findings of the one before, the methodology as a whole creates an opportunity to re-evaluate and review findings and decisions. See the Resource Directory.

There are also many other guides (see the Resource Directory) available which take various approaches to adaptation planning. For instance, there are guides specific to:

- Risk and infrastructure (i.e., A Risk-Based Guide for Local Governments in British Columbia);
- Climate change and health (i.e., Human Health in a Changing Climate);
- Profession specific (i.e., Canadian Institute of Planners);
- Climate Change Risk Assessment Guide (2014);
- ISO 31000 Risk Management;
- Considering climate change in the environmental assessment process (MECP);
- City of Toronto Climate Change Risk Assessment Tool.

The above tools and guides allow practitioners, water resource managers and municipalities to assess proposed stormwater management plans and/or facility designs, to improve resiliency in stormwater management infrastructure, and improve emergency preparedness. Considering the wide range and variety of tools and guides available, choosing the most appropriate approach requires identification of the user's specific adaptation needs and concerns at the onset. Evaluating inappropriate climate change indicators may lead to inappropriate adaptation actions, which could potentially increase system's vulnerability to climate change or unnecessarily increase cost. It is important to note that the tools are not limited to stormwater management and can also be used for other water infrastructure such as drinking water and wastewater treatment plants, etc.

Municipalities are encouraged to develop guidelines and best practices to apply land use planning policies and tools for achieving climate adaptation objectives. For example, policy instruments such as municipal official plans can help establish direction, objectives and overall goals for climate change; and regulatory instruments such as zoning requirements, development permits and defined hazard zones strengthen and define the land-use direction for climate change response. These instruments can be promoted by the use of financial incentives such as charges or fees and grants to enhance the implementation of policies and regulations. (Adapted from Research and Information Gathering on Climate Change Mitigation and Adaptation. McVey, I., et al. 2016)

6.8 Four (4) Step Climate Change Adaptation Processes for Stormwater Management

If a more detailed assessment hasn't already been prepared, the following describes a four (4) step qualitative vulnerability assessment process that stormwater practitioners are encouraged to use to incorporate climate change adaptation strategies into stormwater management projects.

Qualitative approaches begin by first identifying system vulnerabilities to a wide range of future climates and then determining the plausibility of the specific climate impacts using the best available and credible climate information.

A traditional 'top-down approach' is when a limited selection of individual Global Climate Model (GCM) projections are used to attempt to quantify and predict potential climate impacts. Qualitative or "Bottom-Up" approaches reverse this assessment process by first identifying system vulnerabilities to a wide range of future climates (beyond those predicted by GCMs) and then determining the plausibility of the specific climate impacts using the best available and credible climate information. (World Bank, 2014).

Through the application of this qualitative vulnerability assessment process, practitioners can establish bounding estimates for consideration during stormwater planning and design or, if a defensible design estimate cannot be established, how at the early stages of infrastructure planning, approaches can be taken to design infrastructure that is resilient to a wide range of possible future climates. The four (4) step process can be applied to all stormwater projects including:

- Development of stormwater management plans for site, subdivision, or condominium development;
- Design of stormwater management infrastructure;
- Development of stormwater management master plans; and
- Subwatershed and Watershed Plans.

The four (4) step process includes:

1. Identifying Climate Change Considerations
2. Evaluating Risk caused by Climate Change Parameters
3. Climate Change Impact Management Planning
4. Monitoring and Adaptive Management

The steps for considering climate change parameters and, when necessary, applying adaptation strategies into stormwater design are described in this section. Building climate change resiliency into a project is not a reactive process and should be undertaken during early project phase. Waiting until planning and design has been completed before considering climate change may result in inefficiencies, unnecessary design alterations, and exposure to unnecessary technical or legal risks.

6.8.1 STEP 1 - Identifying Climate Change Considerations

Potential climate change impacts will differ depending on location, type of project and other site-specific factors. During the first step of this process, it is suggested that the stormwater practitioner complete the following:

Step 1a) Clearly establish the overall project context, specifically the project goals, objectives, criteria and targets as well as scope, scale and limitations. The context should be clearly articulated before starting the assessment and documented when completed. Objectives should at a minimum include protection of:

i. Human life and health;
ii. Public and private property;
iii. Public and private infrastructure;
iv. Drinking water quality and quantity;
v. Environmental feature and function; and
vi. Terrestrial and aquatic habitats.

Step 1b) Define and document:

vii. The environment features and function at the landscape and local scale using a combination of field activities and / or existing studies.
viii. The state and functionality of existing stormwater management control mechanisms or practices. Existing controls may be an asset or aid in mitigating future impacts.

Step 1c) Evaluate each climate change parameter observed or predicted for Ontario (See Sections 6.3 and 6.4) to determine if it is anticipated to cause impacts for any specific project component. The key climate change parameters that have the potential to cause impacts and which should be considered to determine if they are relevant to the specific stormwater management or water resources projects are listed below. Additional parameters may be relevant on a project-specific basis. These parameters should be, at a minimum, considered during the planning and design process for all projects to mitigate negative climate change impacts on the project level, within communities and/ or at the landscape scale.

Key observed and predicted climate change parameters include (see Table 6.1):

- Increased mean atmospheric temperature
- Increased annual precipitation
- Decreased annual snowfall and increases in lake effect snow
- Increased winter rain events (i.e. rain on snow events)
- Changes in rainfall intensity
- Increased frequency and severity of precipitation extremes
- Changes in lake levels and stream flows

- Changes in soil moisture and groundwater recharge
- Increased potential evaporation rate
- Increased receiver water temperatures
- Other - additional project-specific climate change parameters specific to the project

Step 1d) - Once the potential impact of climate change parameters on a project have been identified, the risks associated with failing to meet project goals, objectives and targets must be evaluated. Not all components of a project will be sensitive to climate change and not all potential impacts will mandate adaptation strategies.

To assess significant risks while avoiding excessive analysis, climate change parameters should be evaluated using the following six (6) ***Climate Change Sensitivity Screening Questions:***

1. Is there a potential for a climate change parameter to result in increased risk, hazard or safety issues in regard to human life and health within or around the project site?
2. Is there a potential for a climate change parameter to result in increased risk, damage or impact to public and property within the project site or on adjacent lands?
3. Is there a potential for a climate change parameter to result in the reduction of the level of service for stormwater management to an unacceptable level?
4. Is there potential for a climate change parameter to cause impacts to drinking water quality and quantity on the project site or resulting from the project site?
5. Is there a potential for a climate change parameter to cause a failure to meet design project goals, objectives and targets?
6. Is there potential for a climate change parameter to cause degradation or impacts to environmental features and functions and/ or terrestrial and aquatic habitats within the project site or resulting from the project site?

The practitioner can answer and document the climate change parameter screening process by utilizing the template below and modify as required (Table 6.2).

Table 6.2 - Climate Change Parameter Screening Template

Climate Change Parameters for Stormwater Management	Apply the six climate change screening questions. (yes/ no)	List Anticipated Impact(s)
Increased Mean Atmospheric Temperature	1. (yes/ no) 2. (yes/ no) 3. (yes/ no) 4. ..... 5. ..... 6.	1. ..... 2. ..... 3. ..... 4. ..... 5. ..... 6. .....
Increased Annual Precipitation		
Decreased Annual Snowfall and Increases in Lake Effect Snow		
Increased Winter Rain Events (i.e. Rain on Snow Events)		
Changes in Rainfall Intensity		
Increased Frequency and Severity of Precipitation Extremes		
Changes in Lake Levels and Stream Flows		
Changes in Soil Moisture and Groundwater Recharge		
Increased Potential Evaporation Rate		
Increased Receiver Water Temperatures		
Other		

If "Yes" to any of the six climate change screening questions for a parameter, proceed to STEP 2

6.8.1.1 STEP 1d) EXAMPLE

Two projects scales are discussed below as examples in Tables 6.3 and 6.4. One example is a stormwater management plan for the development of a site; the second is the development of city-wide stormwater master plan.

Table 6.3 - Predicted Climate Parameters and Possible Impacts on Stormwater Projects

Climate Change Parameters for Stormwater Management	**Response to Screening Questions**	**Example 1: Development of Stormwater Management Plan for a Site List Anticipated Impact(s)**
Increased Mean Atmospheric Temperature	No	
Increased Annual Precipitation	Yes	Impact on annual runoff volume and pollutant loading
Decreased Annual Snowfall and Increases in Lake Effect Snow	Yes	Impact on winter and spring operation
Increased Winter Rain Events (i.e. Rain on Snow Events)	Yes	Increased probability of surface ponding and flooding. Impacts to on-site safety for pedestrians and vehicles
Changes in Rainfall Intensity	Yes	Increased risk of failure or malfunction of minor stormwater management system responses beyond the predicted or design frequency.
Increased Frequency and Severity of Precipitation Extremes	Yes	Impact on runoff rates and associated conveyance and storage sizing
Changes in Lake Levels and Stream Flows	Yes	Impact if site adjacent to lake or stream (outlet conditions and receiver requirements)
Changes in Soil Moisture and Groundwater Recharge	No	
Increased Potential Evaporation Rate	No	
Increased Receiver Water Temperatures	No	
Other	n/a	n/a

Table 6.4 - Predicted Climate Parameters and Possible Impacts on Stormwater Projects

Climate Change Parameters for Stormwater Management	Response to Screening Questions	Example 2: Development of City-Wide Stormwater Master Plan List Anticipated Impacts
Increased Mean Atmospheric Temperature	Yes	Potential impact on in-ground stormwater infrastructure (freeze-thaw cycle impacts)
Increased Annual Precipitation	Yes	Impact on local water balance
Decreased Annual Snowfall and Increases in Lake Effect Snow	Yes	Impact on freshet response
Increased Winter Rain Events (i.e. Rain on Snow Events)	Yes	Increased probability of surface ponding on roadways, urban and riverine flooding. Impacts to emergency services during event.
Changes in Rainfall Intensity	Yes	Increased risk of failure or malfunction of minor and major stormwater management system responses beyond the predicted or design frequency. Increased probability of surface ponding on roadways, urban and riverine flooding.
Increased Frequency and Severity of Precipitation Extremes	Yes	Impact on urban flooding and erosion processes
Changes in Lake Levels and Stream Flows	Yes	Impact on aquatic habitat, surface water consumption and assimilative capacity
Changes in Soil Moisture and Groundwater Recharge	Yes	Impact on groundwater consumption and baseflow
Increased Potential Evaporation Rate	Yes	Impact on local water balance
Increased Receiver Water Temperatures	Yes	Impacts to environmental features and functions and/ or terrestrial and aquatic habitats
Other	n/a	n/a

6.8.2 STEP 2 - Evaluating Risk caused by Climate Change Parameters

Once the sensitivity to climate change parameters to which the project is vulnerable have been identified (Step 1), questions as to the likelihood of those parameters arising can be addressed in a more efficient and targeted manner.

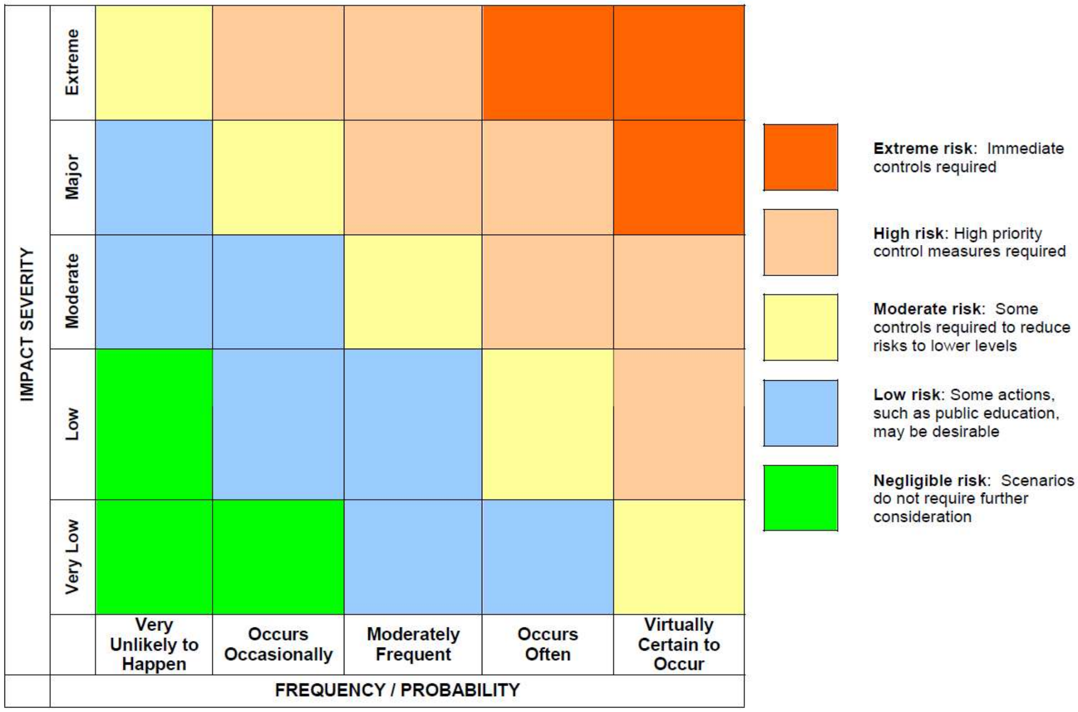
Climate change is a field that is characterized by uncertainty. There is uncertainty associated with climate projections and the impacts of these projections, especially on a local scale. Uncertainty is a common issue facing engineers and risk management offers a reliable approach for prioritizing complex risk issues and for selecting preferred risk reduction strategies. To use a risk assessment framework in a climate change context, the following climate change risks must be established:

- **a)** Probability (certain to very unlikely to occur); and
- **b)** Impact severity (severe to negligible impacts).

The **Climate Change Risk Evaluation Matrix** (Figure 6.1) from Climate Change Risk Evaluation Matrix (Bruce et al., 2006b) adapted from *Adapting to Climate Change: A Risk-based Guide for Ontario Municipalities* (Bruce et al., 2006b), demonstrates how risk can be evaluated. Impact severity is shown increasing along the y-axis, while probability or frequency is shown along the x-axis.

Using this approach, addressing risks can be prioritized with extreme risks requiring immediate adaptation strategies and negligible risks requiring no action. This can be used to assess any climate change impact on a stormwater management project.

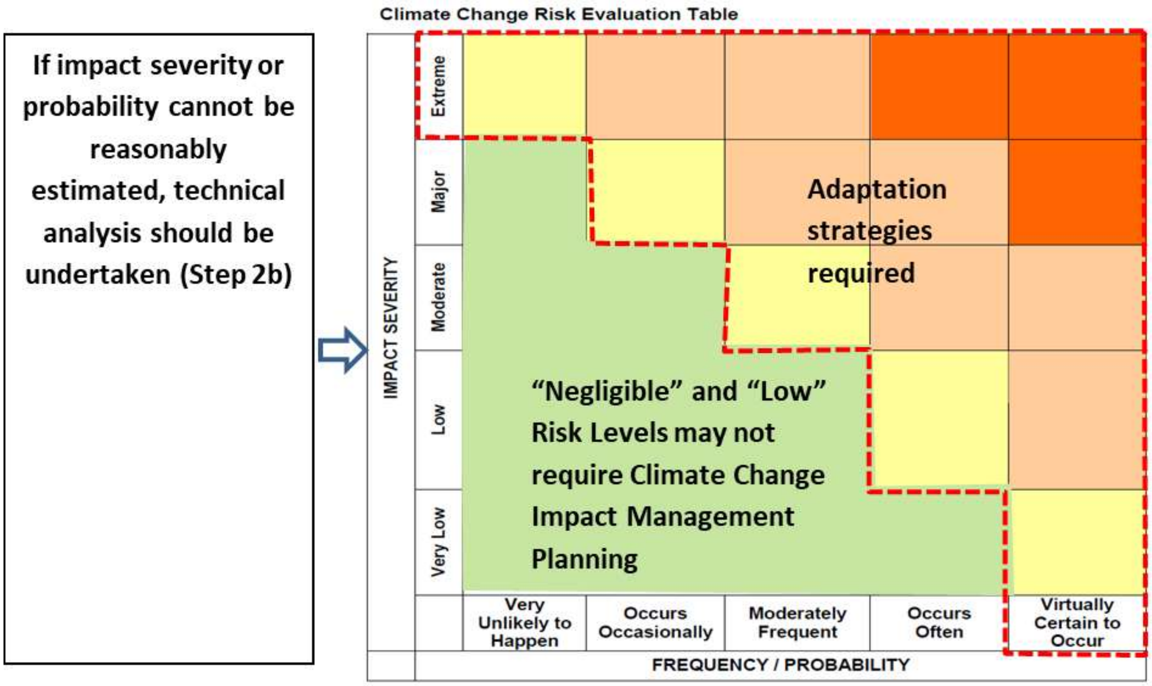
Figure 6.1 - Climate Change Risk Evaluation Matrix



(Source : Bruce et al., 2006b)

Step 2a) – For each parameter and impact identified in Step 1d), assess the probability and impact severity to determine if the threshold level of risk is exceeded. For parameter and impact identified in Step 1d) that meet a threshold level of probability and impact severity, adaptation strategies must be evaluated to avoid an unacceptable level of risk (Figure 6.2).

Figure 6.2 - Application of the Risk Evaluation Matrix



(Source: Bruce et al., 2006b)

Step 2b) - At this step, if the impact severity or probability cannot be reasonably estimated, **technical analysis** should be undertaken (see Section 6.9.2.1). Technical analysis for stormwater management and water resources projects would typically include hydrologic and/ or hydraulic analyses, including associated potential impacts to the form and function of terrestrial and aquatic ecosystems.

For watershed, subwatershed, or city-wide studies, climate change impacts may be wide-ranging and require multi-disciplinary analysis. For smaller site-level projects, it may not be immediately clear if climate change is expected to cause problems for the stormwater management systems. At a minimum, all projects requiring technical analysis should assess the impacts of expected increased frequency and severity of precipitation extremes by including a modelling scenario that reflects predicted climate change.

6.8.2.1 Technical Assessments

It should be noted that technical analysis can not only provide more accuracy with respect to impact severity it can also provide a quantitative indicator of probability. In many cases, a probability can be assigned to the climate change risk via the technical analysis. For example, hydrologic and hydraulic modelling may indicate that inflow volumes calculated using predicted IDF Curves under climate change encroaches within the freeboard that was designed using the existing IDF curve but does not exceed the designed storage volume of a facility during the 1:100-year rainfall event. In this case, the technical analysis can show that the probability of occurrence of failure in light of climate change is very low, the expected level of service will be maintained, and that the risk associated with not increasing the storage volume may be deemed acceptable.

Technical assessment of climate change risks should use the most up-to-date information related to climate projections to the local environment. Technical assessments to address climate change concerns may include but are not limited to:

- Updated water balance analysis for a future climate;
- Updated IDF curves for a future climate;
- Site planting / vegetation sensitivity analysis for a future climate;
- Updated floodplain mapping for a future climate; and
- Others

The following provides guidance in regard to various options to be used in the technical analyses:

Hydrologic Modelling for a Future Climate
When conducting hydrologic analyses, as it relates to climate change, the overall objective is to conduct assessments of future climate change scenarios, account for uncertainties in the predictions, and develop adaptive strategies that would be resilient to a wide range of climate change outcomes.

To ensure that a duty and standard of care have been provided and to help minimize the legal risk associated with the impact of climate change on stormwater management infrastructure, the practitioner should select and apply one or more of the following approaches to account for the range of possible climate change outcomes:

1. Data sets downscaled from a wide selection of Global and Regional Climate Models (GCMs and RCMs) results have been assembled by several Ontario agencies and made available to the public and can be used in hydrologic modelling activities (see Appendix 6). This includes:

    a) Ministry of Northern Development, Mines, Natural Resources and Forestry has established a website where future climate data sets can be downloaded for use in hydrologic models – See the Resource Directory.

    b) Dynamically downscaled climate projections are available for the Province from the Ontario Climate Data Portal - See the Resource Directory.

2. Where intensity-duration-frequency (IDF) curves (see Section 6.9) for the 1:2, 1:5, 1:10, 1:25, 1:50, 1:100-year return period storm events are applied, the practitioner should select and apply one or more of the following approaches to account for the range of possible climate change outcomes:

    a) Apply the results of Localized Climate Projections for the local municipality or Region (as available) developed from statistical downscaling of global model from a full ensemble of the latest generation of climate models (Coupled Model Intercomparing Project version 5 - CMIP5) or most recent.

    b) Apply one or more of the Predicted IDF Curves under Climate Change:
        i) For a local meteorological station from the IDF CC Tool for deriving rainfall Intensity-Duration-Frequency Curves for future climate scenarios (University Western Ontario and the Canadian Water Institute) - See the Resource Directory.

        ii) Intensity Duration Frequency (IDF) curves have been developed for future climate conditions and are available for the Province from the Ontario Climate Data Portal - See the Resource Directory.

        iii) Ontario Ministry of Transportations' IDF Curve Lookup - See the Resource Directory.

    c) An adjustment to the design flows (i.e. percentage adjustment for IDF curves) as dictated by local agencies and/ or municipal standards. It is noted that is not a preferred approach to selected percentage adjustment for IDF curves which have not been selected following the methods outlined previously. This is discussed further in Section 6.9.1).

Hydraulics Analysis for a Future Climate
When conducting hydraulic modelling for stormwater infrastructure, culvert, watercourse crossing, bridge design, or major system conveyance capacity, the practitioner should select and apply one or more of the approaches outlined as 2a), 2b) or 2c) above.

Appendix 6 presents additional information on the above approaches to representing future climate within the framework of the types of models discussed in Chapter 5. The models can predict the impact of climate change on a wide-variety of environmental parameters including local water balance; runoff volumes and streamflow groundwater recharge; seasonal or long-term water quantity; and water quality trends. As well, a full case-study example detailing the Climate Change Sensitivity of the Lake Simcoe Basin is provided in Appendix 6.

6.8.2.2 STEP 2 Example No. 1: The impact of increased air temperature on an urban watercourse

Stormwater management ponds are not designed to mitigate thermal pollution and the lack of shading features at many of these facilities contributes to thermal pollution in riverine systems. As has been discussed earlier in this chapter, average temperatures in Ontario have been increasing over the last 60 years and climate change models agree that temperatures are likely to continue to increase through 2050. Increased air temperatures will cause earlier spring melts and a prolonged seasonal period of warm water in stormwater management facilities especially during the long and dry summer months.

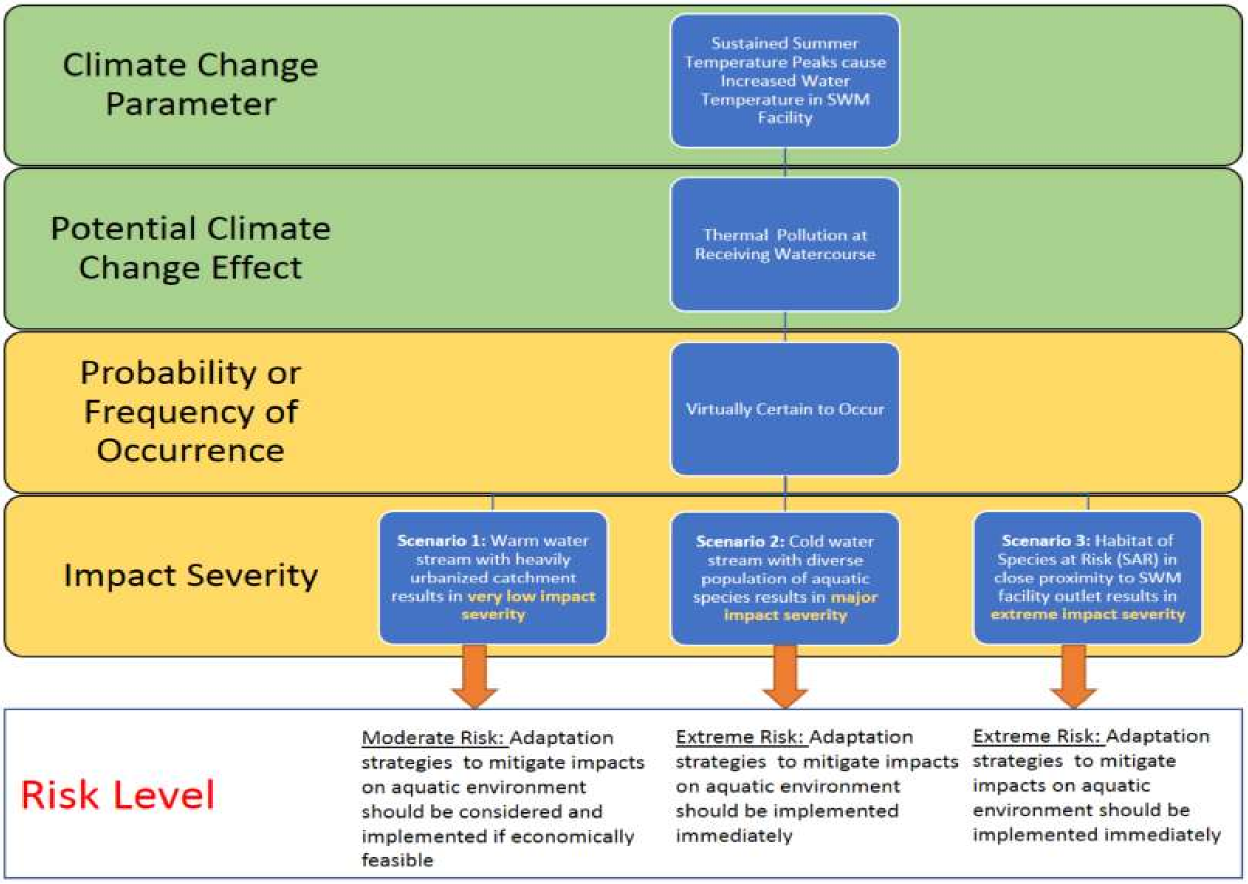
Figure 6.3 illustrates a risk assessment process for evaluating temperature increases in a stormwater management facility. This example focuses on thermal pollution at the receiving stream, but site-specific examples may focus on other temperature-related concerns such as algae growth or the impact on mosquito breeding. Based on historical climate trends and model projections, increased air temperatures are likely to occur and the correlation between air temperature and water temperature in the stormwater management facility is strong. For this example, three (3) scenarios are used to demonstrate how site-specific factors can influence impact severity of the climate change risk.

- In Scenario 1, the stormwater pond discharges into a stream that is characterized by warm water and a heavily urbanized catchment. The warmer water will have little impact on existing environmental conditions, so the impact severity has been classified as low, resulting in a moderate overall risk level.

- In Scenario 2, the stormwater pond discharges into a stream that is characterized by a coldwater regime and has a diverse range of aquatic life. The warm stormwater effluent has the potential to harm cold water fish habitat reducing fish diversity downstream of the stormwater management pond and thus an impact severity rating of major has been classified for the climate change risk.

- In Scenario 3, the stormwater management pond discharges to a stream reach that is in close proximity to habitat of a Species at Risk (SAR), for example a Redside dace. The resulting impact severity for this scenario has been classified as extreme.

Figure 6.3 - Example 1: Stormwater Management Facility Temperature Increase Impacts on an Urban Watercourse



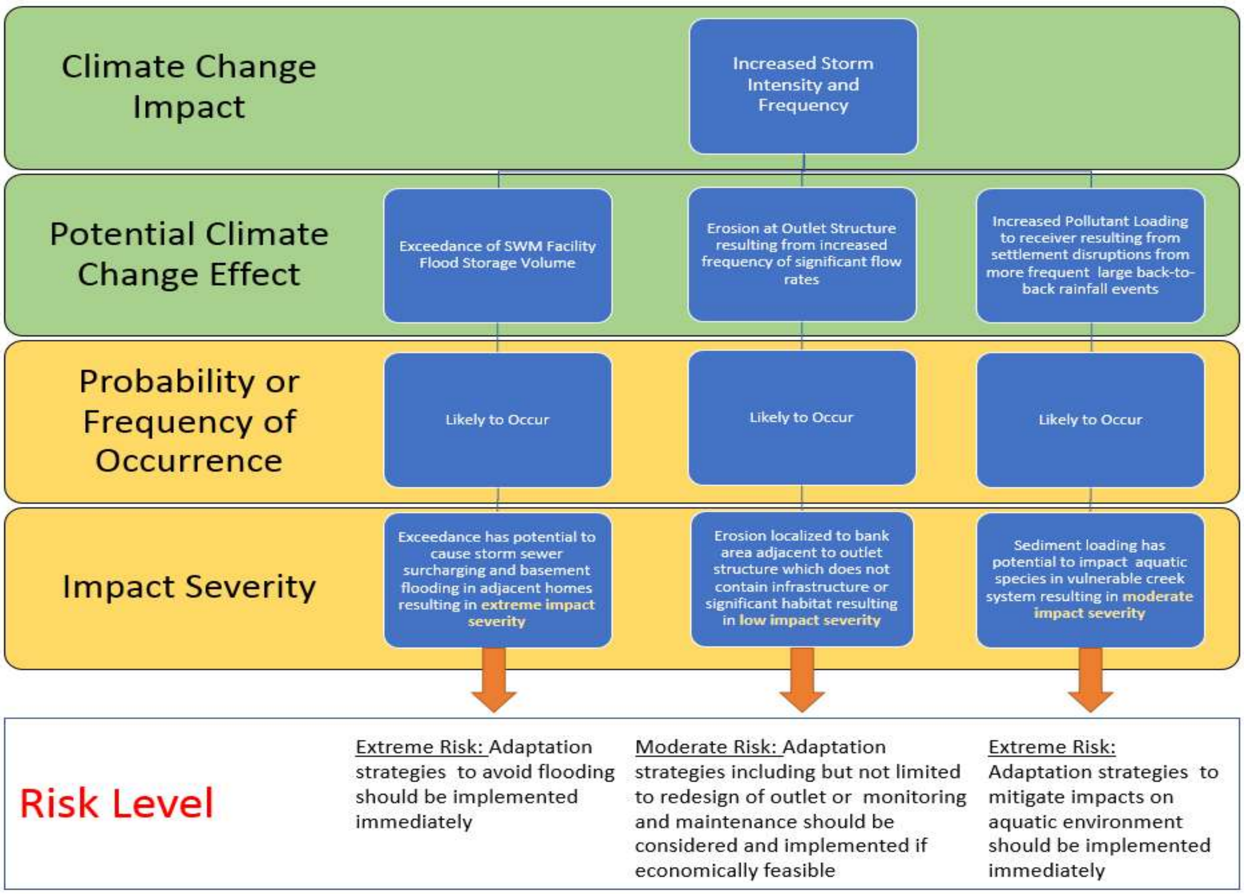
Although the ponds in Scenarios 1, 2 and 3 were identical and the same potential climate change effect and associated probability were assumed, the associated risk levels were weighed by site-specific conditions of the receiving watercourse. Using the matrix shown in Figure 6.1, the resulting climate change risk of Scenario 1 is moderate, where as Scenario 2 and 3 are extreme. Adaptation strategies to mitigate thermal pollution on the environment should be considered for Scenario 1, but climate change risks that are considered high or extreme (Scenario 2 and 3) should be given priority.

6.8.2.3 STEP 2 Example No. 2: The impact of storm intensity and frequency on an urban stormwater management facility

A change in the intensity and/or frequency of rainfall events can have both acute and long-term effects on stormwater management facilities. Rainfall events that produce a larger volume of water than the design flow can result in many complications. If a sufficient outlet or emergency overflow is not provided, large volumes of water can cause surcharging of the storm sewer systems, resulting in flooding in upstream urban areas. More frequent intense rainfall events can also cause erosion at points of flow concentration such as inlet and outlet structures. From a water quality perspective, stormwater management facilities function by allowing sediment to settle during inter-event periods. Consecutive storms that lack a sufficient inter-event period can cause stormwater management facilities to discharge sediment-laden water.

Figure 6.4 illustrates a risk assessment process for evaluating three (3) different potential climate change effects related to increased storm intensity and severity.

Figure 6.4 - Example2: Increased Intensity and Frequency of Rainfall Events Risk



In all cases, the probability of increased intensity and frequency was given a probability of occurrence classification of likely. For this high-level risk assessment, impact severity might not be known with great accuracy. For example, technical analysis (modelling) may be necessary to identify the extent of hydraulic effects such as storm sewer surcharging. At this stage, conservative assumptions (worst case) can be made and refined via technical analysis. In this example, due to the risk of flooding properties adjacent to the stormwater management facility, an extreme impact severity was assigned to the climate change impact. For the impact of erosion at the outlet structure, a low impact severity was assigned due to the localized nature of the impact. If initial analysis determined that bank failure of the facility, damage to critical infrastructure or harm to significant habitat was possible as a result of the erosion risk, the impact severity would be increased to major or extreme.

Using the matrix shown in Figure 6.1 the risk classification for the exceedance of stormwater management facility flood storage volume is extreme. As a result of this classification, adaptation strategies to avoid flooding should be implemented immediately. The low impact severity score associated with the erosion risk results in a risk classification of moderate. Adaptation strategies including, but not limited to, a redesign of the outlet or a monitoring and preventative maintenance plan should be considered and implemented, if economically feasible. The climate change risk of increased sediment loading resulting from rainfall events with short inter-event periods has been evaluated as an extreme risk for this facility largely due to aquatic species vulnerability in the receiving watercourse. Based on this classification, adaptation strategies to mitigate impacts on aquatic environment should be implemented immediately.

6.8.3 STEP 3 - Climate Change Impact Management Planning & Design Adaptation

The risks such as failing to meet project goals, objectives, performance criteria and targets identified through Steps 1 and 2, including via technical analysis, are mitigated through climate change impact management planning and design adaptation.

The application of adaptation measures to reduce the project's vulnerability to changes in specific climate parameters is critical to long-term viability as well as reducing environmental impact and protecting public health and property. Climate change impact management planning typically involves applying adaptation measures to reduce the project's vulnerability to changes in climate parameters and/ or modifying the design to account for expected climate change impacts. Incorporating LID BMPs into a project is an excellent way to reduce some risks associated with climate change. Another example of climate change impact management planning is increasing the storage capacity of a stormwater management facility based on expected changes to intensity and frequency of extreme precipitation events or incorporating LID into urban environments. Additional strategies are discussed in Section 6.8.3.1.

6.8.3.1 Adaptation Options

Because of the uncertainties over the impacts of climate change on the water environment, where possible measures that can cope with a range of future climate conditions should be chosen. The following options of measures should be prioritized (in decreasing order of priority) (adapted from UN, 2009):

Option 1: Win-win options – cost-effective adaptation measures that minimise climate risks or exploit potential opportunities but also have other social, environmental or economic benefits. In this context, win-win options are often associated with those measures or activities that address climate impacts, but which also contribute to climate change mitigation or meet other social and environmental objectives. For example:

- Tree planting in urban settings shade impervious areas and intercept rainfall providing environmental, aesthetic, and social benefits;
- Use smart growth and sustainable growth strategies that decrease road building and include transportation choices other than automobiles;
- Protect wetlands through "no net loss" concept and re-establish wetlands where feasible to hold runoff and recharge groundwater.

Option 2: No-regrets Options – cost-effective adaptation measures that are worthwhile (i.e. they bring net socio-economic benefits) whatever the extent of future climate change. These types of measure include those which are justified (cost-effective) under current climate conditions (including those addressing its variability and extremes) and are also consistent with addressing risks associated with projected climate changes. For example:

- Promoting good practice in street cleaning to limit pollutant loading to end-of-pipe facilities and receiving water bodies;
- Promote landscaping with native vegetation to further reduce runoff and the need for irrigation;
- Minimize impervious surfaces such as parking lots, roads, and rooftops;
- Encourage riparian buffers along streams, rivers, and waterways and maintain flood plains;
- Increasing forecasting and warning capabilities;
- Modifying inspection and maintenance programs.

Option 3: Low-regrets (or limited-regrets) Options – adaptation measures where the associated costs are relatively low and where the benefits, although mainly met under projected future climate, may be relatively large. For example:

- Constructing drainage systems with a higher capacity than needed to accommodate current climatic conditions can have limited additional (incremental) costs, but can help to cope with increased run-off as a result of expected climate change impacts;
- Removing or diverting flows from undersized storm sewers to mitigate the damages associated with more frequent intense storm events;
- Increasing the flood storage volume of existing ponds in flood prone areas and/or increasing the sizing of future ponds to avoid an increased frequency of urban flooding;
- Utilizing LID or GI to reduce runoff volumes during all rainfall events (see Section 6.8.3.2);
- Replacing storm sewers with higher capacity systems.

Options 4: Flexible adaptation Options – measures which are designed with the capacity to be modified at a future date as climate changes. For example:

- Influencing the design of a stormwater management facility so that its capacity can be increased at a future date;
- Dynamic control systems for facilities which respond to real-time climate data;
- Reducing seasonal storage levels in dams.

Climate change impact management planning is project specific and adaptation strategies implemented during this step will be dependent on time, cost, complexity, jurisdictional regulations, and risk assumption. Both short-term and long-term consequences of adaptation strategies should be considered. General considerations for climate change during the adaptation process are identified in Table 6.5.

Table 6.5 - Consideration for Climate Change During the Adaptation Process

General Considerations	Explanation
Capitalize on local knowledge and data	A good knowledge of existing local conditions, including collection and analysis of historical and predicted data used to develop IDF information, has high value in designing infrastructure under projected climate change scenarios (i.e., understanding how systems have responded to past extreme conditions will be useful in understanding how systems are likely to respond to future extreme conditions as they become more frequent).
Carefully consider the anticipated service life of infrastructure	Anticipated service life of new and existing infrastructure becomes an increasingly important consideration under projected climate change scenarios. Common practice was to assume that historical data were a good indicator of future climate, meaning that required design capacities for most drainage and stormwater infrastructure would not change over time. Due to projected climate change, this assumption is no longer valid, implying that required design capacities may change over time. It's also useful to consider operation, maintenance, inspections and monitoring to ensure the infrastructure performs as designed or potentially is more or less resilient than design.
Do not count on beneficial aspects of climate change	Projected climate change is anticipated to adversely affect most infrastructure. However, in some instances and some particular locations, there may be beneficial aspects, theoretically allowing a reduction in required design capacity under a future climate as

General Considerations	Explanation
	compared with design using historical information. In these cases, and because of the inherent uncertainty in projections for climate change, it would generally be recommended to neglect these beneficial aspects in selecting an ultimate capacity for infrastructure design, except in unusual circumstances.
Consider an adaptation design increment when investing in larger, long-lived infrastructure	In general, installing infrastructure with increased capacity normally results in a relatively small additional incremental cost (e.g., the cost of increasing pipe size to the next commercially available diameter) at the time of initial construction. In many cases, this may be a reasonable approach to provide allowances for projected climate change.
Allow for flexible designs that can accommodate future infrastructure upgrades where possible	There may be cases where it is not necessary to construct all anticipated capacity required due to projected climate change at the outset (e.g., a detention facility that might need to be expanded in the future due to the effects of climate change). In these circumstances, it may be reasonable to make appropriate considerations (e.g., acquire necessary lands) for this possible future expansion, but complete the additional construction work only when necessary.
Arrange for possible expansion of major flow path	Most infrastructure commonly designed using IDF information considers establishing a major flow path for use during extreme conditions. In many areas, it may be reasonable to expect the major flow path to be used more frequently, or require expansion, due to projected climate change. A reasonable approach in some cases may be to make the necessary arrangements for anticipated future expansion.

6.8.3.2 LID Adaptation Options

Planning and implementation of stormwater green infrastructure and LID can contribute to the adaptation of the built infrastructure and the environment to climate change. Planning for and achieving the objectives for stormwater management discussed in Section 1.3 under the current or any future climate conditions is a way of increasing the resiliency of our communities, the built infrastructure and the environment to climate change.

Stormwater green infrastructure and LID manage the rain where it falls and snow melts to help maintain the ecosystem function and value of water (e.g., vegetation, habitat for fish or wildlife) while rapid conveyance of runoff can potentially increase the cumulative impact on downstream communities and ecosystems, which could be exacerbated due to climate change. LID practices use vegetation, media and sunlight along with mechanisms such as water infiltration, evaporation, transpiration and rainwater harvesting and reuse. Where LID is implemented on property lots or on the road rights-of-way, these aspects and mechanisms of LID help to maintain or restore the natural water cycle and reduce runoff volume and thereby contribute to flooding control and erosion control. Reducing the runoff volume also reduces contaminant loading into waterways indirectly or directly via municipal storm sewers, thus increasing protection of the environment. LID filtration practices can reduce contaminant levels in runoff as well as allowing some water volume to be retained in the ground. While conventional end-of-pipe control facilities are generally less effective in helping to maintain the ecosystem function and value of water, some are designed with volume detention such that stormwater is temporarily stored with controlled release of stormwater to waterways that can reduce the risk of flood and erosion.

Several scientific studies have highlighted the climate change resiliency of urban stormwater infrastructure when designed with source-based stormwater controls. A selection of studies is summarized below.

A study titled "*Assessment of low impact development for managing stormwater within changing precipitation due to climate change*" by the researchers at the USEPA and the University of Wisconsin-Madison evaluated the effectiveness of LID BMPs, specifically at compact development sites with decreased impervious cover, for reducing stormwater impacts on surface water under changing precipitation patterns. The study identified that the stormwater response of the site was most sensitive to changes in the impervious cover followed by changes in the precipitation volume and rainfall event intensity. The study concludes that even a modest reduction in impervious cover by incorporating LID BMPs into urban design has the potential to significantly reduce increases in stormwater runoff volume and pollutant loads associated with increases in precipitation intensity and volume (C. Pyke et al., 2011).

Another study, titled "LID implementation to mitigate climate change impacts on runoff" analysed potential LID BMPs, specifically rainwater harvesting and bioretention, to control and decrease stormwater runoff in urban areas subject to potential future climate change impacts on wet weather flow. This study used the EPA SWMM code to model an urban catchment in New York City with and without LID BMPs. Increased rainfall associated with climate change produced additional runoff volume and higher peak flows from the catchment. The scenario with LID BMPs was found to provide adaptation benefits to stormwater volume and peak flow (Z. Zahmatkesh et al., 2014).

As well, see Section 1.8.3 for the analysis of the impacts of climate change and the adaptation benefits of LID on their stormwater management system (storm sewers and facilities) as part of the City of Kitchener's Integrated Stormwater Management Master Plan (Aquafor Beech, 2016).

6.8.4 Step 4 – Monitoring and Adaptive Management

Many of the methods used to manage water resources in the past, directly or indirectly, commit an organization to future decision pathways and restricts making other, alternative decisions. The monitoring and adaptive management step is in place to incorporate lessons learned, determine the timing or triggers for the review or update to the completed climate change assessments and define reporting and communication plans.

The implementation of a monitoring and adaptive management plan provides information that can be used to reduce risk and allow for adaptation to predicted future changes. This step involves collecting and evaluating data on key climate parameters over the lifetime of a project and modifying the project or introducing new adaptation measures in response to updated information. An example would be updating the timing of the seasonal drawdown and filling of a water control structure in light of changing rainfall and snowmelt patterns.

Vulnerabilities can be mitigated during this phase by incorporating remedial measures, new operations procedures and or management processes. Monitoring of climate change impacts is an important aspect of this phase and should be incorporated into standard stormwater management monitoring programs. Maintaining access to local precipitation records is important as is long-term monitoring programs that track responses in storm sewers, stormwater management facilities and along natural stormwater receivers. Where hydrologic models are available, these should be updated and calibrated against any significant rainfall event, especially those that exceed previous calibration boundaries.

Infrastructure performance or environmental triggers signal the need to revisit the completed climate change assessment to incorporate new climate data or predictions, technology or management approaches. Triggers may be temporal, based on the data set available or assumptions made in the technical analysis. It is not intended that the established approach be static, but rather evolve with policy and supporting science.

See Chapter 9 for potential monitoring approaches and procedures.

6.9 Rainfall Intensity Duration Frequency Methods

One method of modifying a project design to accommodate future climate change is through the use of modified intensity-duration-frequency (IDF) curves. IDF statistics are used in many water management applications, including drainage design, stormwater and watershed planning, flooding and erosion risk management, and infrastructure operations. In Ontario, regulatory authorities such as the Ministry of Transportation, Ministry of Environment, Conservation and Parks, municipalities, and conservation authorities mandate the use IDF statistics as one of the major criteria in the design of stormwater management systems

(Coulibaly *et al.*, 2016). The IDF statistics are based on historical rainfall records, which are updated by Environment and Climate Change Canada.

Up-to-Date IDF Curves and IDF Curves for Future Climate Conditions
Keeping IDF Curves up-to-date ensures that the most recent rainfall events are included in probabilistic hydrologic calculations. IDF curves for future climate conditions go further by using downscaled GCMs to simulate predicted future rainfall patterns.

IDF curves are used by stormwater practitioners to design stormwater infrastructure. They are localized risk-evaluation tools based on historical rainfall records across the province. Even though IDFs are regularly updated, the increased frequency and severity of rainfall events resulting from climate change presents a risk to much of Ontario's stormwater infrastructure. It is important to note that not all precipitation events "are created equal" when discussing IDF relationships. Municipal engineers may be concerned with short duration events that cause flooding very quickly in urban settings with high impervious cover and short times of concentration. These short-term events (typically 3 hours or less) are often the product of thunderstorms that may be associated with convective heating or fast-moving storm fronts. These systems are the ones responsible for most urban stormwater failures including the surcharging of sewers.

On a watershed basis, water resource engineers are also concerned with longer duration precipitation events. These events are often the product of vast weather systems such as hurricanes or tropical depressions that have lost energy before reaching Ontario, but still have the potential to drop vast volumes of rainfall. Rain on snow events that also have the potential to generate excessive runoff and generate riverine flooding.

Increasing the spatial coverage of the rainfall monitoring network across Ontario and updating IDFs as new data are collected are key actions to move towards climate change resilient stormwater infrastructure.

If the primary concern related to a development is the behaviour of the system under a more intense storm event, a modified IDF curve approach can be used. IDF curves have been developed for future climate conditions and are available for the Province from the Ontario Climate Data Portal (see the Resource Directory) or the Ontario Ministry of Transportation's IDF Curve Lookup (see the Resource Directory). These curves offer a means to estimate flows and generate future runoff events that is well understood by most urban hydrologists and engineers. The modified design storm intensities can be used to determine optimal sizes of the stormwater management facilities and the required infrastructure.

It is important to note that the results of global climate models should be considered with great care and proper analysis is to be undertaken of any future rainfall predictions (e.g. IDF curves) to ensure that the values used in hydrologic analysis truly represent, as much as possible, future rainfall predictions. Although the approach is simple to implement, there is uncertainty regarding the accuracy of these future IDF curves. As noted by (Coulibaly, et al, 2016), there is a lack of consensus on the most appropriate methods for developing the curves due to the wide array of distribution functions, future climate model datasets, downscaling methods, and future scenarios that could be used in creating future IDF statistics. With the large range of possible approaches available, there is the potential for significant variability among future IDF statistics for a given area. This variability and the current lack of consensus on the most adequate methods ultimately translates into uncertainty associated with the development of IDF statistics and on how climate change is projected to affect local rainfall regimes. Therefore, it is recommended, as with the use of GCMs, that practitioners account for uncertainties in the predictions, and develop adaptation strategies through the application of multiple sources of climate predictions to reduce the variability.

Example: Many Ontario municipalities have conducted climate change and/or IDF analysis studies to provide direction for municipal infrastructure planners in light of climate change risks. Of note is the City of Niagara Falls which conducted an IDF curve update and climate change analysis as part of their 2015 Master Drainage Plan Update Study. Updated IDFs for four of the five climate stations within the City were found to generate rainfall volumes and intensities that were slightly lower than those generated by the previous IDF curves (Hatch Mott MacDonald, 2015). Additional analysis conducted for Niagara Falls found that the "average annual rainfall volumes for the past 15 years (2000 to 2014) were actually 5.5% lower than the long term average, and significantly lower (by 12.6%) than the average annual rainfalls in the 1970's, 80's and 90's; and the frequency of the larger rainfall events (> 25 mm) that cause most of the stormwater management and combined sewer overflows problems were all significantly lower than the long term average (by 15%-25%)" (Hatch Mott MacDonald, 2015). Even with these findings, it was recommended that the City use the more conservative (higher intensity) IDFs and apply a 5% increase to provide a safety factor in the design of future stormwater infrastructure (and upgrades) to account for possible future climate change impacts.

These finding are supported by a provincial-scale study titled Potential Impacts of Climate Change on Stormwater Management (Hulley et al., 2008) studied potential impacts of climate change on stormwater management practices in southern Ontario based on findings of the United Nations Intergovernmental Panel on Climate Change. This study found that the frequency of relatively intense rainfall may increase as a result of increased ratio of precipitation to number of wet days, little change in the number of drought days and an expected increase in annual precipitation. The study did however note that the level of model uncertainty associated with the 2007 IPCC results, and the resolution of the numerical tools, is not adequate to support detailed predictions regarding IDF curves. It also noted that general trends, such as the expected increase in more intense precipitation events, are generally supported by the IPCC summary reports.

It should be pointed out that there is risk associated with applying IDF increases on conveyance infrastructure without properly assessing the impact on downstream infrastructure and natural systems. This is further discussed in the subsequent section.

6.9.1 Unplanned Negative Outcomes

As stormwater practitioners in Ontario adapt stormwater infrastructure to observed and predicted climate change risks, it is important that the environmental, social and economic risks associated with our solutions are fully analyzed. One area of concern is applying capacity increases to conveyance infrastructure without properly assessing the downstream impacts.

For example, to provide an expected level of service during the 1:5-year event, a municipality may decide to increase storm sewer pipe sizes in light of expected climate change. If the catchment area where increased pipe sizing is implemented is uncontrolled (i.e. discharge to a watercourse such as a creek or river), the increased flow may cause localized erosion at the outfall and the cumulative impact of several retrofits may cause erosion and flooding downstream. Sensitive environmental features such as fish spawning grounds and wetlands may also be affected by the changes in flow regime and sediment transport. As such, it is important to consult with managers of natural watercourses (i.e. local conservation authorities or Ministry of Northern Development, Mines, Natural Resources and Forestry) when considering modifying standard pipe sizing across a large catchment or subwatershed area that is uncontrolled.

For catchments that drain to stormwater management facilities, while the risk is generally lower, there still remains a risk associated with increasing pipe sizes. Where significant changes to the conveyance network are considered, hydrologic modelling should be updated to ensure the stormwater management facility can meet design objectives under increased flows.

Capital costs are also considered when implementing climate change adaptation strategies. Within our existing stormwater management framework, aging infrastructure and a lack of upgrade capacity has prevented many municipalities from meeting a city-wide level-of-service for stormwater conveyance capacity, stormwater quantity control and stormwater quality treatment. In many instances, solutions are feasible but prove to be too much of a financial burden especially when applied to large geographical areas over a short period of time. Climate change impacts threaten to exacerbate this problem. It is up to municipalities to assess the impact of observed and predicted climate change on existing infrastructure and prioritize upgrades in a prudent and economically feasible manner. This would entail prioritizing high-risk