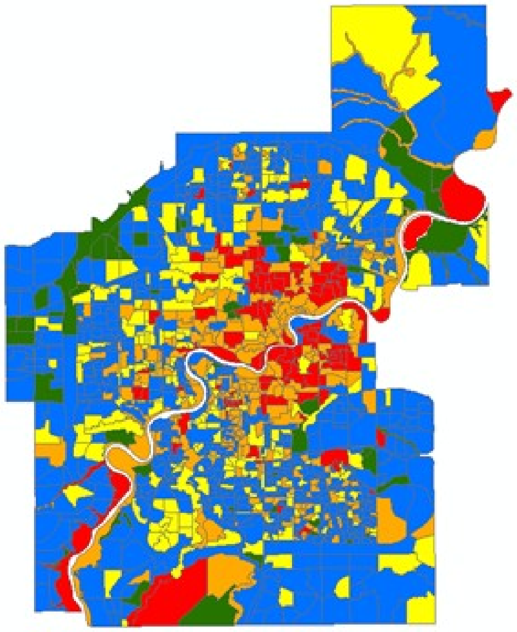
Method	Risk Grid	Risk Map
2		

Figure 5-8: Evaluation of the Weighting Method 2

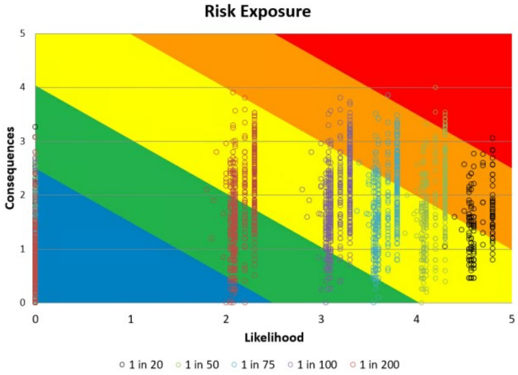
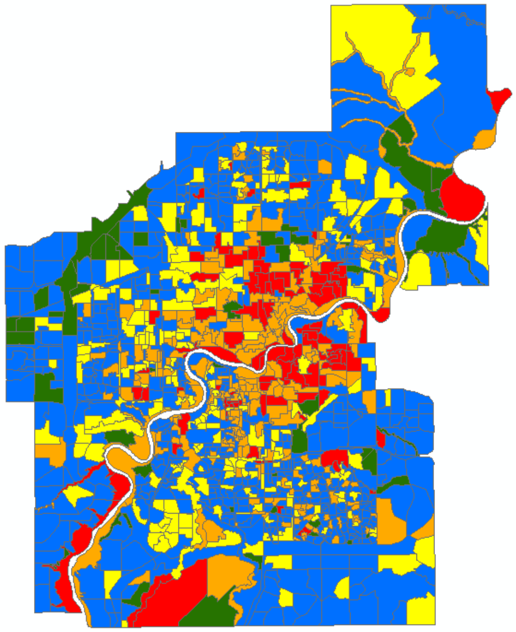
Method	Risk Grid	Risk Map
3		

Figure 5-9: Evaluation of the Weighting Method 3

Analysing each of the different weighting scale individually there was very little difference between each weighting method. Table 5-6 demonstrates the number of sub basins that have either increased or decreased one risk ranking category. For example, if a sub basin with a low rating in Method 1 increased to a medium-low in Method 2, that sub basin would be counted. The biggest difference between each of the weighting scales occurred with the application of Method 3, the traditional financial weighting, which resulted in the greatest impact on the change of sub basin ratings. This was expected due to the cost of replacement of properties within each sub basin.

Table 5-6: Comparison between different weighting systems resulting in a sub basin changing from Risk Description by 1 either up or down based on the 2018 results

	Method 1 – Equal Weighting	Method 2 – Public Engagement	Method 3 – Traditional Weighting
Method 1 – Equal Weighting	-	20	44
Method 2 – Public Engagement	20	-	52
Method 3 – Traditional Weighting	44	52	-

It was expected that this minimal differentiation would also be apparent in the number of sub basins included on the risk grid for each of the weighting methodologies. The preferred method of demonstrating the risk on a grid was to have each storm event referenced. This meant that each sub basin could have up to five occurrences on the grid, one for each storm level. Table 5-7 below indicates the number of sub basins that are at risk of flooding for each weighting method as seen on the grids in Figure 5-7 through 5-9.

Table 5-7: The number of sub basins represented within the risk grid for each of the weighting scale

	# of sub basins at 20 year	# of sub basins at 50 year	# of sub basins at 75 year	# of sub basins at 100 year	# of sub basins at 200 year
Method 1 – Equal Weighting	126	460	472	568	610
Method 2 – Public Engagement	126	460	472	568	610
Method 3 – Traditional Weighting	126	460	472	568	610

Table 5-7 shows no difference in the number of sub basins that are at risk in any of the different weighting scales. This is due to the fact that once there is any indication of flooding as part of the likelihood there will always be a consequence scale. Since the weighting does not change the likelihood, the number of sub basins within the grid will remain constant; the only change is where they will be located in regards to the consequence scale. Table 5-7 also shows that there is an increase in the number of sub basins at risk of flooding as the storm event increases. This was expected due to the increase in intensity with increasing return periods.

5.3.3. Additional Separation to Assist with Prioritization

After the weighting analysis, additional separation within the risk score was applied to assist with prioritizing the sub basins of highest risk. One of the goals of the SIRP risk ranking strategy was to facilitate future flood mitigation strategies/funding and the results using only five separations for the risk score made it difficult to build and present a final flood mitigation strategy to Edmonton's Utility Committee. So, instead of using the five risk breakdowns of High, Mid-High, Mid, Mid-Low, and Low, an additional separation was required specifically for the higher risk sites.

The decision was to increase the number of risk score categories specifically for the High and Mid-High ranking. These 2 risk scores were subdivided into three distinct risk rankings each, which resulted in an expansion to six risk ranking of highest priority. Since the Mid-Low and Low risk score areas were not going be under review for many years, they were combined to one risk score area. The new breakdown was reclassified as A, B, C, D, E, F, G, and H risks, with A being the highest risk areas. The utilization of a letter system would also allow for inclusion of future breakdowns of the risk scoring as projects are completed.

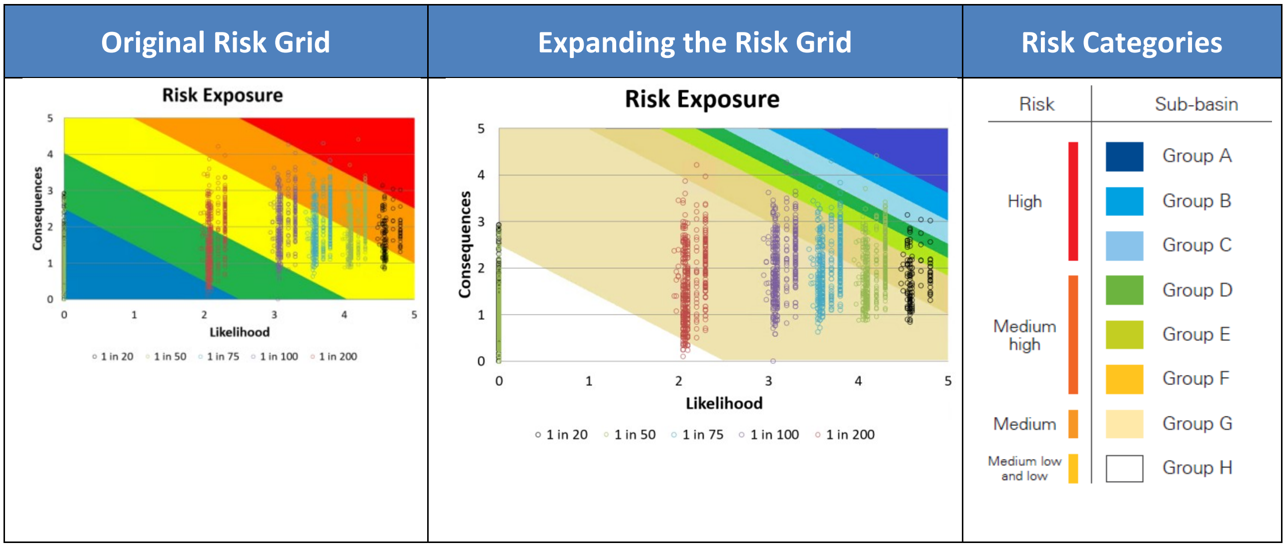


Figure 5-10: Graphical Representation of the Expanding Grid Risk

Figure 5-11, Figure 5-12, and Figure 5-13 below, demonstrate the risk ranking utilizing the A through H risk score breakdown that was presented to the Utility Committee (EPCOR, 2018). The differences that were difficult to see between the High Risk areas, of Figure 5-7, Figure 5-8, and Figure 5-9 are more obvious in the Figure below. This differentiation in the high-risk sites now classified as A, B, and C allow for specific focus on sub basins for flood mitigation projects.

In the end, the final decision by Edmonton's Utility Committee was Method 2, the Public Survey Weighting.

Method 1 - Equal Weighting	**Number Basins by Risk group**	
Health and Safety – 25% Environment – 25% Social – 25 % Financial 25%	Group A - 1 Group B - 6 Group C - 45 Group D - 35 Group E - 69 Group F - 140 Group G - 553 Group H - 461	Groups A-C include High Risk Basins Groups D-F include Medium High Risk Basins Group G is Medium Risk Basins Group H is Medium Low and Low Risk Basins

Method 1 – Sub-basin Priority Map

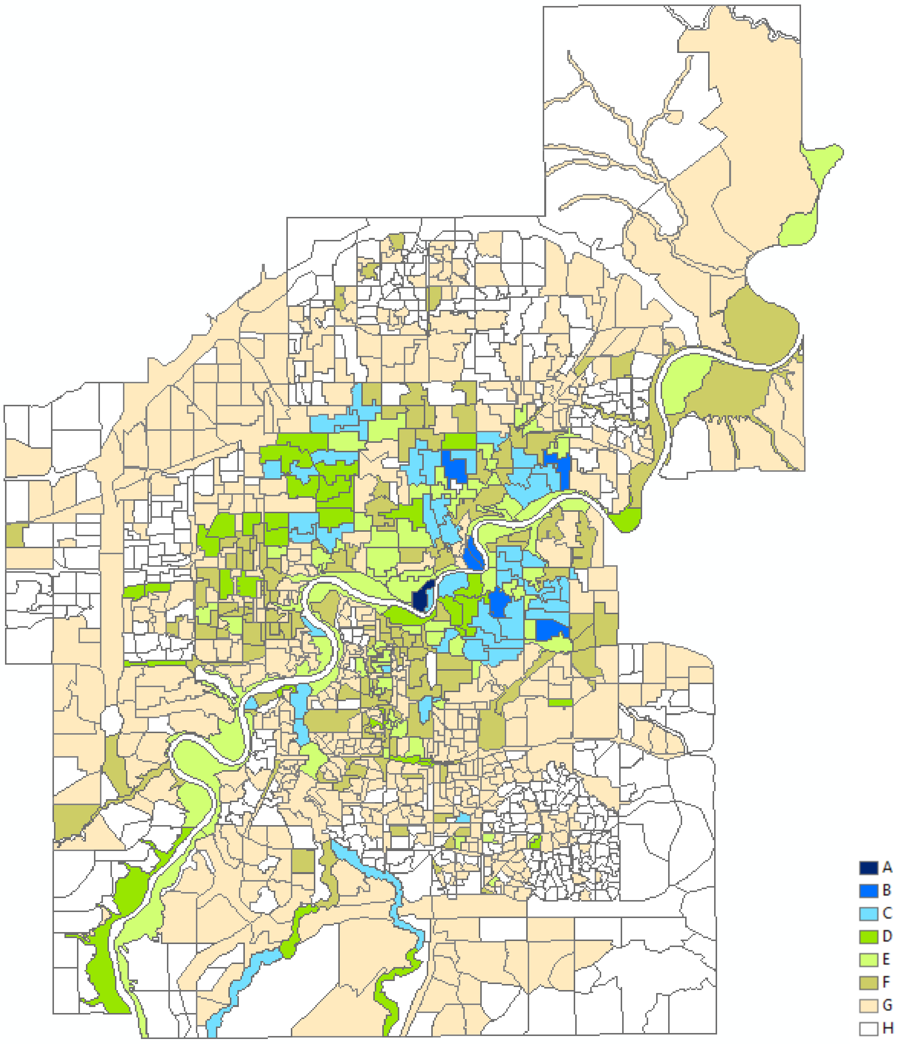


Figure 5-11: SIRP 2018 Equal Risk Weighting

Method 2 – Public Opinion Survey Preference	Number Basins by Risk group	
Health and Safety – 30% Environment – 15% Social – 30 % Financial 25%	Group A – 1 Group B - 9 Group C - 51 Group D - 39 Group E - 66 Group F - 139 Group G - 543 Group H - 462	Groups A-C include High Risk Basins Groups D-F include Medium High Risk Basins Group G is Medium Risk Basins Group H is Medium Low and Low Risk Basins

Method 2 – Public Opinion Survey Preference Map

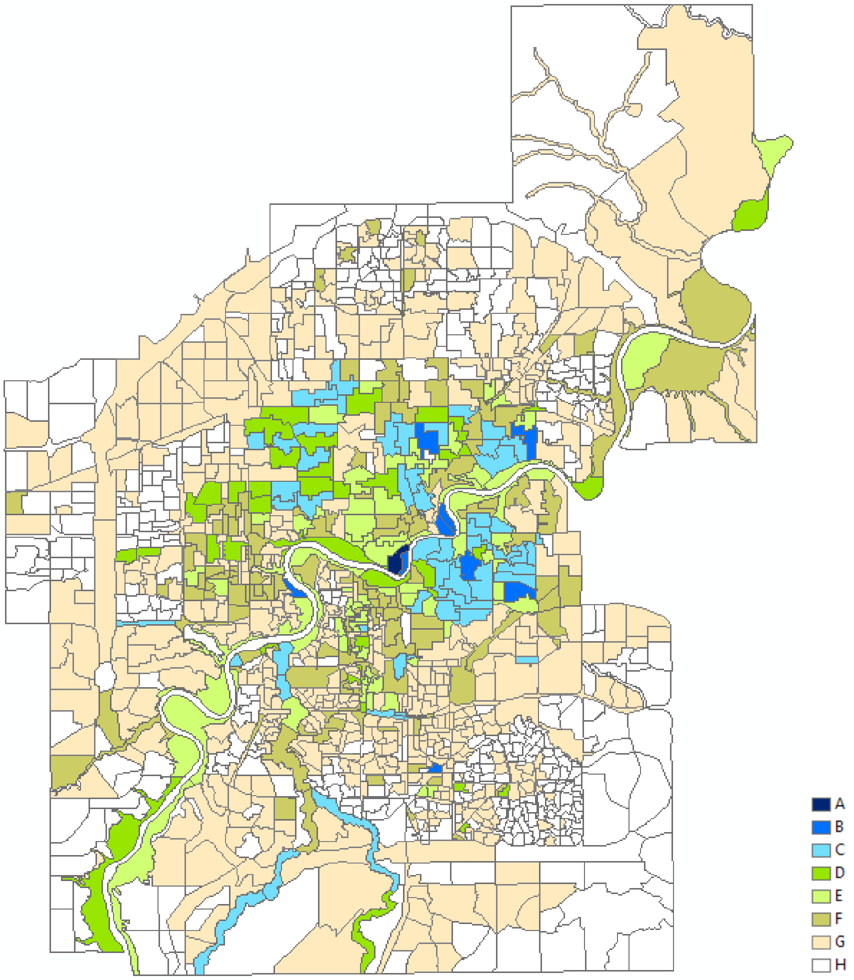


Figure 5-12: 2018 SIRP Public Risk Weighting

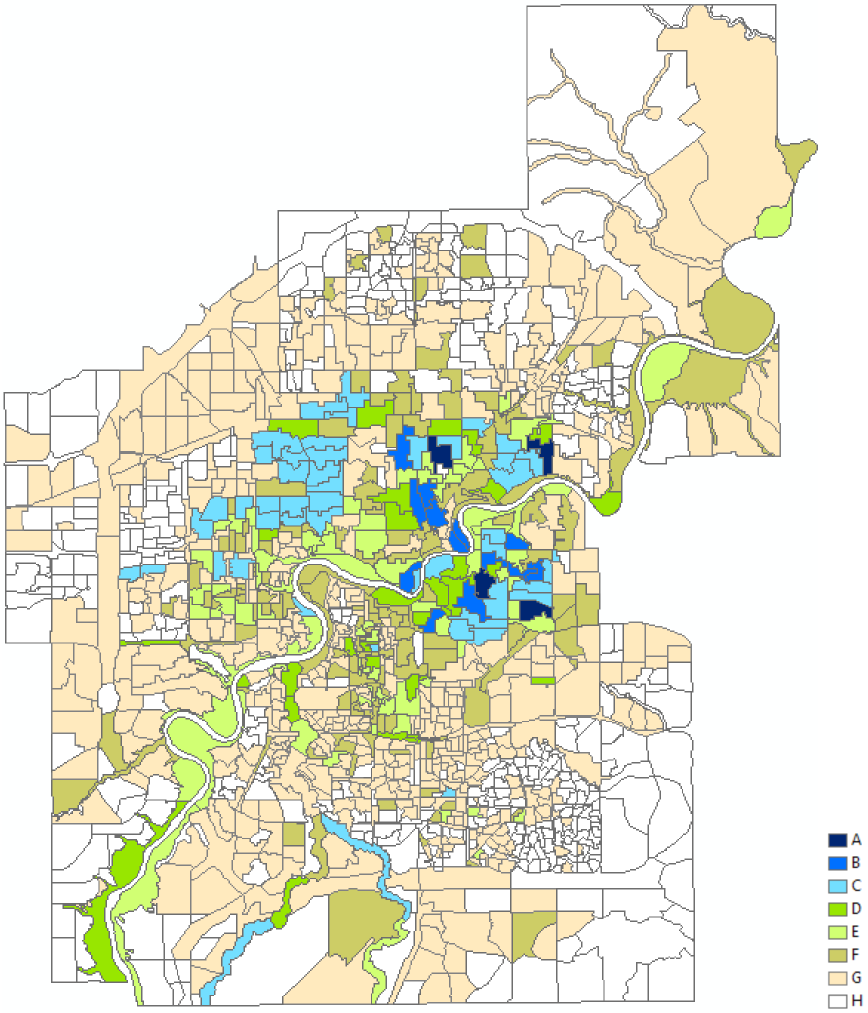
Method 3 – Property Damage Focus	Number Basins by Risk group	
Health and Safety – 20% Environment – 20% Social – 20 % Financial 40%	Group A - 4 Group B - 13 Group C - 46 Group D - 30 Group E - 72 Group F - 143 Group G - 553 Group H - 449	Groups A-C include High Risk Basins Groups D-F include Medium High Risk Basins Group G is Medium Risk Basins Group H is Medium Low and Low Risk Basins
Method 3 – Property Damage Focus Map		
		

Figure 5-13: 2018 SIRP Financial Risk Weighting

The equal and public weighting methods in Figure 5-11 and Figure 5-12, Methods 1 and 2 respectively, are very similar between all of the high risk sites. The major difference is seen in Figure 5-13, Method 3, when financial risk has the highest weighting. The major difference between the financial method and the other two methods is the focus on the A and B sub basins. There is only 1 sub basin within the A risk classification for Methods 1 and 2. It strongly suggests that the lessons learned from the public engagement survey is that the focus for standards of living is the continued use of utilities. The sub basin classified as A in methods 1 and 2 includes one of the two water treatment plants for the City of Edmonton, as well as, a major electrical substation. If this sub basin experienced a flooding situation it would create significant impacts on most of the residents within the City of Edmonton and surrounding areas.

The Financial weighting method, or Method 3, has 4 sub basins within the A risk classification and moves the highest risk sites away from sub basins that have critical social infrastructure to sites with larger number of properties that are at risk. This is important confirmation of the fact that traditionally financial focus for flood mitigation is primarily on a cost benefit analysis for implementing projects. Additionally, the sub basins identify with Method 4 does not include the sub basin identified in Methods 1 and 2, and instead focuses on sub basins that have a high number of residential properties at risk. It is clear that Method 3, which weighs heavily on cost benefit, does not address the social requirements emphasized in the Public Survey.

Similar to Table 5-6 above, Table 5-8 shows the difference between each of the weighting scales or weighting methodologies by the number of sub basins that have changed risk category when applying the A-G risk scale. There was a 5 to 10% change in sub basin risk categories with changing by 1 either up or down. Between the Method 2 and Method 3 there was only one sub basin that changed by two risk categories. This change is due to the high Health and Safety consequence with low financial consequence in regards to the depth of flooding as seen within the JBA purchased data.

Table 5-8: Comparison between different weighting system using the A through H risk score which results in a sub basin changing from Risk Description by 1 either up or down

	Method 1 – Equal Weighting	Method 2 – Public Engagement	Method 3 – Traditional Weighting
Method 1 – Equal Weighting	-	52	113
Method 2 – Public Engagement	52	-	131 1 changed by 2 categories
Method 3 – Traditional Weighting	113	131 1 changed by 2 categories	-

The risk ranking methodology results that were created and illustrated in the map and graph (Figure 5-8 and Figure 5-12) allowed various planning teams and the public to observe the impacts a flood would have on a sub basin. This proactive risk ranking methodology allows for planning engineers to review the municipality as a whole and build long term strategies to reduce the risk of flooding. As an example, the inclusion of a dry pond over several sub basins may create a linked drainage network between those sub basins, which could increase or decrease the flooding risk when compared to not including the dry pond. This is also helpful when applying pipe networks over the risk map to easily identify areas that do not have adequate outlets. These were utilized by EPCOR to build the Stormwater Integrated Resources Strategy, which is the 20 year flood mitigation strategy to reduce the risk of flooding within the City of Edmonton. As such, the novel risk methodology as illustrated in this thesis is an impactful tool to provide information on flooding risk change(s) when a proposed flood reduction application is initiated prior to construction.

6. Case Studies

The long-term goal of this project is to create a risk ranking methodology that can be updated as projects are completed or on a by-yearly basis. There were three areas that were used to validate the methodology; the use of new hydraulic modeling analysis, historical pictures, and application of the new flood strategy. An updating methodology is now required to be able to adapt as new detailed models are created. This is the key to demonstrating that the risk of flooding decreases as capital work is completed.

Two Edmonton neighbourhoods, Parkallen and Hurstwood, were utilized for the first review of dynamic capacity and evaluated as major capital flood mitigation projects were already underway. There were two flood mitigation projects completed shortly after the creation of the risk ranking methodology. EPCOR utilized these two projects to validate the benefits of the projects for proceeding forward to construction. The third area reviewed was the sub basin that includes the Terwillegar Dog/Recreation Park. This type of sub basin is one of the areas that is at high risk of flooding but requires an approach different than traditional flood mitigation to reduce the risk of flooding (i.e. the emergency management plan).

6.1. Parkallen Dry Pond

Parkallen, which was flooded in 2012, has a large green space within a low area of the neighbourhood. A mitigation project had been proposed as part of the Expanded Flood Mitigation Strategy, and concept design had begun, when SIRP risk ranking process began. This project was identified as a prime example of how the risk ranking system can demonstrate changing risk as benefits of flood mitigation projects are realized.

Figure 6-1, below, provides a close up of the neighbourhood as to its risk ranking. The sag area (lime green) identified in both the hydraulic model and the JBA flood map put the risk of that are at an E ranking. This area was also subject to high sewer surcharging which brought the remaining sub basins within the neighbourhood to an F ranking (orange). It is expected that the risk will decrease with project completion once the surface flows are collected and stored in a SWMF (2 dry ponds), preventing the flow from entering the sewer system to cause surcharging.

Parkallen: Flood Risk Mitigation Opportunity

Sub Basin 1239, 1252, 1254

Original Risk Ranking

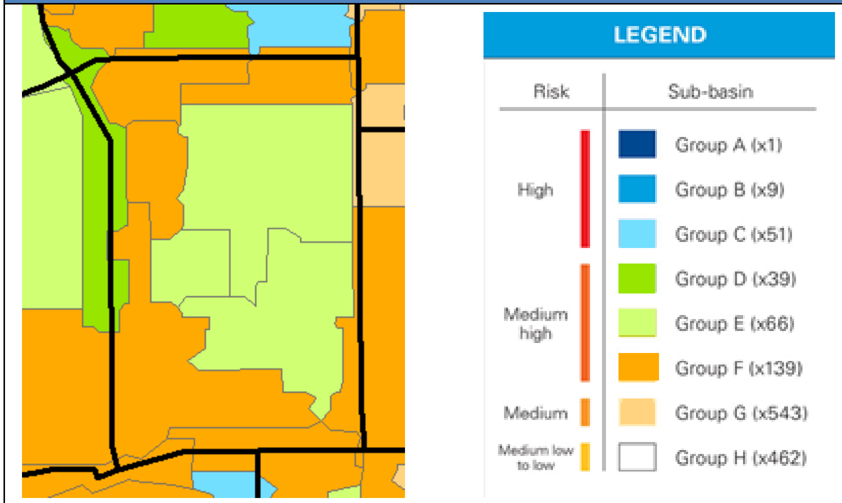


Figure 6-1: Parkallen Original Risk Ranking

Unfortunately, the surface 1D-2D hydraulic model only provided 5 and 100 year inundation levels. Since the SIRP risk ranking methodology does not include 5 year rainfall events, it is impossible to utilize this storm event. Therefore, only the 100 year storm event was employed, using the original risk ranking and new hydraulic model results, both for existing conditions and the expected conditions following mitigation.

For the conditions prior to construction of the flood mitigation project, the initial evaluation with the SIRP risk model for only the 100 year event was directly evaluated with the new hydraulic model. It should be noted that the results of all the other consequence criteria remained the same for the evaluation. Figure 6-2 (a), below, shows the extent of flooding expected for this 100 year event. Figure 6-2 (b) has the more detailed hydraulic model results for the same event, superimposed on the SIRP Risk Model sub basin risk model. Figure 6-2 (b) shows that the SIRP risk ranking methodology matched the results of the detailed hydraulic model under the current sewer system.

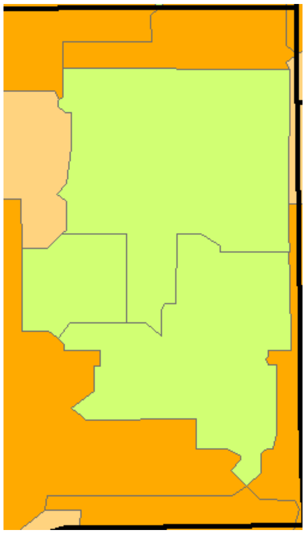
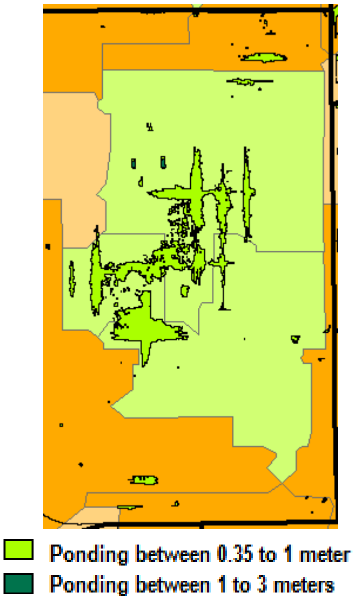
SIRP Risk Model including only the 100 year results	**Substitution of new detailed hydraulic model (100 year storm)**
Before Flood Mitigation Project and Maintaining all other criteria for 100 year storm	
(a) 	**(b)** 

Figure 6-2: Parkallen Risk Ranking comparison for the 100 year event.

The hydraulic model results show that the flooding is contained within these two cell dry ponds – see the dark green flooding locations in Figure 6-3. As explained in Environmental Consequences (Section 5.2.2), flooding within the SWMF footprint is removed from the flooding volume calculation since flooding for the Parkallen neighbourhood is both expected and acceptable for the dry pond location.

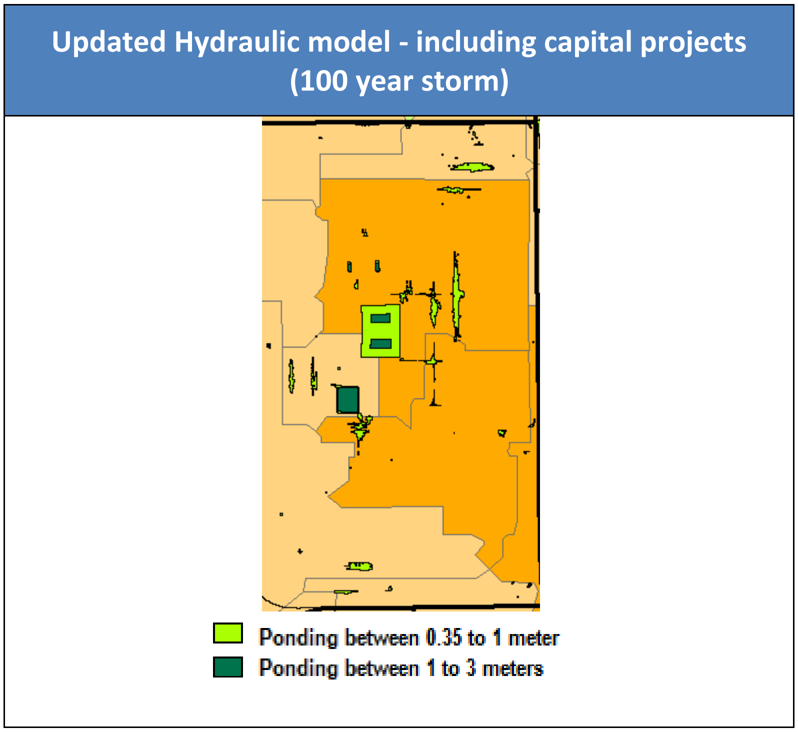


Figure 6-3: Parkallen Risk Ranking with installation of Dry Pond

The risk for this neighbourhood was reduced from a risk weighting from E to F. The agreement with the City of Edmonton Utility Committee with the approval of the risk ranking methodology was that focus would be on sub basins with a risk score of E or higher. This reduction moves the sub basin from an area that requires work to minimized risk. This reduction reaches the approved risk ranking for targeted application of flood mitigation works. Although there is still a moderate risk of flooding, this can be explained through sanitary surcharge.

6.2. Hurstwood Wet Pond

The Hurstwood Wet Pond project is different than the Parkallen project because of its lowest initial risk level of H. Since flooding projects are to be applied to high-risk neighbourhoods this project would not historically be approved for funding. This is one of the many areas where the only data available was the JBA flood maps.

Figure 6-4: Relative Location of Maple Ridge Industrial

Maple Ridge Industrial, an industrial park within the Hurstwood area, includes a small section of residential properties, as shown in Figure 6-4 (note the white rectangular area). The area to the west of the proposed project location is private property (A), the neighbourhood of Maple Ridge to the north is an industrial area (B) and south is farmland (C).

This project was originally proposed because of the flooding experienced in 2012. Pictures from this flood, shown below in Figure 6-5, depict water levels of up to 1 meter in the area. These photos were taken by a City of Edmonton Drainage Employee a few hours after the storm had passed, and validate the type of flooding that this area experienced. Due to the photographic evidence, it was deemed necessary to provide flood mitigation for extended periods of flooding.

Figure 6-5: Flooding within the Industrial Neighbourhood in 2012

When reviewing the original SIRP risk ranking model for the area, it was discovered that the risk was the lowest weighting. This could be explained since no hydraulic modeling had been completed and there was no underground piping network. Even the JBA flood maps showed minimal surface ponding outside of the creek and SWMF until it reached the 1:1,500 storm event, see Figure 6-6. Recall that flooding up to the 0.35 meters is considered acceptable along roadways.

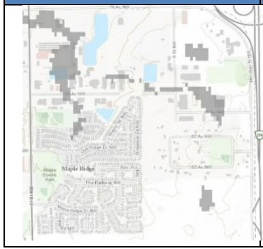
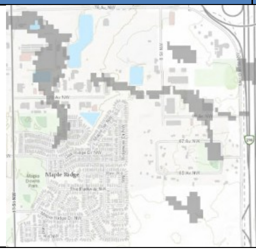
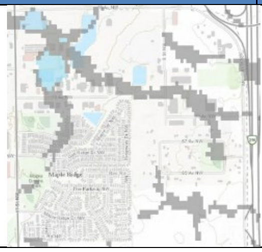
20 year Storm Event	50 year storm event	100 year storm event	1,500 year storm event	Grid
				⬜ 0.0m <= x <= 0.3m 🟦 0.3m < x <= 1.0m 🟩 1.0m < x <= 3.0m 🟨 3.0m < x <= 6.0m 🟧 6.0m < x <= 9.0m 🟥 x > 9.0m

Figure 6-6: JBA flood maps for the Maple Ridge Neighbourhood

Researching previous hydraulic model revealed that a 2013 model was used when this project was first evaluated. The 2013 model added pipes, see Figure 6-7 (a), instead of swales to provide a logical flow path for modeling the storm water, strictly due to the model software requirements. With the inclusion of a new hydraulic flood model, results of the risk ranking in the area downstream increased the total risk score from a category H to F. This type of model is not considered the most reliable form of analysis since there was no indication as to the depth of flooding due to the fact that the swales were modeled as pipes and additionally, only a few of the swales in the project area were included in the model. The model results only indicated the areas where the pipe would surcharge to above ground level.

The model results provided by the consulting team working on the Hurstwood Wet Pond design in 2018 provided additional surface topography. The consultant focused on the immediate contour, see Figure 6-7 (b), for surface modeling. The contour model was only in the immediate area of the project location and determined the volume required for the proposed wet pond. With these new hydraulic models the risk increased from H to F and G for the area which brought the flood risk within expected levels. With the inclusion of additional detailed models some areas can indicate risk of flooding. The changes seen within this sub basin strengthened the requirement that flooding maps be applied whenever possible.

Hurstwood 2013 Modeled Pipes	**Hurstwood 2017 Surface Model to determine Pond size**
(a)	(b)

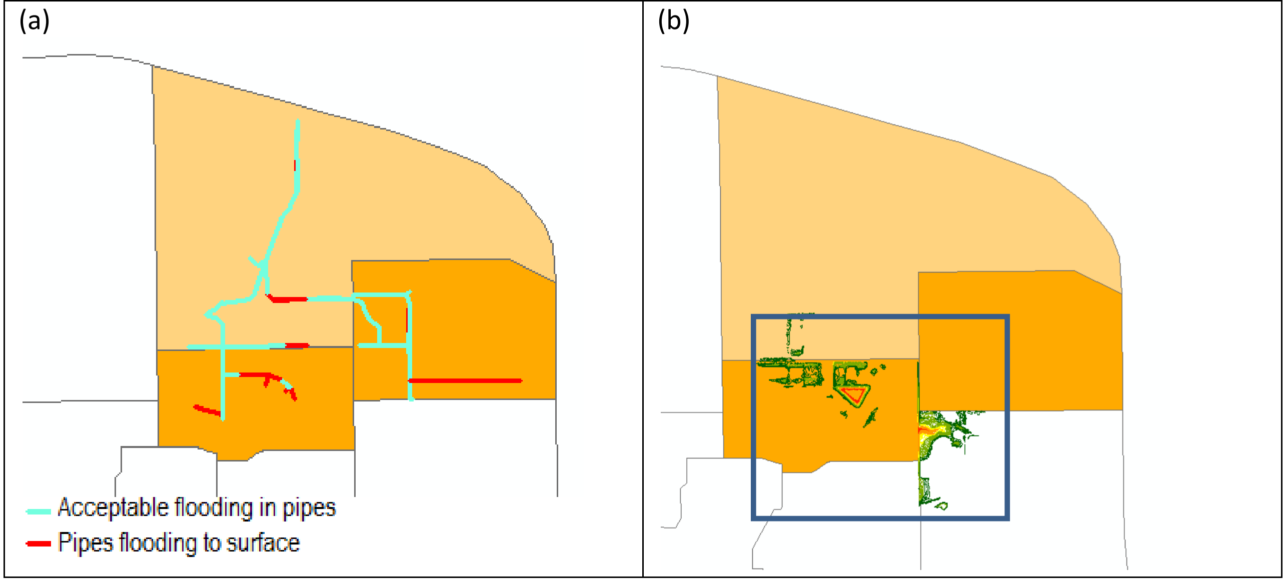


Figure 6-7: Pipe & Surface model results

6.3. Terwillegar Dog/Recreation Park

This last area of review was not part of an ongoing project but was requested to be reviewed due to the results of the high-risk ranking. The Terwillegar Dog Park is its own sub basin within Edmonton's River Valley and is surrounded on two sides by the North Saskatchewan River.

This sub basin is considered at high risk of flooding due to rising river levels at the 20 year event. Its proximity to the river means that flooding can be over 9 meters above normal river levels. This area has no buildings that could be damaged, but contains a parking lot. The green space is used as an off-leash dog park and a recreation park for cyclists. Therefore, applying traditional flood mitigation by building a flood wall would be expensive for a park, and the public would not appreciate losing access to the river.

This is where the IRP approach is beneficial. Instead of mitigating the effects of flooding, the IRP approach can focus on management during a flood, in the form of an emergency management plan for this sub basin. The emergency management plan is in the process of being finalized, however recommendations include; placing barricades at the top of the road into the park to prevent people from driving their cars down, or installing messages either on site or through social media.

Using the risk grid approach, Terwillegar can be downgraded to a rating of "H" once an emergency management plan is finalized. Although there is still a risk of flooding at this location, the risk to human life is minimized with the emergency plan. With the implementation of the emergency plan, this sub basin now has a very low priority for flood mitigation, even though there is a high likelihood of flooding.

6.4. Adaptability through Updates on the Sub Basins

An internal EPCOR 2019 update – not released to the public – increased the number of sub basins from 1,310 to 1,392. This was mostly because of an approved annexation that increased the size of the City of Edmonton. A few additional changes to the sub-basins resulted from a closer evaluation of the nearby risks. An example of this change in sub basin shape included a change within an industrial area that included an underpass. This sub basin was split in two, which focused the risk within the area that was actually at risk, the underpass, and not on the surrounding industrial sites.

Another change to the sub-basins included approximately 70 sub basins with creeks running through them. Although hydraulically correct for the overall drainage of the area, the risk within the sub basin was focused solely on the creek. The surrounding neighbourhood had minimal to low risk of flooding. To adequately determine the risk within the creek and the surrounding neighbourhood, the creeks were split into their own sub basins to properly indicate the area that is at risk of flooding.

No additional separation of sub basins is expected unless the City limits expand. It is expected that future sub basins will require splitting as the City urbanizes the agricultural lands along the outskirts of the City Boundary. These are visible in the maps as extremely large areas in the municipal periphery, where some new development is occurring. Since the new development has a higher level of service and is built for the 100 year storm event, the risk of flooding to these areas is already lower than in older areas. As the current infrastructure ages, these sub basins will need to be segregated to adequately determine the risk.

6.5. Applicability of the Risk Ranking Methodology to Other Municipalities

When creating the risk ranking methodology there were some considerations on how to utilize the risk ranking methodology for other municipalities. Although this has not been tested to date, there is a reasonable assumption that the methodology can easily be applied to other municipalities. This desktop review will look at potential changes to the different steps that were described in Figure 4-1 for application to a new municipality.

Based on the four steps the largest changes would be seen in Step 1 and 2. The first major change regarding Step 1 would be building a new sub basin model to match with the new municipality’s watersheds and sewer sheds. This is a critical change since each municipality is unique in the underground pipe network design and geography.

Step 1 also requires the review of available data sets. Even if a municipality does not have many hydraulic modeling results, the use of the JBA Risk Management flood maps would provide a high level risk evaluation for the municipality. To provide the most realistic results the inclusion of any past hydraulic models, operational data, and asset condition ratings would be preferred. If there are additional data sets that were available that had not previously been included the review of the key statements can be evaluated to determine where they could best be included.

If EPCOR were to create the risk ranking methodology the same software would be used. If other municipalities were to create their own risk ranking methodology other geospatial software could be utilized. As long as there is geospatial software the methodology would remain the same.

For Step 2, any changes would be based on the difference between design standards based on the preferred IDF curves. For the City of Edmonton the five storm events that were chosen were based on the 4 hour event. Other municipalities might prefer to only focus on one storm event or have different rainfall durations. These changes would affect the likelihood and consequence data evaluation but the key statements would remain the same.

Although the consequence key statements were built for transferability between municipalities there a few changes that could be required. A review of the municipality's design standards regarding flooding at street level would be the largest change. The City of Edmonton's design standards states that up to 0.35 meters of water on the street is acceptable. This change would be fairly straightforward within the evaluation requirements for updating the risk ranking methodology.

It would also be a good idea to complete a public engagement survey to determine the residents preferred focus for the municipality. This would change the weighting system to reflect the aspects within the municipality that residents deem critical. Based on the results it could change the prioritization for the top sub basins.

Step 3 was the application of the risk ranking equation and importing the risk onto a map and grid. The methodology to create these would remain the same. There are a few methods that were discussed as to the presenting of the information which provide flexibility to meeting the requirements that the municipality might have.

Step 4 then requires regular updates to keep the risk map current. The municipality could then utilize the risk ranking result to build a flood mitigation strategy.

With the list of changes just discussed, the methodology described within this document and the key consequence statements remain the same. It is therefore a reasonable assumption that this methodology can be successfully applied to other municipalities.

7. Conclusions and Recommendations

7.1.Conclusions

Flood events have increased in both frequency and magnitude over the past decades, and methods to manage flood risk must adapt. Expanding the toolbox to include risk methodologies layered over hydraulic model results provides a more realistic view of the risk of flooding throughout municipalities. The ease with which the SIRP program can incorporate different hydraulic & hydrological models, operational data sets, asset condition, to name a few, which allows almost instant updates as design standards change or storm events are reclassified.

The objective of this work was to create a new methodology that would prioritize investments of flood mitigation projects in municipal settings. This was accomplished by creating a visual representation, in the form of a colour-coded risk geospatial map, of the flood risk throughout the City of Edmonton. By creating likelihood and consequence scales a total risk could be calculated for each sub basin. The total risk was then placed on a colour scale which then visually represented the risk. The system is now in use in Edmonton, and the final result has been approved by both EPCOR and the City of Edmonton as the method to prioritize flood mitigation projects.

The SIRP risk ranking methodology serves as an alternative to the traditional method of cost-benefits used for developing flood mitigation strategies. It prioritizes projects based on the maximum risk of flooding seen within the sub basin with weightings that emphasize social risk. Using risk management as a prioritization method, focus is then on capital or other forms of upgrades to reduce the specific risk within the sub basin. This allows for overall review of the area to determine how best to reduce the risk instead of prioritizing projects that are outside of high risk flood areas since they have lower costs. The goal is instead of reviewing a large area and prioritizing projects based on cost benefit the focus would remain within high risk flood areas and how best to reduce that risk. This method was compared to the previous City of Edmonton flood mitigation projects which prioritized projects based on cost benefit analysis. The result was that previous projects that had been postponed due to low cost benefit were prioritized due to the high risk of flooding. The use of multiple storm events assisted in this refocused prioritization since the areas that were now top priority experience flooding not only during extreme even but during small rainstorm events as well.

Since extensive flood information has been available for the City of Edmonton since 2004, the SIRP risk ranking methodology focuses on the creation of a likelihood and consequence grid applied to sub basins within the city based on drainage patterns, social infrastructure, and environmental impact. This allows for multiple areas to be compared objectively against each other based on a forecasted storm event. Furthermore, the information through comparison assisted in predicting the consequences when flooding would occur.

This new dynamic methodology requires that risk rankings be adjusted as new data become available on the benefits of completed flood mitigation projects. The creation of the risk ranking methodology required detailed analysis of the City of Edmonton past data sets, and creation of new data sets and the assistance of a small amount of purchased data.

Since this risk ranking methodology was applied to flooding in 2018 for the City of Edmonton, the process involved requires a number of iterations and adaptation as new information was learned and applied to the risk ranking. For example, data collection was considered fairly straight-forward since flood mitigation projects and studies had been completed within Edmonton over the last decade. The data and models that fueled these past studies were applicable to the risk ranking. Studies into flooding methodologies, synergies with other programs within Edmonton and flooding events in Canada indicated that new data was required. New data sets that were built during the creation of the SIRP project include the LID, creek erosion, and operational data sets, and the identification of critical social sites. One additional data set was purchased from JBA Risk Management for their flood risk maps which are also used by insurance companies.

Due to the short timeline to complete the new flood methodology, the focus for choosing software that already had a license available. Geospatial analysis software was deemed to be the most versatile since geographical changes in terrain and hydraulic models are geotagged. This geotagging process would allow the evaluation within an area based on what was currently there. The second step was to determine appropriate likelihood and consequence scores which would be used to evaluate the data sets.

Traditional design standards typically state that flood mitigation projects should provide a level of service up to the 100 year 4 hour storm event. By implementing a risk grid approach the likelihood of flooding changes, from a single storm event to calculating the risk of a series of storms. This allows sites that have a risk of flooding during smaller events to become the priority instead of sites that might only flood during the 100 year storm event.

Building the consequence themes of the grid included evaluation and incorporation of synergies with the City of Edmonton's Climate Change Adaptation Strategy (Edmonton 2020) and the Public Engagement Survey, initiated by the SIRP team. Three types of flooding were included in the climate change adaptation strategy: urban, riverine, and sewer surcharge. Consequence categories had already been developed by the City's Climate Change Adaptation Strategy and included health and safety, environmental, social, and financial categories. Many of the data sets used within the SIRP risk grid were evaluated using all four of these categories. New key statements were created for SIRP that facilitated in the evaluation of the data sets but remained at the same risk as the Climate Change program. Since there were four consequence factors that were separate from each other, the final weighting to create a single consequence factor was key. To allow greater flexibility in the weighting, the results from the public engagement were used. These prioritized flood mitigation programs on social infrastructure over the traditional application in areas with the highest financial impact.

Once the likelihood statements, consequence statements, and software were evaluated for their merits and application, the risk ranking methodology was built and optimized. The goal of building a risk ranking methodology that can visually demonstrate flood risk was achieved. The result was a colour coordinated map of the City of Edmonton which indicated the risk of flooding.

SIRP's new risk ranking methodology and associated geospatial visualization provides easy understanding to areas with the City that are at risk of flooding. This approach is based on historic data, current conditions, present learning's and can be updated. The flood risk map is also an invaluable tool for the development of Edmonton's flood mitigation strategy, providing a structured and feasible approach to the application of public funds. The finalized risk ranking methodology has been used by the City of Edmonton since its approval in 2018. The methodology developed is broad enough that is can be applied to other municipalities to address flood mitigation programs.

Conclusively the methodology that was created as part of this thesis has provided valuable insight into the missing pieces of flood mitigation work. Although hydrological models do provide a wealth of information it can only be applied to best case scenarios. Understanding ageing infrastructure and changing design standards creates many differences when comparing hydraulic models and experienced flooding events. Increasing the amount of knowledge able to be reviewed has only increased the value seen for owners and operators in the management of the drainage system to minimize flooding affects.

7.2.Recommendations

There is ongoing work to continue to update the risk ranking as flood mitigation projects are completed. There were a number of lessons learned regarding flooding that will also require updates to the risk methodology, such as underpass locations as their own sub basins and the risk of parkades. Changes to the system through asset management and new learnings from climate change modeling studies means risk ranking is a dynamic process.

One potential addition to the SIRP framework is a 500 year 4 hour storm event as one of the likelihood storms to be evaluated. At this time, there are a number of areas that are at high risk of flooding during smaller events (20 and 50 year) and these are currently the focus for flood mitigation strategies. Once the number of sub basins is no longer affected by the 20 or 50 year storm event following the installation of flood mitigation projects, the 500 year storm event could be evaluated. The expansion into the 500 year storm event would provide the proactive method of determining areas that may begin experiencing flooding due to climate change.

Urbanization is another aspect that should be reviewed for the City of Edmonton. In the last twenty years, the population of the City of Edmonton has doubled (City of Edmonton, 2022); early predictions are that it will double again in the very near future. The City of Edmonton has dealt with population expansion through annexation, if this continues then it is expected the resulting population increase will put a strain on the older mature piping network increasing the risk of flooding with the reduction of flow capacity. This concern is part of the requirement that the risk ranking methodology be regularly updated. This will allow review of the continued expansion as well as densification within the core. Although there has been internal EPCOR reports that indicate the overall flow volumes within the pipe network have decreased slightly even with the growing population, it is theorized that this reduction is based on the installation of low flow management systems within new homes and the renovation of older homes. The pipe network will require ongoing monitored to maintain a realistic flooding risk. With the lowered dry weather usage within the pipe network there is a larger capacity available for storm water.

Since the risk ranking methodology was finalized in 2018, some additional steps were taken to automate the risk evaluation process and a 2019 risk ranking grid and map were made available to EPCOR staff. A third update is scheduled to be completed in 2022, which includes some of the missing sections highlighted from 2018, such as the parkade data, an update to LID, and updated critical infrastructure lists. An additional update that was unexpected at this stage was the disaggregation of some sub basins in south Edmonton through new residential development. Additional sub basins were also included with annexation of area south of Edmonton. These changes increased the number of sub basins to 1,392. The risk methodology was easily applicable to these areas once the sub basins were built.

Application of flood mitigation measures can only be completed using the knowledge available. The methodology described in this thesis allows for a holistic review of all of the known data sets to evaluate risk. As mentioned previously, elevators and underground parkades were originally considered at low risk to the public but during the creation of the risk ranking Toronto experienced a large rainstorm event that trapped two men in an elevator as the water poured into the parkade. Following this incident, EPCOR evaluated all parkades to determine whether they had any method to prevent flood water from entering the structure. This was the first new data set that increased the calculated risks, but it is not expected to be the last. As flooding occurs around the world, events will continue to be evaluated to determine the mechanism that caused problem, what was done to mitigate it, and how it could be incorporated into the SIRP model.

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Appendix A – Creating a Flood Strategy (Part 2 of SIRP)

The Risk Ranking part of the SIRP (Stormwater Integrated Resources Planning), presented in this thesis, was approved by the City of Edmonton Utility Committee in October 2018. This Risk Ranking methodology provides the ability to see the community flood risk through multiple lenses. Following the Risk Ranking grid, the mitigation part of SIRP was developed using the Risk Rank and was approved in May 2019. The SIRP risk ranking strategy will now be updated and released to the public at regular intervals.

EPCOR developed and presented the flood mitigation plan to the City of Edmonton, which will reduce the risk of flooding for sub basins within the ranking of A through E on an initiative basis. Mitigation work in sub basins with the risk rankings of F and G are to be incorporated, on as an opportunistic basis, when other utility work is defined for those areas. The only exceptions for this proposed work protocol are sub basins within critical infrastructure. These areas are to be reduced to H risk through planned proactive work. This plan was approved as part of the May 2019 SIRP strategy proposal.

One of the findings through the creation of the risk ranking was to adequately explain the ongoing risk of utilizing historical flood mitigation measures. Piping storm water as quickly as possible to the creeks and rivers marginally decrease the risk of flooding within the community but it greatly increases the risk of erosion within these creeks.

EPCOR's new approach is to retain the majority of storm water with green infrastructure to allow the pipe network to be the additional capacity which would deal with the extreme storm event volumes. This methodology also returns the storm water to a similar pre development water cycle system. Pipes are still important in certain situations but with the results of the SIRP risk ranking it allowed for a targeted approach.

Along with green infrastructure a number of initiatives were proposed which created the following five themes of flood mitigation work which can be seen in the figure below. The approval of SIRP strategy using the risk ranking methodology was approved in May 2019.

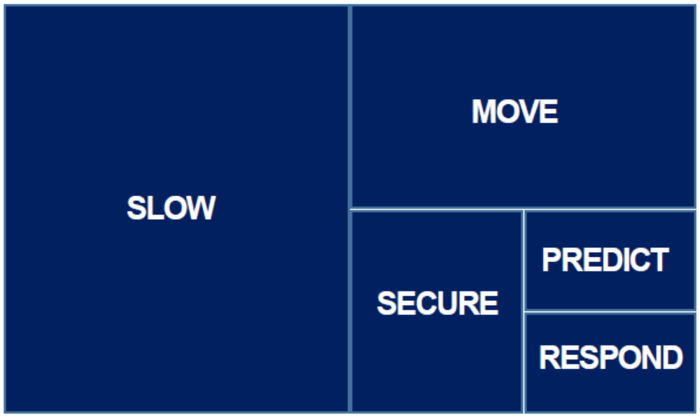

Figure A-1: Five Capital Project Themes