City of Prince George

Integrated Stormwater Management Plan

Technical Working Paper # 2 – Engineering and Asset Management Issues

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AECOM: 2015-04-13

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Executive Summary

AECOM Canada Ltd. (“AECOM”) has been contracted by the City of Prince George (“the City”) to develop an Integrated Stormwater Management Plan (ISMP) so the City can fully understand and work towards sustainable service delivery of stormwater management. One of the major tasks of this assignment was to review various engineering issues associated with the City’s stormwater system including:

- Developing a rain gauge monitoring program;
- Identifying natural assets and determining appropriate green infrastructure (lid) options for the City;
- Proposing amendments to the subdivision and development servicing bylaw and associated draft design guidelines;
- Identifying requirements for development contributed assets;
- Assessing stormwater asset risk;
- Making recommendations for an asset condition program; and
- Identifying asset longevity options.

The results of the review of engineering issues and recommendations is provided in this Technical Working Paper (TWP#2). A summary of key findings is provided below.

Rain Gauge Monitoring Program
There are 15 existing and historic precipitation gauges in and around the City. Of those 15 gauges, there are two that are still active and have reliable long-term data. We recommend that the City install a new (third) rain gauge in the northwest of the City to better capture rainfall patterns in the northern part of the City which are likely to vary from other sections of the City and will help inform future development north of the Nechako River. A third rain gauge would also help the City identify changes in rainfall patterns due to climate change.

Natural Assets and Low Impact Development (LID)
The City has many valuable natural assets (rivers, creeks, lakes, marshes, swamps, and forests) that help in the management of stormwater. The City should further develop its stormwater/roads maintenance program (e.g., street sweeping, ditch cleaning and catch basin sump cleaning) to help protect these natural assets. The City is currently analysing its natural assets in more detail as part of a separate initiative.

The City also has assets such as infiltration facilities, ditches, ponds, and underground storage facilities that are defined as green infrastructure, LID, or stormwater best management practices (BMPs). However, the City does not have a comprehensive LID strategy for new development. It is recommended that the City adopts an LID strategy for new development that focuses on features that have been found to work in northern climates. Features such as bioswales, bioretention cells, soil systems, permeable interlocking concrete pavement, perforated pipe, chamber systems, rain gardens, and soakaway pits have been found to work in northern climates under the right conditions (e.g., in consideration of topography/elevations, groundwater, other infrastructure, soils and pre-treatment).

To develop an LID strategy the City will need to:

- Identify goals;
- Identify budget, maintenance, climatic and operational constraints; and
- Identify internal capabilities and external opportunities to fund the construction and maintenance of LIDs.

To be successful, the City should maximise the life of LID features through pre-treatment, design all features with maintenance in mind, and educate internal and external stakeholders.

Revise Subdivision and Development Servicing Bylaw and Draft Design Guidelines

The Subdivision and Development Servicing Bylaw and Draft Design Guidelines should be revised to address:

- Climate change and new design storms (i.e., 10-year storm and rain on snow events);
- Setting limits on allowable run-off rates and volumes and requirements for stormwater treatment for new development;
- Allowing for and even requiring the use of open channels rather than storm sewers under certain conditions;
- Design requirements for oil-grit separators;
- Requiring erosion and sediment control (ESC) plans to be prepared and monitored by a professional and extending the need for an ESC plan to more types of development;
- Limitations on the use of corrugated steel pipe for culverts, sewers and catch basins;
- Improving design standards for detention ponds, particularly for constructed wetlands;
- Requiring detention pond operations and maintenance (O&M) cost estimates and recommended cleanout schedules from designers and only accepting ponds once appropriate and approved vegetation is established;
- Determining erosive velocities for vulnerable stream channels before designing upstream detention facilities;
- Specifying installation requirements for sewer relining projects to minimize environmental and health risks;
- Limiting the installation of basements in areas of high risk due to groundwater and flooding;
- Developing lot grading guidelines for developers;
- Specifying maximum grades in ditches and sewers and maximum velocities in sewers;
- Reviewing minimum depth of cover for storm sewers;
- Specifying bike-friendly catch basins; and
- Specifying the procedure for utility disconnects.

The Design Guidelines are only effective if they are effectively applied. The City can help promote effective application by:

- Mandating adherence of the Design Guidelines within the Subdivision and Development Servicing Bylaw;
- Having enough well-trained staff to review design submissions; and
- Educating developers, designers, contractors, and City staff on the requirements within the Design Guidelines, Subdivision and Development Servicing Bylaw and Storm Sewer Bylaw.

Condition Assessment

The City has started a regular condition assessment program for its pump stations and cross culverts. The City conducts periodic inspections for its detention ponds. It is recommended that the City:

- Maintain its pump station and cross culvert condition assessment program;
- Conduct condition assessments of its detention ponds every five years; and
- Develop a regular storm sewer and ditch inspection program.

Developing a regular storm sewer condition assessment program will allow the City to:

- Better forecast infrastructure renewal and rehabilitation needs;
- Avoid infrastructure failures and the resulting economic, social, and environmental costs; and
- Leverage cost-effective methods to extend the life of assets before the asset becomes too deteriorated and must be replaced.

In addition to the recommendations and issues identified above this report includes the following:

- Lifecycle costs for standard stormwater assets;
- Risk scoring methodology and risk scores for the City's storm mains, culverts, pump stations, ditches, catch basins, detention ponds; inlets and discharge points; and
- Information on assessing the condition of and rehabilitating storm sewers.

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1. Introduction

AECOM has been contracted by the City of Prince George to develop an Integrated Stormwater Management Plan (ISMP) so the City can fully understand and work towards sustainable service delivery of stormwater management. One of the major tasks of this assignment was to review various engineering issues associated with the City's stormwater system including:

- Developing of a rain gauge monitoring program;
- Identifying natural assets and determining appropriate green infrastructure options for the City of Prince George;
- Proposing amendments to the Subdivision and Development Servicing Bylaw and associated Draft Design Guidelines;
- Identifying requirements for development contributed assets;
- Assessing stormwater asset risk;
- Developing recommendations for an asset condition program;
- Identifying asset longevity options; and,
- Identifying replacement costs for existing and proposed engineered assets.

The results of the review of engineering issues and recommendations is provided in this Technical Working Paper (TWP#2).

2. Rain Gauge Monitoring Program

The growing concern of cities and municipalities towards effective stormwater management emerge from the increasing frequency and amplitude of problems related to rainwater runoff. Issues such as creek erosion, flooding, and pollution of natural water bodies can lead to significant costs for municipalities. While the conversion of natural land to impervious surfaces or inadequately managed runoff are undoubtedly some of the causes explaining the increasing importance of these issues, the most important factors to take into account are the increase in precipitation intensity and number of days with heavy rainfall observed across Canada since 1950 and particularly pronounced in British Columbia (Vincent et al. 2018, Picketts et al., 2009).

In addition, some municipalities may experience greater impacts from freeze-thaw events (e.g. rainfall on snow events). If these new observed tendencies pose serious concern, the situation is unlikely to change for the better in the future, since across the scientific community there is a consensus that the amplitude and frequency of short-duration (a day or less) extreme precipitation is projected to increase based on emission scenarios over the second half of the 21st century (Environment and Natural Resources Canada, 2019). Governments and scientists often request stakeholders to consider changes in precipitation trends in their planning. However, very few tools are at the disposal of stakeholders to characterize or forecast precipitation trends at the local scale.

A rain gauge monitoring plan will provide essential technical information (e.g. IDF curves, back-to-back precipitation events information, water balance estimation) for infrastructure design, track local scale changes in precipitation and provide an estimation of the long-term evolution of these changes. Given that the most effective and sustainable stormwater management plans include actions to be taken by citizens on their properties, information gained from the rain gauge monitoring plan could also be used as an important mobilization tool to motivate citizens to undertake concrete actions. The main goal of this rainfall monitoring plan is to propose the optimal alternative for future computations of IDF curves within the City of Prince George, based on existing rainfall monitoring resources (i.e., gauges and data types) and an instrumentation strategy for new rainfall gauges. To achieve this goal, the following specific objectives were identified:

1. Review of the actual rainfall monitoring resources in the Prince George City area;
2. Identify optimal locations to install new rainfall monitoring stations,
3. Provide technical information on rainfall monitoring station instruments,
4. Suggest analysis of the collected rainfall data;
5. Short-term improvement of IDF curves; and
6. Raising citizen awareness about rainfall dynamics.

2.1 Review of instrumented stations and available data

Numerous climatological stations have been installed within the vicinity of the City of Prince George. From the meteorological stations listed within the Pacific Climate Impacts Consortium Data Portal[1] accessed in January 202115 were equipped with rainfall and/or total precipitation measurement instruments, which recorded historical series of precipitations within the Prince George area.

Differences between rainfall and precipitation data are related to the instrument types used at the meteorological station. A station equipped with both a rain gauge and a snow gauge can provide the portion of total precipitation that has fallen as rain or snow. Depending on the instruments installed, a post-processing of the measured precipitation using other meteorological variable (e.g. air temperature, relative humidity) can also be used to

[1] https://data.pacificclimate.org/portal/pcds/map/

distinguish liquid and solid precipitation. More details on instruments, measurement types and post-processing will be provided later on.

Depending on the instrument types, available energy sources and the objectives of the meteorological station, rainfall or total precipitation can be recorded for different periods. Time steps for meteorological measurement usually available through online open data portals (e.g., ECCC, PCIC) are monthly, daily, or hourly. However, these period statistics are sometime computed from raw measurements computed at shorter time intervals at the station, such as 15-min or below. Data from these shorter intervals can sometimes be obtained by a direct request to the meteorological manager and be adapted for some specific data analysis (e.g. rainfall intensity, IDF curve computation). More details on possible measurements analysis are provided later on.

The following figure shows the location of the rain or precipitation gauges that have been installed within the City of Prince George, as well as the shortest data interval available for each station. We are aware that other rain gauges had historically been in operation within the City's limits (see McElhanney Consulting Services Ltd. report, 2014, Figure 1-2), but these gauges were not included in this review since the historical collected data were not available and the gauges are no longer in operation.

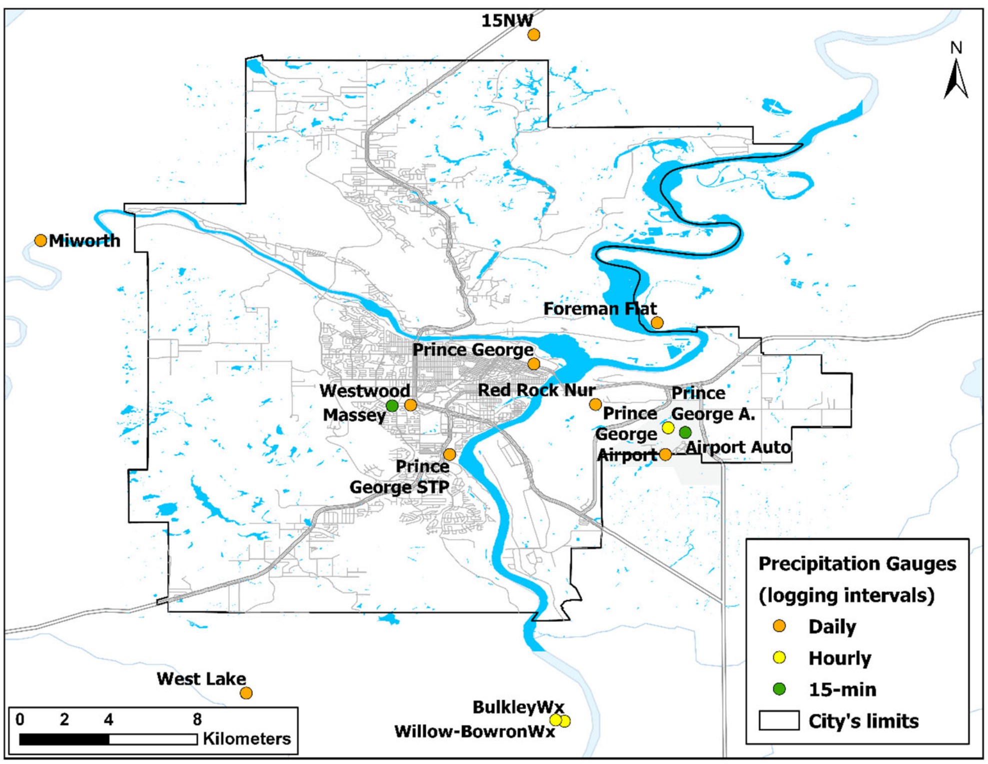


Figure 1 Locations and Data Intervals of Precipitation Gauges in Prince George

Locations and available data were first recovered from the PCIC Data Portal and classified based on the network managing the station, available measurement logging intervals, the monitoring period, the quality of the data series and the available measurements. The manager of the stations was contacted to determine if shorter measurement intervals were available and any details regarding the instruments used at the stations.

Details were provided by Environment Canada for stations; Prince George Airport (1096439), Airport Auto (1096453) and Massey Auto (1096454), that are still in operation and that could be used in the near future. Station Prince George Airport (1096439), that is managed by NavCanada, has data available daily since 2014, but are not continually validated, which means they must be interpreted with caution.

Both station Airport Auto (1096453) and Massey Auto (1096454) are equipped with automated total precipitation weighing gauges (Geonor & Pluvio), measuring at intervals of 15-min. Although the quality of data is validated by ECCC, the precipitation data are not precise for solid precipitation (snow). Liquid precipitations (Rainfall) during summer months are not problematic and liquid precipitation during transition periods (temperatures close to freezing point) could be validated using a comparison with monitored air temperature, relative humidity, and computed dew point. These points are detailed in future sections.

Table 1 summarizes the details of the instrumented precipitation stations.

Table 1 Summary of the available data at the meteorological station equipped with precipitation gauges

Climate station ID	Name	Network	Measurements interval		Monitoring period			Climate variables		
								Precipitation		Others
			Available Online	Obtain from EC	Start	End	Data gaps	Rainfall	Total	
1096439	Prince George Airport	NavCan	Daily	Hourly	2014	2020	limited		X	X
1096450	Prince George A.	EC	Daily	Hourly	1960	2002	limited	X	X	X
1096453	Airport Auto	EC	Hourly	15-min	2009	2020	limited		X	X
1096468	Prince George STP	EC	Daily	-	1975	2020	limited	X	X	X
1096470	Westwood	EC	Daily	-	1974	1976	limited	X	X	X
1096454	Massey	EC	Hourly	15-min	2012	2020	limited		X	X
1096435	Prince George	EC	Daily	-	1956	1957	limited	X	X	X
1096460	Foreman Flat	EC	Daily	-	1962	1966	limited	X	X	X
1096458	15NW	EC	Daily	-	1984	2004	limited	X	X	X
1096465	Miworth	EC	Daily	-	1985	2002	limited	X	X	X
1096455	West Lake	EC	Daily	-	1999	2011	limited	X	X	X
109220	Red Rock Nur	ARDA	Daily	-	1969	2002	Frequent	X		X
1113694	BulkleyWx	FLNRO-FERN	Hourly	-	2007	2018	limited	X		X
1095439	Willow-BowronWx	FLNRO-FERN	Hourly	-	2007	2018	limited	X		X
1113682	CPFWx	FLNRO-FERN	Hourly	-	2007	2018	limited	X		X

** ECCC : Environment and Climate Changes Canada; ARDA: Agricultural and Rural Development Act; FERN: Forest Ecosystem Research Network*

Of these 15 stations, 11 were characterized with long (long enough to be analyzed) series of data and with only limited periods of missing data. Stations Prince George Airport, Prince George A. and Airport Auto are all located within the Prince George Airport limits and the two latter stations can be used (with caution with the instrument used) as a prolongation of the series of data recorded at the first station.

Years/ Stations	Prince George Airport	Prince George A.	Airport Auto	Prince George STP	Massey	15NW	Miworth	West Lake	BulkleyWx	Willow-BowronWx	CPFWx
1967	ALL	--	--	--	--	--	--	--	--	--	--
1968	ALL	--	--	--	--	--	--	--	--	--	--
1969	ALL	--	--	--	--	--	--	--	--	--	--
1970	ALL	--	--	--	--	--	--	--	--	--	--
1971	ALL	--	--	--	--	--	--	--	--	--	--
1972	ALL	--	--	--	--	--	--	--	--	--	--
1973	ALL	--	--	--	--	--	--	--	--	--	--
1974	ALL	--	--	--	--	--	--	--	--	--	--
1975	ALL	--	--	INC.	--	--	--	--	--	--	--
1976	ALL	--	--	ALL	--	--	--	--	--	--	--
1977	ALL	--	--	ALL	--	--	--	--	--	--	--
1978	ALL	--	--	ALL	--	--	--	--	--	--	--
1979	ALL	--	--	ALL	--	--	--	--	--	--	--
1980	ALL	--	--	ALL	--	--	--	--	--	--	--
1981	ALL	--	--	ALL	--	--	--	--	--	--	--
1982	ALL	--	--	ALL	--	--	--	--	--	--	--
1983	ALL	--	--	ALL	--	--	--	--	--	--	--
1984	ALL	--	--	ALL	--	INC.	INC.	--	--	--	--
1985	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1986	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1987	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1988	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1989	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1990	ALL	--	--	ALL	--	ALL	LIM.	--	--	--	--
1991	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1992	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1993	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1994	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1995	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1996	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1997	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1998	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1999	ALL	--	--	ALL	--	ALL	LIM.	INC.	--	--	--
2000	ALL	--	--	ALL	--	ALL	ALL	ALL	--	--	--
2001	ALL	--	--	ALL	--	ALL	ALL	ALL	--	--	--
2002	ALL	--	--	ALL	--	ALL	INC.	ALL	--	--	--
2003	ALL	--	--	ALL	--	ALL	--	ALL	--	--	--
2004	ALL	--	--	ALL	--	INC.	--	LIM.	--	--	--
2005	ALL	--	--	ALL	--	--	--	ALL	--	--	--
2006	ALL	--	--	ALL	--	--	--	ALL	--	--	--
2007	ALL	--	--	ALL	--	--	--	LIM.	INC.	INC.	INC.
2008	ALL	--	--	ALL	--	--	--	INC.	ALL	LIM.	ALL
2009	INC.	INC.	INC.	ALL	--	--	--	--	INC.	ALL	ALL
2010	--	ALL	LIM.	LIM.	--	--	--	--	ALL	INC.	INC.
2011	--	ALL	LIM.	LIM.	--	--	--	--	ALL	INC.	ALL
2012	--	ALL	ALL	LIM.	--	--	--	--	ALL	ALL	INC.
2013	--	ALL	ALL	LIM.	INC.	--	--	--	ALL	INC.	ALL
2014	--	ALL	ALL	LIM.	ALL	--	--	--	ALL	INC.	ALL
2015	--	ALL	ALL	LIM.	ALL	--	--	--	INC.	ALL	ALL
2016	--	ALL	ALL	LIM.	ALL	--	--	--	ALL	ALL	ALL
2017	--	ALL	ALL	LIM.	ALL	--	--	--	ALL	ALL	INC.
2018	--	ALL	ALL	LIM.	ALL	--	--	--	INC.	INC.	--
2019	--	ALL	LIM.	LIM.	ALL	--	--	--	--	--	--
2020	--	ALL	ALL	ALL	ALL	--	--	--	--	--	--

Table 2 summarizes the available data for each station and each year since 1967. The comparison of the time series available at the stations shows two periods where spatial distribution of precipitation could be investigated due to overlapping time series between stations. The first period is between 1985 and 2000, where precipitation values are available for stations Prince George Airport, Prince George STP, 15NW and Miworth. There are also some years between 2008 and 2017 for which 4 or 5 stations recorded precipitation simultaneously, but there is no period longer than 2 years for continuous comparison for precipitation data between stations.

Years/ Stations	Prince George Airport	Prince George A.	Airport Auto	Prince George STP	Massey	15N W	Miworth	West Lake	BulkleyWx	Willow-BowronWx	CPFWx
1967	ALL	--	--	--	--	--	--	--	--	--	--
1968	ALL	--	--	--	--	--	--	--	--	--	--
1969	ALL	--	--	--	--	--	--	--	--	--	--
1970	ALL	--	--	--	--	--	--	--	--	--	--
1971	ALL	--	--	--	--	--	--	--	--	--	--
1972	ALL	--	--	--	--	--	--	--	--	--	--
1973	ALL	--	--	--	--	--	--	--	--	--	--
1974	ALL	--	--	--	--	--	--	--	--	--	--
1975	ALL	--	--	INC.	--	--	--	--	--	--	--
1976	ALL	--	--	ALL	--	--	--	--	--	--	--
1977	ALL	--	--	ALL	--	--	--	--	--	--	--
1978	ALL	--	--	ALL	--	--	--	--	--	--	--
1979	ALL	--	--	ALL	--	--	--	--	--	--	--
1980	ALL	--	--	ALL	--	--	--	--	--	--	--
1981	ALL	--	--	ALL	--	--	--	--	--	--	--
1982	ALL	--	--	ALL	--	--	--	--	--	--	--
1983	ALL	--	--	ALL	--	--	--	--	--	--	--
1984	ALL	--	--	ALL	--	INC.	INC.	--	--	--	--
1985	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1986	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1987	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1988	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1989	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1990	ALL	--	--	ALL	--	ALL	LIM.	--	--	--	--
1991	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1992	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1993	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1994	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1995	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1996	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1997	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1998	ALL	--	--	ALL	--	ALL	ALL	--	--	--	--
1999	ALL	--	--	ALL	--	ALL	LIM.	INC.	--	--	--
2000	ALL	--	--	ALL	--	ALL	ALL	ALL	--	--	--
2001	ALL	--	--	ALL	--	ALL	ALL	ALL	--	--	--
2002	ALL	--	--	ALL	--	ALL	INC.	ALL	--	--	--
2003	ALL	--	--	ALL	--	ALL	--	ALL	--	--	--
2004	ALL	--	--	ALL	--	INC.	--	LIM.	--	--	--
2005	ALL	--	--	ALL	--	--	--	ALL	--	--	--
2006	ALL	--	--	ALL	--	--	--	ALL	--	--	--
2007	ALL	--	--	ALL	--	--	--	LIM.	INC.	INC.	INC.
2008	ALL	--	--	ALL	--	--	--	INC.	ALL	LIM.	ALL
2009	INC.	INC.	INC.	ALL	--	--	--	--	INC.	ALL	ALL
2010	--	ALL	LIM.	LIM.	--	--	--	--	ALL	INC.	INC.
2011	--	ALL	LIM.	LIM.	--	--	--	--	ALL	INC.	ALL
2012	--	ALL	ALL	LIM.	--	--	--	--	ALL	ALL	INC.
2013	--	ALL	ALL	LIM.	INC.	--	--	--	ALL	INC.	ALL
2014	--	ALL	ALL	LIM.	ALL	--	--	--	ALL	INC.	ALL
2015	--	ALL	ALL	LIM.	ALL	--	--	--	INC.	ALL	ALL
2016	--	ALL	ALL	LIM.	ALL	--	--	--	ALL	ALL	ALL
2017	--	ALL	ALL	LIM.	ALL	--	--	--	ALL	ALL	INC.
2018	--	ALL	ALL	LIM.	ALL	--	--	--	INC.	INC.	--
2019	--	ALL	LIM.	LIM.	ALL	--	--	--	--	--	--
2020	--	ALL	ALL	ALL	ALL	--	--	--	--	--	--

Table 2 Periods of available precipitation data at stations.

** ALL: No data gap during that year.*
** LIM: Limited data gap (less than 20-days of missing values).*
** INC: Incomplete data for that year.*

For the period 1985-2000 of overlapping precipitation data, some statistics related to rainfall intensity were computed to investigate if differences between rainfall patterns were observed within the vicinity of Prince George. Statistics computed were the annual maximum daily rainfall, the average annual rainfall amount for rainy days, and the total annual number of days for which more than 15-mm of rain were measured. The average for each statistic was subsequently computed for the period 1985-2000 and for each station. Precipitation intensity refers to a specific amount of accumulation of precipitation over a specific period. Also note here that statistics were computed from rainfall data available at stations and only for days where the recorded mean air temperature was above 0°C. These criteria are insufficient for a precise analysis of rainfall data aimed at computing IDF curves. However, they are deemed acceptable for the purpose of investing general patterns in precipitation.

Table 3 Rainfall statistics for the period of overlapping data between Prince George stations.

	Meteorological stations			
Statistics for the common period (average 1985-2001)	**Prince George Airport**	**Prince George STP**	**15NW**	**Miworth**
Daily maximum recorded rainfall (mm)	23.8	23.7	24.5	25.2
Number of days with rainfall > 15 mm	4.1	3.6	5.5	5.2
Mean rainfall amount (mm) for rain days	3.6	3.5	3.7	4.3

Simonovic et al. from Western University developed a tool (IDF_CC Tool 4.5) to facilitate access and extrapolation of IDF curves by municipal managers across Canada. The IDF curves presented within the "gauged locations" section of the latest version of the *IDF_CC Tool* (4.5) are directly retrieved from the values computed and available within the Environment Canada IDF dataset, released in Mar/2020 (Environment and Climate Change Canada, 2020). The latest version of the IDF_CC tool also includes a module for ungauged locations. That module allows for the computation of IDF values from a gridded dataset produced from the IDF curves at the gauged stations Gaur et al. (2020). The dataset used to produce the interpolation maps of the IDF value can also be downloaded to produce more analysis for a specific area. The latest values computed from the IDF curves for the meteorological station Prince George Airport (1096439) were retrieved from the IDF_CC Tool and are shown in Table 4.

These values do not consider the potential impacts of climate change, thus the IDF_CC Tool also proposes different scenarios of climate change impacts on IDF curves. According to an optimistic (RCP2.6[2]) or a pessimist (RCP8.5[3]) climate change scenarios presented within the tool, the rainfall amounts (mm) associated with the period and recurrences detailed in table 4, are subject to an increase of 7-9% or 14-17% respectively to both climate change scenarios. The rainfall amounts under different climate change scenarios are provided in **Appendix C**.

Table 4 Precipitation amounts (mm) from the IDF curves at the Prince George Airport (1096439).

		Recurrence (years)						
		2	**5**	**10**	**20**	**25**	**50**	**100**
Periods	**5 min**	4.5	6.5	8.1	10.0	10.7	13.0	15.8
	10 min	6.1	8.6	10.6	12.8	13.6	16.3	19.4
	15 min	7.0	9.9	12.3	15.1	16.1	19.5	23.5

2 *RCP 2.6: Representative Concentration Pathway where radiative forcing peaks at 3 W/m2 before 2100, declining to 2.6 W/m2 by 2100. RCP 2.6 provides a future concentration scenario that would lead to the lowest climate change severity, when compared to scenarios associated with RCP 8.5.*

3 *RCP 8.5: Representative Concentration Pathway resulting in radiative forcing of 8.5 W/m2 by 2100, and where radiative forcing continues to rise beyond 2100. This RCP provides a future concentration scenario that would lead to the most severe climate change impacts, when compared to all other RCPs.*

	30 min	8.2	11.7	14.4	17.4	18.5	22.0	26.1
	1 h	9.8	13.6	16.6	19.9	21.0	24.8	29.1
	2 h	11.7	15.5	18.7	22.5	23.9	28.8	34.6
	6 h	16.7	21.5	25.4	29.8	31.4	36.8	43.0
	12 h	20.8	26.1	30.4	35.2	36.9	42.7	49.4
	24 h	27.5	34.2	38.6	42.9	44.3	48.5	52.8

** Recurrence values were computed from Generalized Extreme values (GEV) analysis.*

2.2 Rainfall patterns and distribution of Rain Gauges

The Guide to Meteorological Instruments and Methods of Observation of the World Meteorological Organization (WMO) details the principal issues of rain gauges instrumentation and data processing. Precipitation measurements are particularly sensitive to exposure, wind and topography, and metadata describing the circumstances of the measurements are particularly important for users of the data. The analysis of precipitation data is much easier and more reliable if the same gauges and siting criteria are used throughout the network. This should be a major consideration in designing a network of rain gauges.

Rain gauge stations should therefore not be positioned arbitrarily, but according to the location of stations already in place, the observed past, and recent trends in regional precipitation patterns and local or smaller scale landscape characteristics. We propose a scale nested approach (i.e., regional, local, and micro scales) to assess if the locations of actual rain gauges could be enough to capture spatial variability in precipitation or if not, the optimal locations for new rain gauges. Since information communicated regarding the objectives of the City with its rain gauge monitoring plan reflects the desire to improve the precision of the IDF curves computed from the available data, the analysis of scale patterns will give a specific attention to rainfall intensity. Logistical aspects of station locations, such as accessibility and security, will also be considered for this rain gauge monitoring plan.

The first factor to consider in a Prince George rain gauge monitoring plan is the spatial distribution of existing and possible future gauges. Precipitation events are a complex phenomenon, changing in time and amplitude due to numerous factors, including global atmospheric dynamics and smaller scale interactions with landscape features (e.g. topography, surficial water). The spatial distribution of precipitation could be greatly variable, even within relatively small areas. Given that precipitation measurements are also particularly sensitive to smaller-scale landscape variability (e.g. trees, building), ideal locations for precipitation measurements must consider all the circumstances mentioned above.

2.2.1 Regional scale

The first patterns analyzed at the regional scale were those that emerged from the 1985-2000 averages of the rainfall intensity statistics (maximum daily rainfall, number of days with more than 15-mm of rain, average total rainfall amount for rainy days) computed at the rain gauges stations within the vicinity of Prince George. To better visualize the spatial patterns, the computed statistics were interpolated using ArcGIS interpolation tools. The following figure illustrates the interpolate maps.

The daily maximum rainfall and the average rainfall for rain days clearly show an increase in rainfall amount from east to west across the City. A north to south decrease in the number of days with rain with more than 15-mm is also observed. For all statistics, the lowest rainfall values are observed at the station Prince George STP (1096468) and tend to increase in the west and north directions.

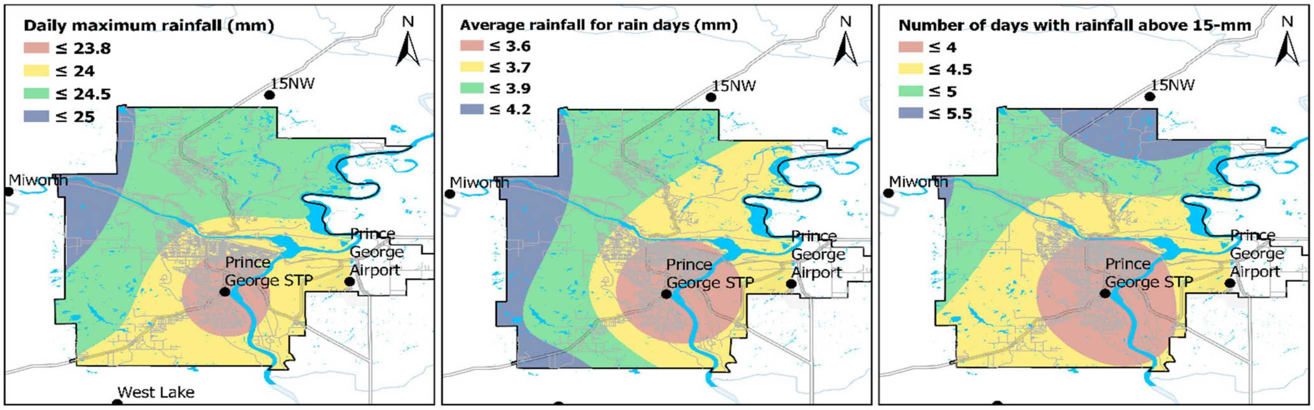


Figure 2 Interpolation maps for rainfall data from 1985-2000 averages

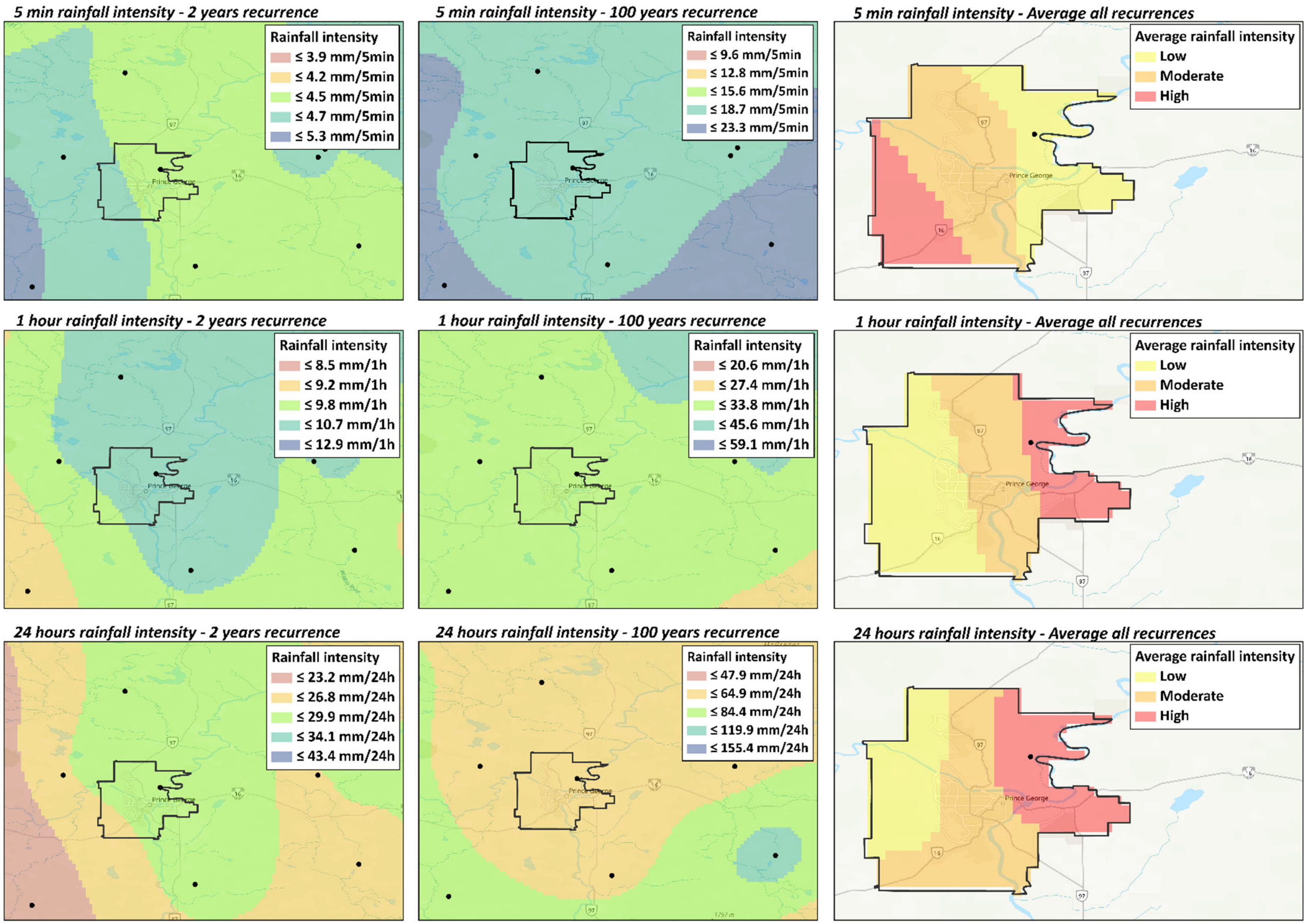


Figure 3 Rainfall intensity patterns from IDF values retrieved from the IDF_CC Tool 4.5

Following the same logic, interpolations of the rainfall intensities retrieved from the IDF_CC Tool 4.5 gridded tool for the computation of IDF curves in non gauged areas, were performed for the periods of 5-minutes, 10-minutes, 15-minutes, 30-minutes, 1-hour, 2-hour, 6-hour, 12-hour, and 24-hour, as well as for the recurrence periods of 2-years, 5-years, 10-years, 20-years, 25-years, 50-years and 100-years. The maps of the interpolated rainfall intensities for the periods of 5-minutes, 1-hour, 24-hour, and the probabilities of occurrence of 2-years and 100-years are shown on the previous figure. A superposition of the interpolated maps for each of the recurrence probabilities was thereafter conducted respectively for the 5-min, 1-h, 24-h periods to identify three specific rainfall intensity classes (i.e., low, moderate and high intensities) to better distinguish the spatial patterns in rainfall intensities. Maps of rainfall intensities classes are also shown in the preceding figure. Even if the intensity classes for the 5-min period are inverted compared to the intensities observed for the periods of 1-h and 24-h, we clearly observe a vertical alignment or a east-west pattern in the distribution of the rainfall intensities classes for all analyzed periods.

The Airport Auto (1096453) and Massey Auto (1096454) meteorological stations or rain gauges remaining in operation (2020) are respectively located (1) east of the city's limits and centrally located in the south-north direction, or (2) centrally located in both east-west and south-north directions.

These positions of the rain gauges suggest that the potential variations in rainfall intensities within the City's limits, highlighted by the rainfall intensities classes derived from the IDF curves of the IDF_CC Tool 4.5, will be partially captured by the rain gauges. Regarding the position of these two rain gauges and the fact that both are recording rainfall at a 15-min interval, they will greatly improve the computation of IDF curves and their spatial application across the city. However, the instrumentation of two supplemental rain gauges within the (1) western and (2) northern portions of the City's territory could help to capture the variability in rainfall patterns observed in both maps of the 1985-2000 rainfall statistics or maps of the IDF rainfall intensity classes. The instrumentation of supplemental rain gauges will also greatly improve the precision of the transposition of rainfall statistics computed for the gauge locations to every other location across the City's limits (spatial estimation technique will be discussed later on).

2.2.2 Local scale

Analysis carried out at the local scale aims to ensure the quality and generalization of acquired data and limit potential errors related to wind effect or rainfall interception. Recommendations for rain gauge sites at the local scale will be based on (1) guidelines from the *Guide to Meteorological Instruments and Methods of Observation,* of the World Meteorological Organization (WMO) and (2) the logistical recommendations of the City of Prince George.

In general, ideal sites for rain gauge instruments do not have steep slopes, irregular surrounding topography, high density of trees or buildings. Based on logistics the City of Prince George suggested using City's water pump station sites or the campus of the University of Northern British Columbia (UNBC) for potential rain gauge sites.

The following figure shows the locations of the rain gauges remaining in operation, the city's water pump station sites (some of which have tipping bucket precipitation gauges that are not calibrated nor online) and the proposed areas for potential supplemental rain gauges. The zoomed areas show contour lines (5m) and some parcels that present good potential for rain gauges based on topography, tree or building density, but also according to the rainfall patterns observed at the regional scale.

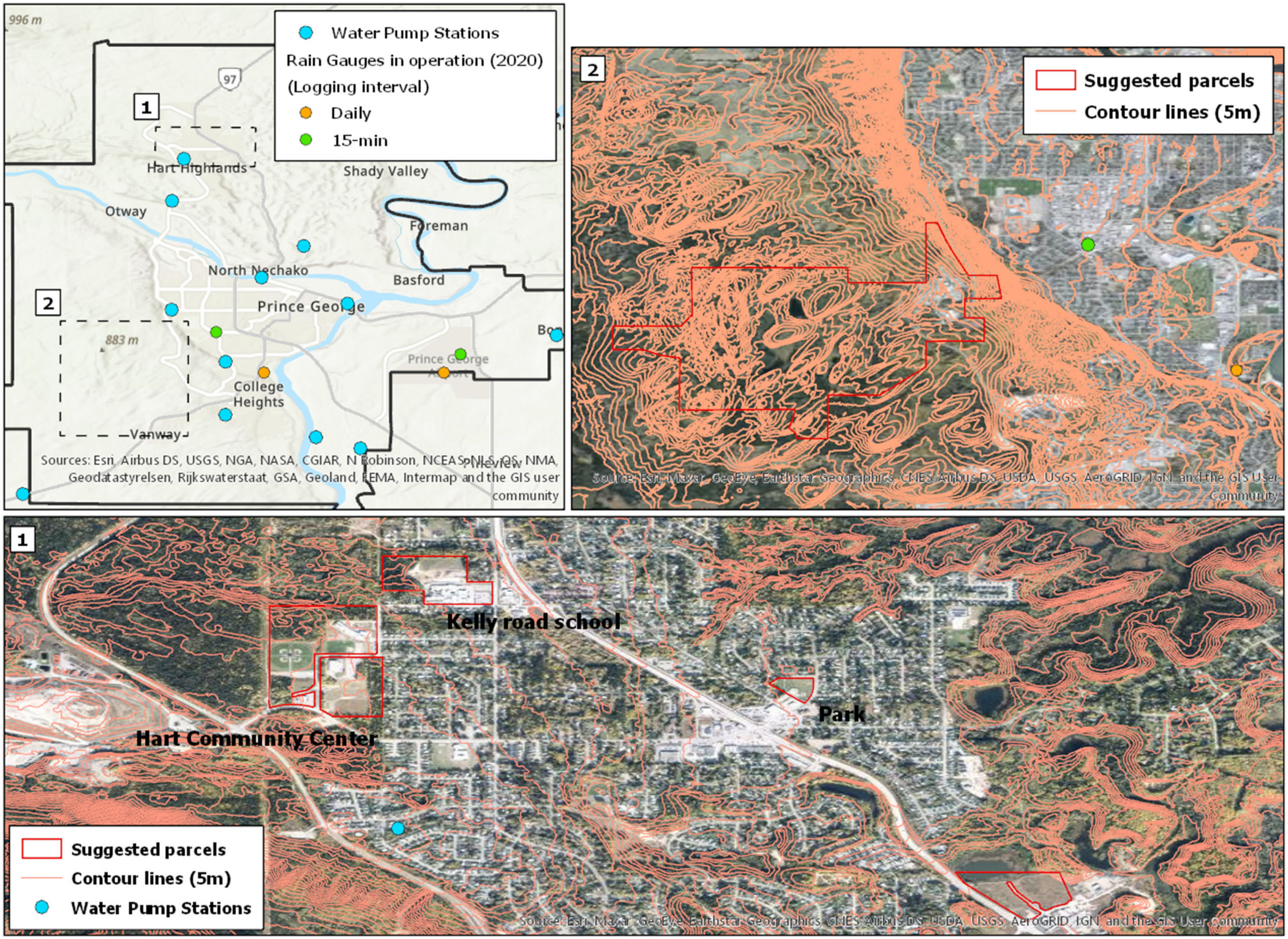


Figure 4 Suggested areas for supplemental rain gauges

The City's water pump station located within the Hart Highlands (see zoomed area 1 on previous figure), is in a good general location to capture the variability in rainfall patterns in the north of the City but satellite imagery shows buildings and trees that may negatively impact data quality if a rain gauge was located there. The previous figure shows three potentially better sites (Cpl Darren Fitzpatrick Bravery Park, Hart Community Centre, Elksentre Arena and Kelly Road School) for locating a new rain gauge.

UNBC is not ideal for the installation of a rain gauge, due to the significant changes in topography and the density of the tree cover (see zoomed area 2 on previous figure). However, much of the south-west or west portions of the City, where it would be beneficial to install a supplemental rain gauge to capture the observed variability in rainfall intensities, is characterized by steep slopes and dense tree cover. Therefore, if the City were to install a rain gauge in the southwest/west portion of the City it could be located at UNBC, but it would involve ground measurements detailed in the section below.

Based on the observed rainfall patterns, the range of rainfall statistics values observed within the city and the location of the Airport Auto (1096453) and Massey Auto (1096454) meteorological stations, the instrumentation of a supplemental rain gauge within the UNBC campus might not be necessary to fulfill the objectives (e.g. improvement of IDF curves precision and transposition of values across the city) of rainfall data processing by the City of Prince George. Comparatively, the instrumentation of a supplemental rain gauge within the northern portion of the city (zoomed area 1), will greatly improve the precision of rainfall statistics transposition across the city. Moreover, the improvement rainfall statistics transposition precision will be even more important for the northern portion of the city, where more residential or industrial development is observed.

2.2.3 Micro scale

The micro scale characterization first refers to the measurements that must be performed in the field to minimize measurement errors related to trees or building effects on wind or rainfall interception. The logistical details of the instrumentation sites such as instrument maintenance, power supply or collected data transmission should also be considered at this scale. The information collected on this scale will also influence the final choice of the rainfall measurement or data transmission instruments. Information collected here is also essential to ensure compliance of rain gauge technical instrumentation criteria detailed in the following table. It's also important to note that criteria for rainfall or snowfall are significantly different.

Characterization or on-site measurements detailed here were not achieved but are detailed as recommendations to the City as tasks to perform for the final selection of sites. The following table details the measurements or validations to perform on site for the final selection or confirmation of sites.

Table 5 Micro scale measurements or criteria for the final selection of rain gauge site(s)

Criteria / measurements	Details
1- Distance from surrounding obstacles (e.g. building or trees)	Measurements of the horizontal distance between the identified site and the surrounding obstacles. The rain gauge should have a horizontal separation that is twice as long as the height of the surrounding obstacle.
2- Height or vertical angle from the top of surrounding obstacles (e.g., building or trees)	The height of surrounding obstacles should be determined to ensure that the obstacle height is less than twice the horizontal distance between the selected rain gauge site and the obstacle. The height of the obstacle can be derived from the horizontal distance and the angle from the potential rain gauge site and the top of the obstacle. A laser rangefinder could be used to perform these measurements.
3- Specific site characteristics	Sites on a slope or on the roof of a building should be avoided.
4- Surface types	Surface surrounding the rain gauge site should be covered with a material enhancing water infiltration (e.g. short grass, gravel, or shingle). Hard, flat surfaces, such as concrete, should be avoided to prevent the splashing of raindrops.
5- Security of the site	Possibility to install safety fences around the rain gauge station, to prevent vandalism or displacement of the instruments.
6- Access to power supply	The accessibility to an energy source greatly simplifies the instruments required or the management of the rainfall monitoring.
7- Access to cellular or Internet network for data transmission	The access to a cellular network should not be an issue in Prince George. The transmission data or access to the rain gauge station via a cellular network is essential for efficient monitoring and management of the collected rainfall data. However, it requires a cellular plan. The access to an Internet network could provide less expensive options for data transmission.

2.3 Instrumentation Technical Information

In the City of Prince George, the measure of total precipitation accounts for both liquid (rain) and solid (snow) precipitation. Precipitation that falls in between rain or snow, such as freezing rain are not distinguished for most Environment and Climate Changes Canada (ECCC) climate stations and remains a studied dynamic to limit potential error related to rain or snow specific measurement. The amount of precipitation, expressed in millimetres (mm), refers to the depth of water which would have accumulated if the surface of the earth were horizontal and none of the water were lost as runoff, evaporation or absorbed into the ground. The total amount of precipitation should be clearly distinguished from total snow that falls or accumulates on the ground that is expressed in centimetres (cm).

The previous section showed that four meteorological stations remain in operation within the City limits. From these stations, two are managed, validated by ECCC and measurements recorded at a 15-min interval allowing the characterization of rainfall intensity over a short period and the improvement of IDF curves. Regarding the need to use these stations' measurements to improve rainfall dynamics understanding, limit risks or damages related to rainfall and to limit the need for supplemental rain gauges to be instrumented, we first need to better characterize the measurement types carried out at these stations. The measurements will guide the instrumentation of supplemental rain gauges to allow comparison of the data collected at the different stations.

2.3.1 Measurements at the ECCC stations

Information within the following sections is retrieved from the following sources; Mekis et al. (2018), Meteorological Service of Canada (2012), Mileska et al. (2019) and Wang et al. (2017). Precipitation variables detailed at Environment Canada meteorological station are outlined below.

- **Total precipitation (mm)**: The sum of the total rainfall and the water equivalent of the total snowfall in millimetres (mm), observed at the location during a specified time interval.
- **Total rain (mm)**: The total rainfall, or amount of all liquid precipitation in millimetres (mm) such as rain, drizzle, freezing rain, and hail, observed at the location during a specified time interval.
- **Total snow (cm)**: The total snowfall, or amount of frozen (solid) precipitation in centimetres (cm), such as snow and ice pellets, observed at the location during a specified time interval.

For some stations, all three variables are provided, while only total precipitation is provided for more recent automated stations. Other climatic variables, such as air temperature, dew point, relative humidity, wind direction, wind speed, atmospheric pressure, are also provided at many ECCC stations.

In Canada, station automation started generally in the 1990s, with more and more stations being recently automated. Prior to automatization, most stations were equipped with manual rain gauge (called Type-B). Snowfall measurements are conducted with a Standard Snow Ruler. The amount of liquid and solid precipitation was determined by a correction of the total amount of water collected in the rain gauge by the snow water equivalent (SWE) of the snow depth accumulated on the ground during the precipitation interval. A daily correction factor was recently developed to improve the precision of that calculation.

The newly automated Environment Canada meteorological stations are usually equipped with two main types of all-weather precipitation gauges, the Fischer and Porter weighing gauge or the Geonor. These automated gauges cannot distinguish between solid or liquid states of precipitation. Additional information from auxiliary optical or other present weather sensors are required to help distinguish precipitation type. Both Prince George meteorological stations Airport Auto (1096453) and Massey (1096454) are equipped with this type of automated all-weather precipitation gauges. Within their hourly database available online ECCC provides a weather indicator (e.g. rain, snow, drizzle, hail, freezing rain) that can be used to distinguish rainfall measurement from the melt of other sources of precipitation. ECCC also processes the 15-min data collected at the gauge to identify trace (T) levels of precipitation (< 0.2-mm), a value of 0.1-mm thereafter applied during rain conditions. For snow conditions, the trace adjustment factor can range from 0.03 to 0.07-mm depending on the station location. Rainfall distinction from total precipitation could also be conducted using the hourly dry bulb temperature and the dewpoint temperature computed from the relative air humidity. These variables are provided for the ECCC stations located in Prince George.

2.3.2 Climatic measurements and monitoring systems

The City should aim to use similar instruments or measurement methods, for any new rain gauges in order to simplify data processing and validations that will allow for the comparison of the collected measurements with those measured at the ECCC stations already in operation. Some instrument types are proposed in the following table for the measurement of precipitation or climate variables necessary for post-processing of the precipitation data. The instrument descriptions aim to guide the city in their future decisions for future instrumentation and for official submission requests for the instrument and the instrumentation of the station. Regardless of the type of instruments chosen for the measurement of precipitation or for data transmission, resources for instrument maintenance and data processing will be necessary.

Table 6 Instruments proposed for the measurements of precipitation

Measurement types	Instrument		Common particularities	Specific characteristics
All-weather precipitation gauges *(Weighing Gauge)*	Geonor T-200B		• Gauges have a protective housing with a container inside for collecting the precipitation. • Gauges use precision vibrating wires (VW) transducer to weight and determine the precipitation collected. • Gauges used at ECCC meteorological station network. • With the use of antifreeze, any solid precipitation is melted in the container, but snow can accumulate over the gauge ring. • A small amount of oil within the bucket will prevent evaporation. • Really good for precipitation intensity measurements. • These gauges are good for long-term use.	• Available in 600, 1000 or 1500-mm total volume, has to be emptied when full. • Conservative resolution •-40°C to 60°C operating temperature range. • Easy compatibility with Campbell Scientific data loggers.
	OTT Pluvio² L			• Available in 750 or 1500-mm total volume, has to be emptied when full. • Conservative resolution of 0.1-mm. • -40°C to 60°C operating temperature range. • Can be equipped with heated ring to prevent snow accumulation on the ring.
All-weather precipitation gauges *(Tipping bucket)*	YOUNG - 52202-L		• The NavCan meteorological stations are equipped with this type of gauge. • The precipitation collected by a pair of buckets that are balanced about a horizontal axis, when a predetermined amount of water has been collected, the bucket tips, spilling out the water and placing the other half of the bucket to receive water. Each tip of the bucket is recorded, and the record obtained indicates the amount or rate of precipitation.	• Has a thermostat-controlled internal heater that melts snow or other frozen precipitation. • Conservative resolution of 0.1-mm. • -20°C to 50°C operating temperature range. • Do not require to be emptied. • Required more significative energy consumption. • Easy compatibility with Campbell Scientific data loggers.

Table 7 Instruments proposed for the measurement of rainfall

Measurement type	Instrument		Common particularities	Specific characteristics
Rainfall gauges *(Tipping bucket gauge)*	Campbell Scientific - RainVUE20		• The precipitation collected by a pair of buckets that are balanced about a horizontal axis, when a predetermined amount of water has been collected, the bucket tips, spilling out the water and placing the other half of the bucket to receive water. Each tip of the bucket is recorded, and the record obtained indicates the amount or rate of precipitation. • Do not perform well for the measurement of other precipitations than rain. • Might need to be removed during winter. • Easy compatibility with Campbell Scientific data loggers.	• Unique aerodynamic shape to minimize wind effects and increase accuracy. • Conservative resolution of 0.3-mm. • 1°C to 70°C operating temperature range. • Do not require to be emptied.
	Texas Electronics - TE525WS			• Basic tipping bucket gauge. • Conservative resolution of 0.3-mm. • 0°C to 50°C operating temperature range. • Do not require to be emptied.

Table 8 Instruments proposed for the measurement of climatic variables needed for the post processing of precipitation data

Measurement type	Instrument		Common particularities	Specific characteristics
Air temperature and relative humidity	Campbell Scientific - HygroVUE10		• Air temperature and relative humidity sensors typically consist of two separate sensors packaged in the same housing. • Easy compatibility with Campbell Scientific data loggers.	• Calibration is easy to carry out by simply changing the sensor element. • -40°C to 60°C operating temperature range. • Conservative temperature resolution of ±0.2°C. • Conservative relative humidity resolution of ±2%.
	HUMICAP - HMP155A			• Calibration cannot be done in the field, as it requires an experienced technician and specialized equipment. • -80°C to 60°C operating temperature range. • Conservative temperature resolution of ±0.2°C. • Conservative relative humidity resolution of ±1.7%.

Table 9 Protection for the proposed instrument

Measurement type	Instrument		Common particularities	Specific characteristics
Measurement Shields	Novalynx - Wind Screen		• Instruments could work without shields, though shields greatly improve the reliability of the measurements.	• The wind screen mounted around a rain or snow gauge helps to minimize the effect of wind on the rain or snow measurements. • Wind effect is especially important for snow measurements. • For comparative purposes of the rainfall measurements, if ECCC stations are using wind shields it will be preferable to also use a similar shield.
	R. M. Young - Solar Radiation Shield			• Temperature sensors at meteorological stations are always equipped with a solar radiation shield. • Its louvred construction allows air to pass freely through the shield, thereby keeping the probe at or near ambient temperature • This shield includes the hex nut adapter for relative humidity sensors.

Table 10 Instruments proposed for the record and transfer of the measurements

Utility	**Instrument**		**Common particularities**	**Specific characteristics**
Computer - data loggers	Campbell Scientific - CR1000X		• All Campbell scientific data loggers and communication devices can easily be used together, in terms of connections and programming. • All Campbell Scientific instruments are reliable and rugged, they are the most commonly used for environmental applications in North America, making it easier to find resources for programming and maintenance of the instruments. • Other companies may provide all-in-one logging and communicating systems	• CR1000X is the general use data loggers of Campbell Scientific that provides measurement and control for a wide variety of applications. • Allow programming measurement and pre-processing routines of the collected data.
Communication	Campbell Scientific - Ethernet Interface NL121			• The easiest and lowest-cost way to add an Ethernet interface connection, allowing the data logger to communicate directly using a variety of Internet protocols.
	Campbell Scientific - Cellular Module CELL205			• External cellular modules that provide serial or CS I/O connectivity to a number of 4G LTE cellular networks
	Campbell Scientific - Ethernet Interface NL121			• Wi-Fi WLAN (wireless local area network) interface that provides connectivity to your data logger through your existing Wi-Fi network or any available Wi-Fi hotspot.

The choice of instrument set up should consider (1) micro-scale characteristics of the selected site, (2) collection purposes and post-processing, as well as (3) the resources available for the maintenance of the station. Stands for the mounting of instruments and security fences should also be considered for instrument protection. Depending on the selected instrument the cost varies between $10,000 and $15,000, as well as $5,000 - $10,000 for programming. The choice of Campbell Scientific instruments has been presented here since they can provide pre-build operation programs for the instruments, provide tutorials or training for the resources responsible for station operation and is the more commonly used instrument in North America.

2.3.3 Technical criteria for instrument installation

Rain gauges

- The rain gauge orifice must be placed above the maximum expected depth of snow cover.
- The height of the orifice should also be placed high enough to limit potential in splashing from the ground.
- To limit wind effect on measurements, the height of the rain gauge orifice from the ground should be limited as mush as possible in respect to the first two criteria (The most commonly used elevation height varies between 0.5 and 1.5 m).
- The height of surrounding obstacles should be less than twice the horizontal distance between the rain gauge orifice and the obstacle.
- The rain gauge orifice must be level to the ground.
- Installation on slopes or on building roofs should be avoided.

Temperature and relative humidity

- World Meteorological Organization (WMO) standards for temperature and relative humidity measurements are approximately 1.5-m above the ground.
- The sensors must be housed in ventilated radiation shields to prevent thermal radiation effects.
- The sensors should not be closer than four times the height of any obstruction's height.
- The sensors should be at least 30-m away from large paved areas.
- Since temperature and relative humidity will be used to interpret precipitation data they should be located close to the gauge.

2.4 Rainfall measurement processing

The typical rainfall measurement process is outlined below.

1. Computation of rainfall amount from total precipitation data (using dew point and distinguishing snow vs rain).
2. Rainfall measurement analysis:
   a) Annual and historical statistics.
   b) Overview of IDF computation curves.
   c) Spatial transposition of rainfall statistic values across the City limits.

2.5 Short-term improvement of IDF curves

It would take many years to collect sufficient data to develop an IDF curve for the proposed new rain gauge. However, in the short term, the City could compare data from the proposed new rain gauge with data from the existing airport rain gauge to determine if a “correction factor” should be applied to the airport IDF curve for any new development in the northern section of the City. The new rain gauge could also be used to help determine if there are any significant impacts due to climate change.

2.6 Raising citizen awareness about rainfall

AECOM is working with the City to develop an interactive map and database that could be used to show the collected rainfall data and that can be shared within the Open Data Portal of the City. Public mapping examples for consideration can be found at the links below.

1. City of Philadelphia : https://phl-water.maps.arcgis.com/apps/webappviewer/index.html?id=c5d43ba5291441dabbee5573a3f981d2

2. Story map Maryland :
https://maryland.maps.arcgis.com/apps/Cascade/index.html?appid=b6beb09709724ce39037584cbc497d0d

3. Monitoring of water quality (French):
https://rpns.maps.arcgis.com/apps/MapSeries/index.html?appid=ac38c90bfdc74158b3d67afa6f19f0ad

4. Vulnerability to erosion (French) :
https://rpns.maps.arcgis.com/apps/MapSeries/index.html?appid=41b21acc6f8b4e6d999ab236c74e2a52

2.7 Recommendations

Based on the observed rainfall patterns at the regional scale, the location of the Airport Auto (1096453) and Massey Auto (1096454) meteorological stations should capture a wide range of rainfall variability within the Prince George city's limits. However, to better capture the rainfall observed, the installation of an additional precipitation gauge within the North - Northwest section of the City (see Area 1 in Figure 4) is recommended. The northwest section of the City would be preferable to the northern area of the City. A third rain gauge will greatly improve the precision of rainfall statistics transposition across the city. Moreover, the improvement rainfall statistics will be even more important for the northern portion of the City, where more residential or industrial development is observed, and these areas are more susceptible to rainfall related problems than forested or agricultural areas.

By developing its own rain gauge monitoring stations, the City of Prince George will also improve its understanding of rainfall dynamics within its territory. It is recommended that a new rain gauge station use similar instruments and measurement protocol as the surrounding ECCC stations. Similar instrumentation will facilitate data comparison.

It would take many years to collect sufficient data to develop an IDF curve for the proposed new rain gauge. However, in the short term, the City could compare data from the proposed new rain gauge with data from the existing airport rain gauge to determine if a “correction factor” should be applied to the airport IDF curve for any new development in the northern section of the City.

3. Green Infrastructure

3.1 Prince George's Existing Natural Assets, Green Infrastructure and LID

Natural stormwater assets are commonly defined as natural features such as wetlands, forests, floodplains etc. that serve a stormwater function. The City's Geographic Information System (GIS) includes the following stormwater specific natural assets:

- Rivers/streams: 1,276 km
- Lakes: 41 (1.8 km^2)
- Marshes: 99 (0.78 km^2)
- Swamps: 1,297 (4.97 km^2)

There are other natural assets such as forests that also serve important stormwater functions such as rainfall interception, evapotranspiration, and erosion control.

Green infrastructure is a term commonly used for "engineered" assets such as rain gardens that have a natural component and are designed to mimic nature. The Green Infrastructure Ontario Coalition (Stormwater Systems - Green Infrastructure Ontario) defines green stormwater infrastructure (sometimes referred to as Low Impact Development) as infrastructure that intercepts, absorbs, and holds stormwater, helping reduce the amount of runoff entering sewers during rain events. The absorption and storage process also filters pollutants which improves water quality. It cites examples of these systems as:

- Bioswales;
- Permeable pavement;
- Rain gardens;
- Stream naturalization; and,
- Downspout disconnection.

Unfortunately, there is not a universally agreed upon standard for what is or isn't considered green infrastructure (GI) versus low impact development (LID) or best management practices (BMP). In general, the term green infrastructure is more commonly used on the West Coast, whereas the term Low Impact Development is more commonly used in other areas of Canada. Some practitioners consider GI to be a sub-set of LID, which can also include engineered systems such as rainwater harvesting. In any case, stormwater management using GI or LID practices involves keeping and using water close to its point of origin (i.e. keeping the raindrop where it falls). Therefore, stormwater ponds, which tend to be regional or "end of pipe" facilities are considered as a BMP but not as green infrastructure or LID.

Through the National Water and Wastewater Benchmarking Initiative, the City reported owning the following assets, which can be considered as green stormwater infrastructure (GI), LID (low impact development) or BMP's (best management practices):

- Surface infiltration facilities: 2
- Subsurface infiltration facilities: 73
- Ditches: 690 km
- Stormwater ponds: 26
- Underground storage facilities: 2

The City has implemented soil systems (see Section 3.5) adjacent to City Hall and is looking to implement bioswale with the new Fire Hall. The City has other assets such as catch basin sumps (5,750 catch basins) that can help provide pre-treatment and protect green infrastructure and natural assets downstream. In addition, the City does require disconnected downspouts for certain types of development.

The City is currently refining and assessing its natural asset inventory with the Municipal Natural Asset Initiative (MNAI), so we have focused our assessment on LID/green infrastructure options suitable for the City of Prince George.

3.2 Prince George's Current Standards

The City of Prince George's Subdivision and Development Servicing Bylaw and draft Design Guidelines permit or require the following BMP/ green infrastructure (GI)/ LID features:

- Infiltration facilities/ recharge chambers;
- Sediment basins/ traps;
- Storage facilities (wet pond, dry pond, constructed wetlands, channel storage);
- Roof leader disconnection; and
- Minimum building elevation (> 100-year flooding level).

3.3 Interviews with Other Municipalities

AECOM set up structured interviews with staff from municipalities across Canada that are directly involved with green infrastructure/LID implementation. AECOM structured the interviews to provide the information outlined below.

- Identify suitable practices implemented in cities which have a similar climate to that of Prince George
- Outline the critical considerations to be made when making implementation decisions, including:
  - The identification of constraints which may preclude GI /LID implementation in certain circumstances;
  - Operations;
  - Maintenance;
  - Budget; and
  - Education.
- Provide information regarding pre-treatment approaches that will help to extend the useful service life of various systems and highlight several common pre-treatment devices/approaches used.
- Identify potential funding sources to help offset some of the costs associated with GI/LID implementation.

The interviewed staff shared successes, challenges and lessons learned as it pertains to GI/LID implementation, with the goal of providing transferrable knowledge to the City to ensure streamlined and successful LID implementation. This sub-section of the report provides a synthesis of the information collected.

Interviewees were from municipalities that have comparable climates and physical constraints (tight soils, shallow groundwater, etc.) to the City of Prince George. Table 11 and Table 12 below summarize the climatic conditions within the municipalities evaluated as they compare to those of the City.

Table 11 Cities with Comparable Temperatures to Prince George, BC*

Climate Parameter	*Prince George, BC*	Calgary, AB	Thunder Bay, ON	Ottawa, ON	Sudbury, ON	Edmonton, AB	London, ON	Guelph/Waterloo, ON	Peterborough, ON
Mean Winter Temp. (°C)	-6.1	-5.2	-9.7	-6.5	-9.3	-9.4	-3.2	-4.1	-5.4
Mean Summer Temp. (°C)	14.5	15.3	16.6	19.9	17.9	16.7	19.6	18.8	18.3

**Data obtained from Canadian Climate Normals (GOC, 2021)*

Table 12: Cities with Comparable Climates to Prince George, BC*

Climate Parameter	*Prince George, BC*	Calgary, AB	Thunder Bay, ON	Ottawa, ON	Sudbury, ON	Edmonton, AB	London, ON	Guelph/Waterloo, ON	Peterborough, ON
Winter Rainfall (mm)	27.7	3.9	22.5	101.6	63.6	4.4	160.2	133.2	111.8
Annual Rainfall (mm)	420.2	326.4	554.3	755.5	675.7	338.8	845.9	776.8	712.5
Annual Snowfall (cm)	234	128.8	241.2	175.4	263.4	118.1	194.3	159.7	151.2
Total Annual Precipitation (mm)	654.1	418.8	795.5	919.5	903.3	446.1	1011.5	916.5	855.3

**Data obtained from Canadian Climate Normals (GOC, 2021)*

While a Canadian City with a climate identical to that of Prince George was not identified, the chosen municipalities identified in Table 11 and Table 12 are sufficiently similar to permit comparison. Table 13summarizes the representatives interviewed, as well as population for the seven comparable municipalities.

Table 13 Representatives and Population of the Municipalities Interviewed

Municipal Jurisdiction	Representatives Contacted	Population
Thunder Bay, ON	• A. Ward - City of Thunder Bay Engineering Dept.	121,621
Ottawa, ON	• D. Conway - Senior Engineer, Stormwater Management (SWM) Projects, Ottawa. • K. Bertrand - P.Eng., Project Engineer, Stormwater Rehabilitation. • L. Jolliet - City of Ottawa Engineering Dept.	934,243
Sudbury, ON	• P. Javor, MSc, P.Eng. - City of Sudbury Engineering Dept.	164,689
Peterborough, ON	• I. Boland, C.E.T - City of Peterborough Senior Watershed Project Manager.	115,245
London, ON	• A. Sonnes – City of London Stormwater Engineering Division.	494,069
Edmonton, AB	• A. Mangory - Senior Drainage Engineer, City of Edmonton.	932,546
Calgary, AB	• B. Van Duin - Drainage Technical Lead, Development Planning. Infrastructure Planning, Water Resources, City of Calgary • L. Van Duin, B.Sc.[2] Executive Director Alberta Low Impact Development Partnership.	1,392,609

1 – Data obtained from the Census Profile, 2016 Census (Statistics Canada, 2019).
2 – Representative of a Regional authority on LID implementation; not of a municipality.

Municipalities interviewed were invited to share their knowledge and experience with GI/LID, generally pertaining to the following topics:

- Preferred GI/LID types;
- Challenges associated with GI/LID implementation;
- GI/LID sustainability; and
- Lessons learned through GI/LID implementation.

3.4 Recommended Implementation Approach

Several recurring themes emerged during the interviews with other municipalities. These findings are summarized below within the sequence a municipality would follow when developing and implementing a GI/ LID strategy. All municipalities interviewed reported that GI/LID features can work in cold climates, provided they are properly designed

3.4.1 Identify Goals Based on Existing and Emerging Issues

A crucial consideration when developing a GI/LID implementation strategy is to determine what the program is aiming to accomplish. The goal of a GI/LID program will shape the selection of suitable features. To determine a goal, it is first recommended to consider the existing and emerging stormwater management (SWM) needs for the different catchments within a jurisdiction. Goals may include, but are not limited to, the following:

- Stormwater volume control;
- Increased protection against flooding;
- Water quality protection and/or improvement;
- Climate change resiliency; and
- Increasing property value.

A unique selection of GI/LID feature types can be combined to successfully achieve any of the above goals. For example, flood risk reduction goals may lead to an approach which emphasizes the creation of large subsurface storage infrastructure, such as vault or chamber-type systems installed below parking lots, parks and other open spaces Goals centred around water quality improvement may use a combination of pre-cast treatment devices (e.g. oil-grit separators, etc.) and non-proprietary approaches, such as bioretention, tree pits and similar landscaped features. Clear SWM goals will drive the selection of appropriate LID features.

3.4.2 Identify Constraints

After considering goals, it is recommended to consider potential constraints which may limit the selection of appropriate LID features, or which may have to be addressed through the design process. The municipalities interviewed highlighted common constraints; several of which are highlighted below, for consideration by the City of Prince George.

- **Soil constraints**: Some forms of vegetation used in GI/LID features may not thrive in certain soils. If vegetation options are limited, hydraulic conductivity will be affected, and ultimately drawdown times which will limit volume reduction and retention performance. Tight soil types, such as clay-rich soils, can also give rise to groundwater mounding concerns, and soil stability concerns, which may in turn affect road subgrades for those GI/LID features associated with right-of-way (ROW) environments.
- **Slopes**: Steep slopes may increase overland flow velocities and necessitate the inclusion of energy dissipation measures at GI/LID inlet locations. Steep slopes may also make stormwater retention difficult, particularly in right-of-ways.
- **Land Use**: GI/LID types may be more difficult to implement in downtown areas with zero lot line developments, especially when compared to greenfield suburban development areas. This does not mean that GI/LID can not be implemented in compact locations, but rather that it will have a bearing on the type of GI/LID features which may be suitable.

- **Adjacent Infrastructure / Utilities:** The presence of utilities and related infrastructure is an important consideration, particularly in retrofit applications. Under such circumstances, modular GI/LID feature types may be more desirable than linear features, as their geometry and footprint may be more easily modified to avoid pre-existing utilities.
- **Budgetary constraints:** Some GI/LID types are more expensive than others, but typically come with the advantage of having a higher unit area performance while also being suitable in a retrofit application where numerous constraints may be present.
- **Maintenance and equipment constraints:** Successful GI/LID selection and feature component design must reflect the equipment and capabilities of the municipality's operations staff. For example, it may be difficult to maintain sump-based pre-treatment devices without the correct vacuum equipment.
- **Legislative / Sourcewater Protection:** The use of GI/LID features in wellhead protection areas is generally limited to filtration and reuse, unless the sourcewater is clean (i.e. free of road salt).

3.4.3 Identify Capabilities (Operations, Maintenance, Budget)

Similar to the identification of constraints described above, the City should next assess its own capabilities with respect to operating and maintaining GI/LID features – both in terms of the type of GI/LID (i.e. type of maintenance required) as well as overall portfolio size (i.e. volume of maintenance required). The City should only implement GI/LID features that are within the means of the City's operation and maintenance staff, and budget. For example, it would be unwise to implement a subsurface perforated pipe infiltration system if the City does not have the ability to periodically scope and flush the perforated pipe, and to provide maintenance of upstream pre-treatment devices. This issue was raised several times during the municipal interviews completed.

Operational Capabilities

Discussions with the City of Ottawa and the City of London provided additional context regarding the importance of considering operational capabilities when selecting suitable GI/LID feature types for implementation. In the City of London, for example, many of the currently implemented GI/LID features require collaboration among several departments in order to successfully operate and maintain, including Parks, Public Works, Sewer Operations, Roads, and Stormwater Engineering. While smaller municipalities may not have the same type or number of departmental structures, a clear understanding of who is responsible for what parts of each GI/LID feature will be critical to ensuring the successful implementation of any GI/LID. It was strongly advised that Prince George consider the capabilities of internal departments that will be involved with the operation and maintenance of GI/LID features before including a specific GI/LID type within its implementation portfolio.

Maintenance Capabilities

Interviewees unanimously recommended GI/LID options which include point-source pre-treatment components to maximize the lifespan of GI/LID features and to facilitate maintenance. Although point source pre-treatment techniques are widely preferred among the municipalities consulted, it is recognized that such approaches are not always possible to include as part of feature's overall design.

In the City of Thunder Bay, pre-treatment requirements are high due to the application of road sand during winter maintenance. Proprietary pre-treatment retrofit devices that are able to directly capture road sand/sediments are not sized correctly to fit within the City of Thunder Bay's stormwater infrastructure. The City has therefore been forced to use surface inlet pre-treatment techniques which include curb cuts with riprap energy dissipators, which requires laborious manual maintenance in order to remove sediment from the interstices of the riprap. City staff have suggested avoiding the use of riprap as a pre-treatment approach for this reason.

Selecting GI/LID feature types and components which are congruent with the maintenance capabilities of the City has been strongly advised in all discussions that AECOM had with municipal staff as part of this assignment. Considering the maintenance capabilities of the City of Prince George will provide insight into the suitable range of

GI/LID features, as well as the constituent components that are maintainable by the community while providing the desired level of service.

Budget Capabilities

The budget that a municipality has in order to implement, operate, and maintain GI/LID features must also be carefully considered. Smaller communities with modest budgets may struggle to fund the capital, operational and maintenance requirements associated with certain types of GI/LID (e.g. modular proprietary units), so a limited number of implementation options may be available.

During discussions with staff from the City of Thunder Bay, it was noted that the City's 2016 Stormwater Management Plan (SWMP) forms the "backbone" of the City's approach to securing funding for their LID implementation program. In the SWMP, a database was developed which identified 550 locations within public lands where potential LID implementation may be suitable. This database identifies locations, approximate sizes, depths, and other important factors to consider as part of preliminary LID design. The City has used this section of the SWMP to leverage third-party funds, and ultimately build many of their LID projects to date. The City of Thunder Bay has committed to an eight-year program of $500,000 per year, for eight years, to complete LID projects, with support from the federal government. They have accessed over $5 million in funding to date for LID and have built 20 facilities. Having a plan which identified locations and approximate stormwater retention volumes, etc. positioned the City to access Federal funding when grant opportunities became available. This is a method that a smaller City – not unlike Prince George - has used to fund LID projects.

Based on dialogue with municipalities that have followed a similar path to Thunder Bay's siting plan, like the City of Ottawa, the following general steps may be considered.

- Beyond identifying locations, the City of Prince George could complete preliminary designs as a means of confirming site-specific implementation feasibility and obtaining preliminary cost estimates. This information would be useful for obtaining funding and setting budgets for GI/LID projects.
- Pursuing grants: Governmental organizations may provide funding for cities who wish to implement GI/LID, particularly demonstration projects. Examples include:
    - Environmental and climate change-based grants available across Canada;
        - Disaster Mitigation and Adaption (DMAP) fund;
        - CleanBC Communities Fund;
    - Third parties:
        - City of Mississauga, Ontario partnered with TD Bank through their Green Streets program. Partnering with external organizations is an option.

While securing funding is a critical step in the GI/LID implementation process, a City that wishes to do so should carefully consider how to utilize such monies for these types of projects. Improperly designed GI/LID can have high downstream costs that stem from difficulties in operating and maintaining some intricate or difficult-to-access components. The City of Prince George should carefully assess the operability of any GI/LID feature types it considers.

3.4.4 Planning for Success

Understanding the Need for Effective Pre-Treatment

The long-term effectiveness of any GI/LID feature largely depends on two factors: effective pre-treatment and regular maintenance. City staff from Prince George have informed AECOM that winter sand application is a regular road maintenance practice for the community. Sand application is intended to improve road safety by providing traction during icy conditions. In municipalities which employ a similar winter maintenance approach (e.g. Thunder Bay, Calgary, and Sudbury), a recurring item of note was the need to design robust pre-treatment devices for any

GI/LID features which would be expected to receive winter runoff impacted by sand application. Therefore, identifying a range of effective pre-treatment approaches for catch basin and surface inlet GI/LID practices should be a priority for the City. This is a similar recommendation to what the City received from Associated Engineering as part of the Winnipeg St. Outfall Plan. Pre-treatment approaches are discussed later**.** It is strongly recommended that the City recognize the need for a robust pre-treatment approach at this early stage in the GI/LID implementation process and plan accordingly.

Designing with Maintenance in Mind

The City of Ottawa has provided a method they currently use to reduce the operational workload requirements of City staff for their own GI/LID implementations. The City has a Right-of-Way (ROW) team that implements a standard agreement used with community groups in order to permit access to ROW infrastructure (ditches, boulevards, etc.). Community volunteers assist with plant maintenance at several locations where vegetated/landscaped GI/LID features have been implemented. Cities such as Ottawa are finding methods of granting community access to GI/LID infrastructure in a safe and legal manner, which in turns provides operational and maintenance cost savings. This method also gives communities the opportunity to be involved with these important infrastructure improvements, in a safe, engaging, and positive way. The City of Vancouver has a green streets program and boulevard gardening initiative which encourages and supports residents to care for landscaped areas within the public right-of-way[4]. The City of Prince George may wish to utilize a similar approach in order to build community support through active engagement and to reduce the long-term maintenance requirements required of the City's operations group.

Representatives from the City of Ottawa and London have both highlighted the impacts of seasonality and GI/LID location on GI/LID maintenance requirements. Landscapers completing private property maintenance in areas adjacent to GI/LID features have been observed disposing of leaves, grass clippings and branches in some GI/LID features, which are sometime misunderstood to be ditches or depressions where it is acceptable to do so. If the City of Prince George wishes to design and implement GI/LID features within a treed area, then the City should be prepared to handle the increased maintenance requirements associated with removing leaves that may hinder performance. The City of London has used their mascot "Filter Phil" to educate the public on the importance and maintenance of GI/LID features.

GI/LID features should also be designed and installed to minimize irrigation needs. Considerations such as plant selection, timing of planting and size of plants installed (e.g. larger stalks from 2-gallon pots rather than smaller plugs) will all help reduce irrigation needs.

Overcoming Internal and External Barriers

Education

In each of the interviews with municipalities and experts, the most commonly reoccurring topic of conversation with AECOM staff pertained to education. There is a need to identify suitable ways to keep relevant parties involved in the GI/LID implementation process educated on the nuanced aspects associated with each feature type. Based on the information gathered in the interviews, the following is strongly advised:

- Educate local engineers and consulting firms on the City's preferred GI/LID options, namely with respect to their design;
- Educate the public regarding the fundamental aspects of GI/LID in a way that the public can understand – what it is, what it does, why it matters to the community, etc.; and
- Educate contractors on how to correctly build GI/LID.

[4] https://vancouver.ca/home-property-development/beautifying-your-boulevard-and-street.aspx *April 2021*

Some designers that may be involved with GI/LID implementation in the City of Prince George may not have the experience necessary to facilitate optimal implementation. For this reason, working with the right designers was identified during the municipal consultation process as an important component for successful GI/LID implementation. Hiring outside consultants from organizations with certified GI/LID professionals is one method for directly obtaining qualified engineers. Having certified engineers with a good track-record of GI/LID design will improve implementation success rates. Likewise, the City could educate their engineering staff internally, possibly by working with the University of Northern B.C. or GI/LID authorities which exist across the country. The City of London has worked with the University of Western Ontario and the City of Toronto has worked with the University of Toronto to monitor the performance of GI/LID features

In addition to developing and/or obtaining qualified designers (whether internal or external) for GI/LID design and implementation, the City will also need to work to ensure that other internal employees are trained in the basics of GI/LID functionality, operations, and maintenance. For example; Parks department staff (which often include a sizable contingent of seasonal or summer staff with a resultingly high turnover rate), maintenance staff, and other departments that will be involved with the GI/LID implementation process will need to be educated on the GI/LID systems they will encounter. Organizations such as the Alberta Low Impact Development Partnership (ALIDP) and the Green Infrastructure Leadership Exchange exist to encourage and teach organizations about GI/LID, and what to consider when developing a detailed approach to LID implementation. The Credit Valley Conservation (CVC) Authority is one of Ontario's 36 watershed-based management agencies and is another resource which offers online webinars on topics ranging from GI/LID design to construction, operation, maintenance, monitoring and more. Education of both internal and external staff at many levels is a key component of successful GI/LID implementation. The Partnership for Water Sustainability in BC[5] and Fraser Basin Council[6] also offer resources to help municipalities in B.C. better manage natural assets and implement GI/LID.

In addition to educating internal staff, municipal representatives also highlighted the importance of educating the broader public. The general public is a key stakeholder in this regard, but they may be unaware or may have misconceptions about the role GI/LID features play in serving their community. When educating the public about GI/LID features, some municipalities have found success by presenting simplified concepts to explain GI/LID features and functions. This includes replacing complex technical terms with those that are easier to understand. For example, GI/LID features are often presented as flood risk reduction and erosion protection features, ecosystems, rain gardens, and pollinator habitats. Removing the technical language barrier will keep the public engaged and supportive of this progressive approach to managing stormwater and improving the environmental quality within the community.

In both Peterborough and Thunder Bay, Ontario, a rain garden subsidy program exists. These municipalities provide private property owners with a $500 dollar rebate towards any on-property rain garden which is constructed after homeowners complete an online educational training course (approximately two hours in length). Public education seminars ensure that GI/LID features are built correctly. Supporting LID implementation on private property helps build stormwater management education within the community which will build public support for GI/LID implementation.

Representatives from the City of Calgary and the City of London emphasized the importance of utilizing educated contractors for GI/LID installation. Experienced contractors can be difficult to find and, therefore, some organizations have begun to educate and train contractors themselves. Landscape Ontario has created a program to certify contractors as Fusion Landscape Professionals (FLPs). The City of London is hosting a FLP training session to build a local market of landscape contractors qualified to build water-sensitive landscape installations such as rain gardens and other low-tech GI/LID features for residential property owners (https://horttrades.com/fusion). The City of Prince George can use these programs as models should they consider

[5] *https://waterbucket.ca/ April 2021*
[6] *https://www.fraserbasin.bc.ca/ April 2021*

pursuing training for landscapers and contractors who may be engaged as part of a broader GI/LID implementation program. Along with contractor education programs, regular construction inspection also supports successful implementation outcomes. Staff from the City of Thunder Bay recommended full time construction inspection to ensure that features are installed according to design. Construction inspection also serves a dual purpose, as staff can use the time on-site as an opportunity to further educate and build GI/LID knowledge among contractors.

Accessing Private Lands

In the Cites of Ottawa, Peterborough, London, and Thunder Bay, Ontario, reimbursement programs have provided a means to engage and compensate private residents for GI/ LID implemented on private property. Private property makes up the majority of the total land fabric in a municipality, therefore it is advantageous to promote the adoption of GI/LID among members of the public. For example, rain garden programs which reimburse residents a portion of the installation costs have been successful in Thunder Bay, London, and Peterborough. Rain garden programs for private property have been especially successful as rain gardens are not an overly complex GI/LID feature type and can be more easily embraced by the public. However, some municipalities have had less success in promoting the adoption of GI/LID features on private property due to the logistics and administration required to implement such programs. Alternatively, partnerships can also be made with commercial and industrial developments and educational institutions, which would allow for increased access to private property, while reducing administration costs. Private property access expands the potential locations for GI/LID implementation and may therefore be of interest to the City of Prince George when identifying suitable ways to achieve its stormwater management goals.

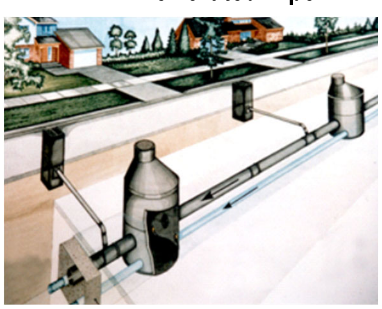
3.5 Options for Prince George

A summary of the broad range of GI/LID feature types that may be considered by the City of Prince George is provided in Table 14. Pre-treatment techniques and devices which would be beneficial to the City of Prince George are presented in **Section 3.6**.

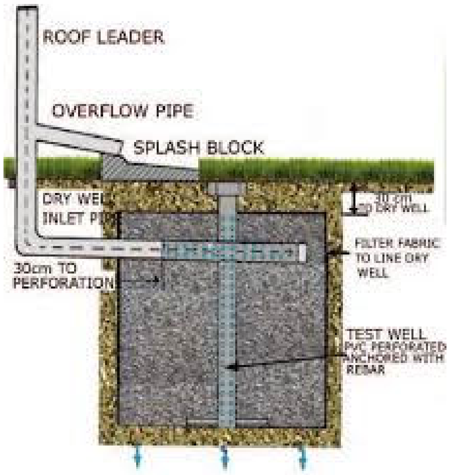
Note that GI/LID's may not be suitable in areas where there is a high risk of pollutants that cannot easily be dealt with through pre-treatment facilities (i.e. certain industrial areas). The table shows GI/LID options for private property and within public right-of ways. The advantage of having GI/LID features on private property is that rainfall is being managed where it lands, and the City does not need to bear the burden of maintenance. The downside is that it is typically more difficult to ensure the long-term survivability of GI/LID features installed on private property. Some municipalities ensure maintenance of on-site GI/LID features through a stormwater credit program (i.e. the property owner only gets their credit if they can provide evidence of maintenance), through the business license renewal process (for non-residential properties), and/or through easements or registration on title that allows the City to inspect and maintain the features.

Table 14 LID Options

LID Types	Description
Bioswale – Right-of-way 	- Consist of open channel surface conveyance within the boulevard areas, commonly behind a curb - Small check dams incorporated within bioswale designs can be used to detain surface water and to promote infiltration/filtration through filter media. - A small amount of retention storage can be incorporated within such designs in order to ensure that water is available for vegetation throughout the interceding periods between rainfall events.

LID Types	Description
Bioretention Cell 	- Bioretention facilities provide filtration and attenuation of stormwater runoff. A subsurface retention area can be incorporated within the design to provide groundwater recharge benefits as well, depending on the opportunities and constraints in the area. - Bioretention cells differ from bioswales, as bioretention is focused on volume reduction and water quality treatment (without a conveyance function), while bioswales serve to convey runoff and provide pre-treatment and water quality improvements
Soil Systems  The example pictured is a supported soil system.	- Soil systems are typically proprietary, and provide effective, modular on-site SWM by means of absorption, interception, and evapotranspiration. - Soil cells typically require low/no maintenance. - Alberta is one of the world's leading implementers of soil cells in North America. - Examples of proprietary soil systems include Silva Cells, Storm Tree, Deeproot, City Green and Blue Green Urban. - The City of Prince George has implemented these systems in front of City Hall and is looking to install them elsewhere.
Permeable Interlocking Concrete Pavement (PICP) 	- PICP can be used to infiltrate stormwater runoff from sidewalk, multi-use trails and parking lots that don't receive winter sanding. - PICP can be configured to incorporate a subsurface granular storage reservoir in order to attenuate and retain additional stormwater runoff.
Perforated Pipe 	- Perforated pipe systems consist of a subsurface perforated pipe located either within a boulevard or underneath the travelled surface of the roadway. - Perforated pipe systems receive runoff and retain a portion of the runoff within a surrounding gravel envelope.

LID Types	Description
Chamber System 	- Chamber or crate-style systems are installed underground, such as beneath parking lots. - These systems receive runoff and attenuate stormwater flows. They are readily adaptable and can be modified to provide partial retention of stormwater. - Chamber systems can be designed for peak flow attenuation, erosion control, as well as water quality treatment.
Rain Garden 	• A rain garden is a landscaped LID feature that is meant to replace an area of land to collect stormwater runoff from surrounding pervious and impervious surfaces. • Rain Gardens offer stormwater infiltration benefits, a natural method of water quality improvement, increased flood prevention, and potential stream channel erosion control (in areas with low native soil infiltration rates). • Rain Gardens are often recommended to be installed on private lands, due to the low maintenance requirements involved post-implementation. In addition, rain gardens may attract birds, butterflies, and beneficial mosquito-repelling insects. Rain Gardens complement any type of landscape found in a neighborhood. - Rain Garden incentive programs are commonly used by municipalities to achieve stormwater management goals in a City through private land access.

LID Types	Description
 **oakaway Pit**	• A Soakaway is a simple excavation with sidewalls lined using geotextile fabric. The excavations are filled with void forming material, such as granular stone, which receives runoff from a perforated inlet pipe. The runoff can infiltrate slowly through the pit, into the surrounding native soil. • Soakaways offer stormwater infiltration benefits, water quality improvement and potential stream channel erosion control (at low infiltration rates). • Soakaways may increase the risk of groundwater contamination in areas where concentration of chlorine and sodium from road de-icing salts in urban runoff are high. Soakaways are therefore recommended in urban locations where sand is used as the primary method of winter maintenance, such as many of the residential locations in the City of Prince George, but rather should only receive relatively clean runoff, such as from rooftops • Soakaways are commonly installed on private lands. Property owners need to be educated on the routine and long-term maintenance requirements of the implemented Soakaways (which are minimal). • Soakaway installation on private lands can be used in conjunction with an incentive program, such as a storm sewer user fee; based on the area of impervious cover on private land that is connected to a storm sewer. Alternatively, Soakaways can be installed in stormwater easements (between private lands), or in an expanded right-of-way, where municipal staff can access the facilities to assist with maintenance when required.
 **Bioswale – private property**	• A Bioswale is an open channel LID feature occasionally installed in new and existing residential developments. • Bioswales provide stormwater conveyance, attenuation, and nominal water quality treatment. When designed appropriately, bioswales provide infiltration benefits as well. • These features provide a conveyance function. In private property settings, this may result in the drainage of stormwater across two or more private properties. Municipalities have highlighted the difficulties of enforcing the function and use of such features in a rear yard setting. Property owners may fill in their section of a bioswale or place a backyard fence through the swale – both of which prevent the correct functioning of the LID. • Municipalities caution against rear-yard bioswale implementation without an easement or without having such features registered on title to ensure their protection for the long-term. • The City of Prince George is looking at installing a bioswale at the new Fire Hall in Carrie Jane Gray Park.

LID features are customizable to suit site constraints and meet stormwater management objectives; as such, many different configurations exist. The aforementioned examples are not intended to be exhaustive, but rather they are intended to provide a broad representation of LID options which may be suitable in the City of Prince George. Preferred/recommended LID feature types will change based on the desired SWM goals of a City, as highlighted in **Section 3.4**. For example:

- Stormwater volume control goals can be met through the use of underground infiltration galleries;

- Large-scale protection against flooding can be provided by subsurface chamber systems;
- Water quality protection and/or improvement goals can be met by a focus on pre-treatment application and bioretention cells for water filtration;
- Climate change resiliency goals are best met with a combination of systems, including bioretention, EES Etobicoke exfiltration system (EES), etc., and
- Increasing property values can be achieved though a combination of well designed, aesthetically pleasing LID features.

Minnesota is considered a leader in green stormwater infrastructure in cold climates in North America. The green infrastructure section of its stormwater manual[7] would be a good resource for the City of Prince George as it looks to implement an LID strategy.

High level cost estimates for different LID features can be determined using the following costing tool from the Toronto Region Conservation Authority's Sustainable Technologies program.
https://sustainabletechnologies.ca/lid-lcct/

3.5.1 Considering Lessons Learned

The representatives and experts that were interviewed have provided the City of Prince George with key takeaways derived from their LID implementation experiences thus far, summarized below.

City of Peterborough, ON

- Permeable Parking Lots
  - These are particularly beneficial in winter climates. Water is able to quickly infiltrate through surface pavers, resulting in less standing water, reducing the need for sand and salt application.
  - In order for permeable parking lots to maintain their infiltration capabilities, designs must take into consideration expected traffic loads. Over-compaction of compressible materials (e.g. topsoil within paving stones) due to higher than expected traffic has been a recurring issue, reducing infiltration capabilities.
  - Peterborough's permeable parking lots consist of concrete paving stones interlaid with a sod surface. Over-compaction of the sod also reduces the ability of grass to grow between paving stones.
- Peripheral Bioswales
  - The City advises careful consideration of hydrology, specifically as it pertains to the depth of the local water table, when designing and implementing bioswales. Bioswales located below the water table will not meet their function of promoting infiltration.

City of London, ON

- Rain Garden Subdivision Retrofits
  - Homeowners were given treatment options for their boulevards (i.e. sod or flowers) as part of a City subsidized boulevard rain garden retrofit program. The City noted that homeowners provided better upkeep to sod retrofits as opposed to flowers. The City has now defaulted to a sod/simple grass finish for such projects unless homeowners specifically ask otherwise.
- Structurally supported soil systems (e.g. Silva cells)

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7 https://stormwater.pca.state.mn.us/index.php?title=Green_Stormwater_Infrastructure_(GSI)_and_sustainable_stormwater_management

- The City's Forestry department is hesitant to allow irrigation of trees from stormwater that contains salt (i.e. winter road run-off). Preventing salt from impacting the trees can be incorporated into the design and this needs to be communicated to stakeholders (i.e. Parks staff). Note that the City of Prince George has developed tree and plant lists to help residents, developers and landscapers choose salt tolerant species (see Appendix B).

City of Ottawa, ON

- Roadside Retrofit Bioretention Units
  - The City of Ottawa experienced high vegetation mortality when bioretention units were online during the early stages of plant development. The City recommends keeping bioretention units offline until vegetation is well established to ensure vegetation can flourish when exposed to regular pulses of ROW runoff.
  - Inlet maintenance and grading requires more consideration and attention to detail than was initially anticipated. An inlet with insufficient grading will not allow for adequate inflow of stormwater, particularly during high-intensity events. Sediment and debris can block inlets that are too small, thereby leading to ever greater bypass.
  - Trash accumulation is a common problem in roadside retrofits; therefore, a municipality needs to consider the existing road design and surrounding land use.
- Boulevard Bioretention
  - In constrained retrofit applications, the City has observed that only very limited surface storage within such features is possible.
  - Surrounding tree-cover provides too much shade for some plants to develop within the features, therefore plants need to be selected accordingly.
  - Damage to cast iron curb inlets and garden edgings was noted during snow removal activities – this was specific to bioretention bump outs. As a result, bump-outs should only be considered in certain locations and designed accordingly.

Additional details related to the above can be found in the summarized interview transcripts provided in **Appendix A**.

3.6 Pre-Treatment

Winter sand application is a regular maintenance practice for the City of Prince George; therefore, pre-treatment methods and devices are recommended to be used in conjunction with LID features to improve water quality, reduce maintenance and increase LID longevity.

There are numerous pre-treatment devices available, many of which are suitable for use in retrofit applications within existing infrastructure (i.e. catch basins and manholes). Other pre-treatment devices and approaches are applicable to surface inlets and include a mix of proprietary and non-proprietary elements. Examples of both surface and catch basin inlet devices are described below. Choosing a preferred device for the City of Prince George should be done in conjunction with Operations staff.

3. Devices Installed within Precast Infrastructure:

   a) Catch Basin Shield

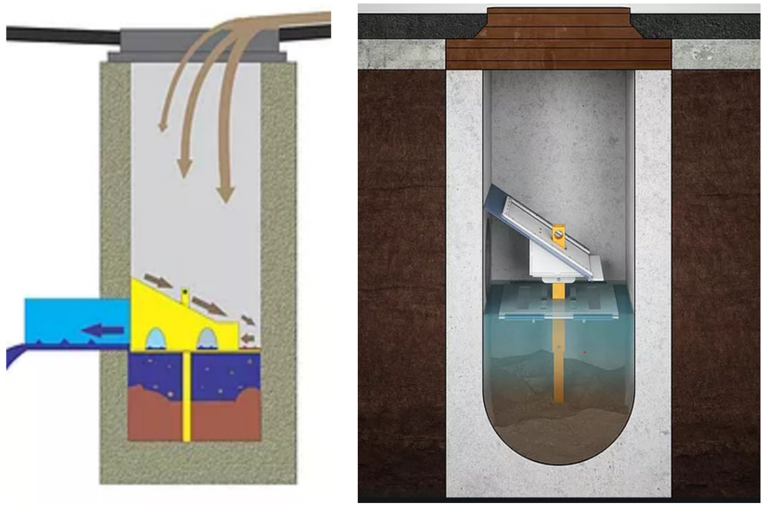

Figure 5 Catch Basin Shield (CB Shield, 2021)

- The CB Shield is a proprietary insert placed in a catch basin.
- The system functions by allowing sediment to settle between designed slots, while water flows towards the outlet.
- The insert prevents sediment in CB sumps from being washed into the outlet waterways during high flows.
- The system features an adjustable leg for height alteration to fit various catch basin sizes. Installation requires less than two minutes of time.
- The device can reach 80% TSS removal.

   b) Catch Basin Pre-treatment Snout

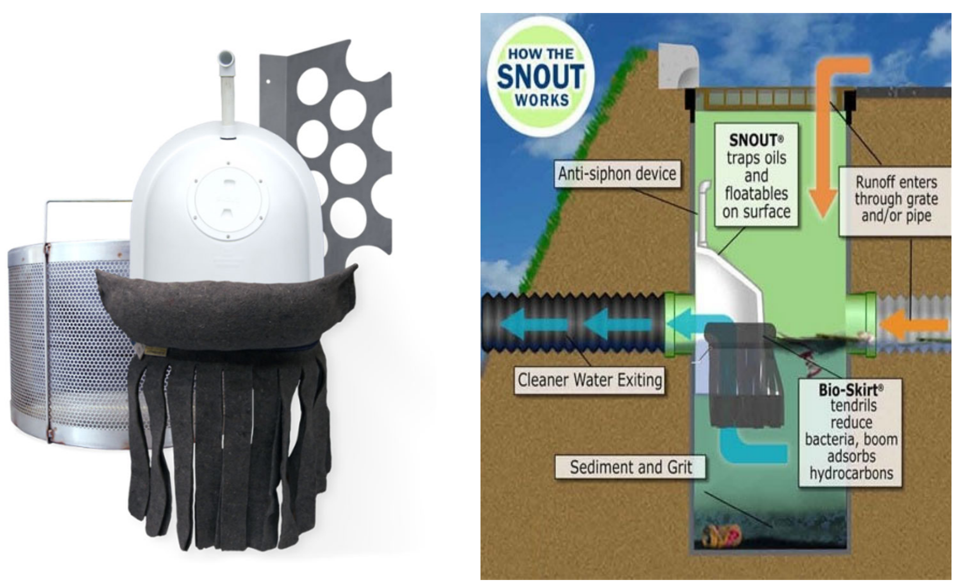

Figure 6 Catch Basin Pre-Treatment Snout (BMP, 2021)

- A catch basin pre-treatment Snout is installed on the outlet of a catch basin.
- Heavy particles sink within the sump, while a vented hood skims off floatable debris and free oils.
- A variety of variations and enhancement components exist; from hydrocarbon capture skirts to simple trash collection in stormwater runoff.
- New models have also been developed to reduce turbulence and velocity in runoff, further increasing sediment capture.

c) EnviroHood

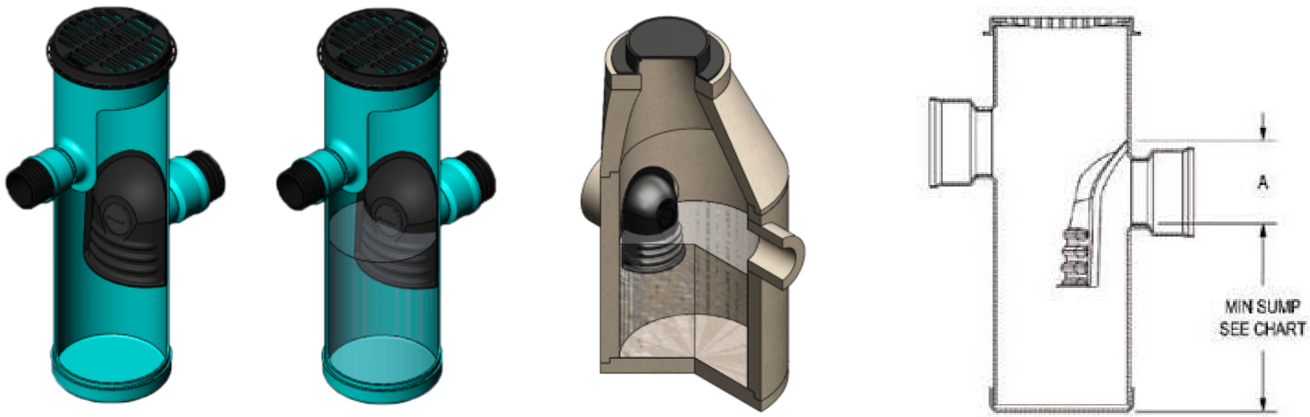

Figure 7 EnviroHood (ADS, 2021)

- EnviroHoods are stormwater management devices that are installed on the inside of catch basins and manholes.
- They provide effective pre-treatment of floating debris and oil in stormwater runoff.
- Molded from High Density Polyethylene (HDPE).

d) LittaTrap

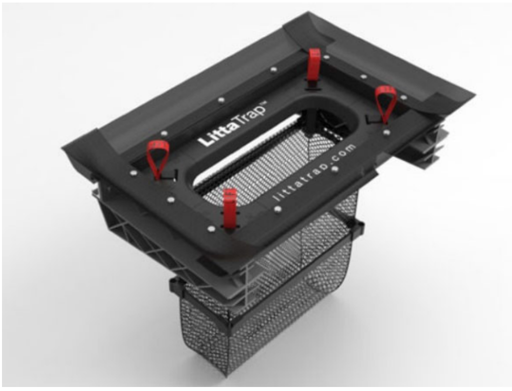

Figure 8 Littatrap (Enviropod, 2021)

- The patented stormwater management retrofit design reduces the energy of inflowing water to capture total suspended solids (TSS) in the basket and sump system.
- Stores all the captured dry gross pollutants.
- Comes in a range of sizes to fit most catch basins.

4. Surface Inlet Pre-Treatment:

    a) Rain Guardian Bunker

Figure 9 Surface Inlet Pre-Treatment - Rain Guardian Bunker (Rain Guardian, 2021)

- Lightweight and durable and can support over 300 lbs (136 kg) on the top grate.
- Easily installed in rain gardens and bioretention units.
- Quick and easy cleanout/maintenance.
- Well suited for residential applications.

    b) Rain Garden Bunker

Figure 10 Surface Inlet Pre-Treatment - Rain Garden Bunker (Rain Guardian, 2021)

- The Rain Guardian Bunker is a type of bioretention pre-treatment unit that captures stormwater from a surface inlet.
- The device consists of a recycled plastic build which provides weather and corrosion resistance.
- The device achieves 60-90% solids reduction in stormwater runoff.

3.6.1 Site Specific Feasibility Screening Criteria

When working with specific candidate sites for LID implementation, feasibility screening criteria, as presented in Table 15, should be considered. These criteria should be considered during the early selection and design phases of LID implementation for any given candidate site.

Table 15 Feasibility Assessment Criteria for LID Design and Selection

Criteria	Description
Outlet Location	Ability of the LID system to discharge to a suitable outlet or overflow (storm sewer or watercourse) based on capacity, elevations, and additional infrastructure requirements.
Overflows	Ability of inlet elevations of stormwater to the LID feature to remain congruent with the location of overflow appurtenances; ensure adequate freeboard is maintained and that LID features do not surcharge onto roadways or otherwise impact drainage system functionality.
Topographic/ Elevation Constraints	Ability of the proposed LID servicing option to be integrated within the existing/proposed grades without the need for significant alteration. This would include all surface and sub-surface infrastructure.
Influent Location(s)	The ability of LID features to accept stormwater at or below grade via curb inlet or daylighted CB lead according to ultimate road/area design. Also includes the ability of a given LID system to receive runoff from multiple point-source inlets.
Stormwater Quality	Ability of LID features to function in the face of anticipated sediment/water quality pollutant loadings; risk of clogging and ease of long-term maintenance.
Groundwater	LID feature's ability to maintain desired separation between the base of the feature and the seasonally high groundwater elevation (typically 1m).
Utility Conflicts	Proposed LID system must not conflict with existing or proposed utilities; SWM approach must be able to be integrated within existing land use topology.
Road Structure	Ability of the proposed LID system to be integrated within the proposed streetscape without compromising the road subbase due to prolonged saturation within bearing soils or within the travelled ROW. Long-term design life of the SWM feature must also not be compromised.
Safety and Sightlines	Ability of proposed LID system to be integrated within the proposed road design without compromising vehicle sightlines or pedestrian safety. LID system must meet loading requirements if placed within 1 m of any travelled area.
Drainage Functionality	LID system must satisfy SWM objectives (filtration, attenuation, and retention to the extent possible) without sacrificing or placing at risk the conveyance capacity or functionality of the remaining drainage system. Conveyance of drainage from external areas, risk of road surface ponding and possible surcharging are all impacts to be considered.
Vegetation Viability	Ability of surface vegetated practices to thrive with little to no maintenance, including long-term irrigation. Vegetation and planting beds (if present) must also be resistant to invasive species, salt, freeze-thaw and weeds.
Maintenance Requirements	Proposed LID measures must be resilient in the face of day-to-day operation and require minimal regular maintenance while reliably providing a high level of service to the surrounding area even during winter rainfall events or freeze-thaw periods. Inlets need to be chosen carefully to minimize maintenance needs in the winter (i.e. an inlet design that does not need to be regularly cleared of snow).
Cost Effectiveness	Relative cost of the various LID options which satisfy all other criteria and constraints.

3.7 Recommendations for Prince George

AECOM conducted interviews with municipalities and organizations in several regions of the country to provide the City of Prince George with introductory guidance intended to support the City with the development of a successful LID implementation strategy. The information presented follows the general steps that should be taken when developing an LID implementation program. Past successes, challenges, and lessons learned shared by municipal representatives from many jurisdictions have been included with the goal of avoiding unnecessary challenges in Prince George. LID feature and components - including pre-treatment devices - have been presented which would be suitable to the City of Prince George. This report can be used as a guide during the early stages of LID design and installation in the City. The steps toward LID implementation can be summarized as follows:

- Identify goals based on existing and emerging SWM issues;
- Identify budget, maintenance, climatic and operational constraints;
- Identify internal capabilities and external opportunities to fund the construction, operation, and maintenance of LID features;
- Plan for success by:
  - Maximizing service life through effective pre-treatment;
  - Designing all features with maintenance in mind; and
  - Overcoming internal and external barriers through education and private landowner partnerships.

4. Subdivision & Development Servicing Bylaw and Design Guidelines

A subdivision and development servicing bylaw allows a city to regulate the subdivision and development of land in order to promote the orderly and economic development of a city. The bylaw sets the requirements for the provision of works and services for development. This includes Infrastructure Specifications, similar to those found in the Master Municipal Construction Documents (MMCD).

The City's Design Guidelines were developed in 2001 to guide engineers and the development industry in the design of engineering servicing facilities and systems. The Design Guidelines have been noted as "Draft" since 2001 and are not enacted by bylaw. However, they are used to provide the minimum design criteria and standards for proposed works. Stormwater related items addressed include the widths of rights of ways, utility separation, drainage principles, storm runoff computation, minor system design, major system design, storage facility design (including ponds, constructed wetlands and channel storage), infiltration facilities, other storage options and pump stations.

The City of Prince George is currently reviewing its Subdivision & Development Servicing Bylaw and draft Design Guidelines to identify any required or desired updates. We have reviewed the stormwater sections of the City's Subdivision & Development Servicing Bylaw and draft Design Guidelines as well as similar bylaws and design guidelines from other municipalities. With input from City staff, we have identified a number of issues and proposed solutions for the City to consider as it revises its Subdivision & Development Servicing Bylaw and draft Design Guidelines. Identified issues include:

- Climate Change (updated IDF, 1:10 year, min pipe size/slope etc.);
- Stormwater volume/rate and quality controls, including the use of green infrastructure and LID;
- Design requirements for the sizing of oil and grit separators and access for maintenance;
- Erosion and sediment control;
- Standards for culverts, detention ponds and liners (for relining sewers); and
- Maximum allowable sewer/culvert grades and requirements for energy dissipation to avoid the wearing out of pipes.

4.1 Climate Change and Design Storms

The draft Design Guidelines were prepared in 2001 and the Intensity-Duration Frequency (IDF) curve presented in the guidelines, which is based on Environment Canada's weather station at the Prince George Airport, dates from 1997. Since then Environment Canada has updated the IDF curve for the airport, which needs to be revised in draft Design Guidelines.

Historically and increasingly, it has been found that intense rainfalls can be very localized in nature. Therefore, a single rain gauge may not capture (i.e. may miss) some significant rainfalls and may underreport rainfall frequency within a municipality. This is why many municipalities are setting up multiple rain gauges within their municipalities to better capture local rainstorms and to define design storm frequency more accurately. This was further discussed in Section 2.0.

In addition to recent increases in rainfall intensity, it is projected that the City will experience even greater increases in rainfall intensity due to climate change. Since most stormwater infrastructure that is currently being installed is designed to last over 50 years, it is important that infrastructure design considers future increases in rainfall intensities.

The Design Guidelines state that the minor system design storm is the 5-year storm, however the City is now requiring the 10-year storm. This is a great first step for increasing capacity to manage more intense rainfalls. The Design Guidelines need to be revised to state that the 10-year storm is the design storm for the minor system. The City is working to implement a new rainfall monitoring program that will refine the City's IDF curve and can be used to help project future climate projections. Until this program is implemented, the City could apply the 30% increase projected by the University of Western Ontario's IDF CC tool to help design infrastructure for future rainfall amounts (https://www.idf-cc-uwo.ca/).

The City of Prince George also experiences other rainfall events that are less intense but may cause flooding due to snow and frozen catch basins. The City may want to provide a range of design events for consideration, such as:

1. Intense rainfall – 10-year design storm;
2. Rain on snow event – 2-year storm; 100% imperviousness – minor and major system available; and
3. Rain on snow event with frozen catch basins – 2-year storm; 100% imperviousness – only major system available.

The City's Design Guidelines stipulate runoff coefficients to be used in the determination of stormwater flows for the design of drainage system components. Run-off coefficients, which range from zero to one are used specifically to estimate the proportion of rainfall that reaches the stormwater system. The higher the coefficient the greater the proportion of rainfall that runs off into the stormwater system. Paved areas such as roadways have a high run-off coefficient and landscaped areas have a low run-off coefficient. It is recommended that the City review the run-off coefficients that it specifies in its Design Guidelines (see Table 5.3.5.2.1 in the Design Guidelines). Currently the City specifies a runoff coefficient of 0.1-0.25 for Parks, Playgrounds, Cemeteries and Agricultural Land. The City of Greater Sudbury specifies a runoff coefficient of 0.1-0.35 for these land use types. Whereas the City of Surrey specifies a run-off coefficient of 0.25-0.3 for these land use types. Using too low of a run-off coefficient would result in design engineers underestimating the amount of run-off and under sizing stormwater infrastructure.

The City is currently developing a Climate Action Workplan to identify priorities in five-year increments. The recommendations in this TWP are in line with comments expressed at the recent Climate Action Workshop; particularly with respect to post-construction vegetation survivability, changing climate (e.g. greater stormwater flows), overland flow from frozen catch basins, and the benefits of infiltrating stormwater back into the ground.

4.2 Stormwater Controls

The Subdivision and Development Servicing Bylaw could be used as a tool to enact current best practises in stormwater management as it pertains to stormwater runoff rates, volumes, and quality. Setting stormwater controls can be performance based (e.g. infiltrate and/or retain the first 25 mm of rainfall) or prescriptive (e.g. maximum impermeable areas, disconnected downspouts and the construction of rain gardens and boulevard swales) or a combination of both (e.g. a developer can construct required features or meet the performance target). A performance-based approach tends to work better in a municipality where developers are well-versed in the design and construction of low impact development (LID) as it typically requires modeling, analysis, and the knowledge of the performance of different LID features. As the City of Prince George is relatively new in the use of LID features, it may want to consider a combined approach where it offers a prescriptive option that is easy for developers new to LID to follow but to also provide a performance based option that offers flexibility to those developers who may have specific constraints and can successfully develop an effective LID strategy.

Stormwater volume, rate and quality restrictions can be applied to private property and public rights-of-way at the time of development or redevelopment. The City's Design Guidelines do offer options for managing the quantity of stormwater (e.g. storage and infiltration facilities) but do not specify exactly how much needs to be stored or infiltrated during frost free periods as well as during winter months. Many municipalities require post-development flows to match pre-development flows. Note that this must be done carefully so that it does not increase the duration of erosive forces on downstream channels. This can be achieved by controlling stormwater volumes (e.g. through infiltration, vegetative uptake, and evapotranspiration) as well as by controlling discharge rates from storage facilities below the erosive velocity of the downstream channel.

In order to manage the quantity of stormwater the City's Design Guidelines outline the design of stormwater storage facilities and stormwater infiltration facilities. More specifically the Design Guidelines provide general design parameters and specific requirements that must be considered and addressed in the planning and design of stormwater storage facilities as well as the requirement for a maintenance and service manual. The Design Guidelines also outline general design requirements that must be considered in the planning and design of stormwater infiltration facilities. The City's Subdivision and Development Servicing Bylaw provides a standard drawing for a recharge chamber. The City would benefit from providing more specific requirements for the design and maintenance of stormwater infiltration facilities on private property and within the road rights-of-way.

Section 17 of the City of Edmonton's Drainage Design Standards[8] outlines design criteria that applies to the design of LID facilities including bioretention gardens, bioretention basins, box planters and soil cells. Section 17.6 of Edmonton's Standards addresses cold climate design considerations. The City of Edmonton's Low Impact Development Best Management Practices Design Guide addresses the design of other LID facilities.

The City of Surrey's Design Manual provides details on the design of infiltration trenches and the associated Standard Drawings provide a typical infiltration trench details.

The City's current DG specify that no new ditches shall be created for servicing land development projects on Municipal rights-of way, except in designated lowland areas in the floodplains where poor soil exists. However, with a growing interest in low impact development to moderate stormwater flows, the City may want to consider allowing ditches and other open channels.

When considering whether to use/permit an open channel or a buried pipe the City should consider many factors such as:

- Whether it is fish-bearing;
- Desired aesthetic;
- Maintenance;
- Topography/slope;
- Soil types/erodibility; and
- Need to control flows.

The table below outlines when channels or pipes may be more desirable.

Table 16 Evaluation of Open Channels vs. Pipes

Asset type	Preferred	Undesirable
Open channel	• If small reductions in velocity (i.e. 1% slope) and volume are desired (help downstream system)	• If it is a street with high levels of contamination (oil, debris, sediment etc.) that would be difficult to contain/clean within an open channel • Areas with high levels of pedestrian traffic and on-street parking (i.e. downtown areas)
Pipe	• If no reduction in velocity is desired (i.e. <0.5% slope) • If high velocity is expected (i.e. >4% slope)	• In general (i.e. under normal conditions) open channels better mimic the natural water balance and help reduce and detain stormwater

[8] *https://www.edmonton.ca/residential_neighbourhoods/documents/Volume_3_Drainage_.pdf*

	• A road with high levels of contamination (oil, debris) that would be easier to contain and clean within a traditional curb and gutter, CB/OGS configuration	

4.3 Oil Grit Separators

Prince George's Design Guidelines do not include design requirements for oil-grit separators (OGS). Design requirements would help the City and developers determine the appropriate sizing for any OGS as well ensure proper access for maintenance. The City of Surrey's Design Criteria Manual (Section 5.6 and associated Standard Drawings[9]) provides a good example of design requirements for oil-grit separators Surrey's design criteria also requires that the Consultant provide an operation and maintenance (O&M) manual and outlines what should be included. The City of Surrey's Design Criteria are schedules to the City's Subdivision and Development By-law.

Note that the locations or property types that require oil-grit separators are outlined in the City of Prince George's Storm Sewer Bylaw (Section 2.9). Recommendations for amending the types of properties or locations (such as prior to discharge to a fish-bearing watercourse) that require an oil-grit separator are outlined in Technical Working Paper #3. Note that some municipalities such as the City of Surrey reiterate the property types that require an oil-grit separator within their Design Guidelines.

4.4 Erosion and Sediment Control

The City's existing bylaws do not have the required provisions to ensure erosion and sediment control (ESC) best practices are followed. The Storm Sewer Bylaw prohibits discharge for sediment (>500 ppm) which is significantly higher than best practice and requires laboratory testing to confirm. The City of Prince George's Design Guidelines only requires developers to produce erosion and sediment control plans for certain types of development. The City does not specify what the ESC plans should contain nor that they be prepared and monitored by a qualified professional. Whereas, the City of Kelowna requires developers to retain a Qualified Professional (P.Eng., RPBio, P.Ag, AScT, CPESC, CISEC or CESCL) responsible for inspecting and monitoring the ESC Facilities (Schedule 4 of Kelowna's Subdivision, Development and Servicing Bylaw - Bylaw 7900). It is important that negative environmental and infrastructure impacts and resulting liability from insufficient erosion and sediment control lies with the developer and not the City.

In order to improve erosion and sediment control associated with all development including the clearing of land before subdivision, the City has investigated the development of a new Erosion and Sediment Control Bylaw. However, the City is currently considering the strengthening of existing bylaws, particularly the Subdivision and Development Servicing Bylaw, to help address some of the ESC issues. Updating the development and building permit requirements to extend the need for an ESC plan to more types of development and requiring the services of a Qualified Professional for ESC in larger developments would help strengthen ESC requirements associated with new development. Also adding requirements to the Subdivision and Development Servicing Bylaw with respect to vegetation such as how soon it needs to be installed and minimum survivability (e.g. 80% survivability after one year).

4.5 Culverts

Developers will construct road crossing culverts as required for new development, but it is then typically up to City to maintain and renew these culverts at the end of their service life. Corrugated steel pipes (CSP) are typically cheaper to install but the material's lifespan is shorter, on average, than other pipe materials such as concrete or HDPE. Allowing developers to install pipes with shorter lifespans creates a greater financial burden on the City as

[9] https://www.surrey.ca/sites/default/files/media/documents/DesignCriteria.pdf

the City will be required to repair or replace the culvert earlier than if other pipe materials were used. The advantage to metal pipes such as CSP is that is allows for easy locating in the winter when culverts need to be cleared for drainage. However, non-metal pipes could be constructed with a metal component (e.g. metal collars or imbedded steel) to facilitate winter locates.

The City's Subdivision and Development Servicing Bylaw (Section 02641 in Division 2) only lists corrugated steel pipe as an option for constructing culverts. The City should reconsider allowable culvert materials, particularly in areas known to have corrosive soils.

Any crossings (driveway or road) of fish-bearing streams should be constructed using an open bottom structure (typically concrete) to maintain a natural channel bottom and facilitate fish passage. The City is planning to meet with the Province to discuss which culverts need to be made fish passable. Some streams (e.g. high up in the Parkridge watershed) are noted as "fish inferred" but they are dry for portions of the year. The City can use the environmental assessment associated with each of the Watershed Drainage Plans to help determine which channels would likely provide valuable fish habitat if culverts were made fish passable.

The City's Design Guidelines, Subdivision and Development Servicing Bylaw or Storm Sewer Bylaw do not address who owns driveway culverts and who is responsible for their maintenance, repair, renewal and upgrading, when required It is important to specify whether it is the City or the property owner who is responsible for driveway culverts. We will be conducting a survey with municipalities across Canada to determine how other municipalities handle driveway culvert maintenance and renewal.

4.6 Detention Ponds

Prince George's Design Guidelines recommend the use of wet ponds, dry ponds, and constructed wetlands for controlling the flow of stormwater. We have identified the following areas where the Design Guidelines could be improved with respect to stormwater detention ponds:

- Provide design details for constructed wetlands. Currently the Design Guidelines only provide design details for wet ponds and dry ponds;
- The design details do not mention the need to provide an area adjacent to the pond that would be suitable for the dewatering of removed sediment during maintenance;
- The design details do not mention the need to provide upstream treatment (e.g. oil-grit separator) in areas where excessive sediment or contamination may be a concern (e.g. industrial areas, arterial roadways or high-crash intersections); and
- The design details do not mention the need to provide a bypass so that the pond can be "closed" for maintenance or to contain any spills.

The City of Ottawa has a comprehensive manual on the design of stormwater management facilities which would be a good reference for the City of Prince George.

As previously mentioned, it is important that ponds and their outlets are properly designed so that they do not increase downstream channel erosion. This can occur if the outflow from the ponds extend the duration of "medium" flows that exceed the scour velocity of a channel. The Varsity Creek ravines have experienced erosion due to development and the resulting flow from the upland areas. The upland area is cleared of trees which greatly increases run-off and ponds can make things worse if they just increase the duration of erosive forces.

The Design Guidelines specify that designers must provide a maintenance manual for each pond designed. The Guidelines should also require what the maintenance manual shall include and cost estimates for completing the recommended maintenance activities so that the City can better plan future maintenance needs. Section 16.5 of the

City of Edmonton's Drainage Design Criteria[10] outlines what shall be included in a stormwater management facility's Maintenance and Service Manual. Some cities will also ask the developer to complete or pay for the maintenance until the community that the pond services is mostly or completely built out.

The City should not accept detention ponds until after vegetation is established, the vegetation is shown to survive (e.g. 80% survivability after one year) and the performance of the pond is proven over an extended period. The UniverCity development on top of Burnaby Mountain requires all on-site GI/LID features and ponds to be monitored for performance for a minimum of two years before the ponds are accepted by the City of Burnaby.

Temporary detention ponds used for erosion and sediment control during construction should be addressed in the City's Erosion and Sediment Control requirements. The City of Burnaby outlines clear erosion and sediment control needs during construction, including the performance and maintenance of temporary detention ponds[11]

4.7 Relining – Fish Friendly Standards

The Design Guidelines do not provide details on relining options for City storm sewers. Relining is not often an option for deteriorated storm sewers since they may require upsizing due to increased development, higher design standards and climate change. However, when upsizing is not required and relining is an option, design engineers should be provided some guidance on acceptable relining options and protocols that do not adversely affect the downstream natural environment

The main concern of culvert/storm sewer relining is that it is an outdoor plastic manufacturing process (installing and curing), which is a less controlled environment when compared to regular manufacturing that could happen in a factory (more controlled environment). During the curing, cutting, and handling (if poorly done) of the installed material, some chemical products could be emitted/produced, which could have some impacts on the natural environment. There have been some reported unwanted environmental consequences (fish kill and water contamination) in different locations across North America due to some high levels of certain chemicals. Relining of a culvert within a fish bearing stream must also be evaluated to ensure fish-passage after construction, particularly as relining typically reduces the diameter of the culvert. There are also health and safety concerns as some gases are produced during the curing process, and if workers are not wearing proper PPE (protective personal equipment), it may cause some health implications.

In general, the chemical contamination incidents that were reported was mostly found to be attributed to the improper handling of the material by the contractor. This could be due to reduced quality assurance/control measures during the installation and curing and/or poor specifications that did not establish control measures to limit consequences.

Generally, the most utilized material for lining contains styrene products and is one of the main materials used in the City of Toronto in rehabilitating storm, combined and sanitary sewers. There has been some utilization of non-styrene products that are believed to have less of an environmental impact. However, there is no definitive research that explicitly states the fact that this material has zero environmental consequences from a chemical and environmental perspective. But some cities request to use non-styrene resins in outfalls or places that are closer to water bodies.

Generally, the use of lining, whether it is styrene or non-styrene, should have enough specifications to enhance the material handling and installation process to minimize the environmental impacts. In addition, there are some instances where contractors are advised to use the UV method instead of hot water or steam in the curing process. This could also reduce some environmental and health impacts. UV is generally more expensive than hot water or

[10] [10] *https://www.edmonton.ca/residential_neighbourhoods/documents/Volume_3_Drainage_.pdf*
[11] *https://www.burnaby.ca/Assets/Sediment+Control+Information.pdf*

steam. In cases hot water is used for curing, this water may need to be collected by a vacuum truck and disposed of at a specific location but not to flow through the system.

There is a list of recommendations/specifications to minimize environmental impacts of lining that should be considered when tendering such a job, including but not limited to:

- Contractor shall capture particles and shavings created during any CIPP cutting activities and not permit entry into the environment. This capture activity may include but is not limited to a portable device to capture emitted particulate dust.
- Contractor shall not permit floating materials to enter the surface water or nearby vegetation.
- Materials deposited on the particle collection mat or barrier material shall be collected and disposed of.

The City may only want to consider relining culverts/sewers that are not fish-bearing nor upstream of fish-bearing channels until the City is comfortable that local contractors can adequately minimize environmental impacts. More information about relining and other methods for extending the life of storm mains are provided in **Section 8**.

4.8 Basements

In areas where there are no storm sewers (e.g. ditches only) or a high groundwater table (e.g. swamp) basements can be problematic. Allowing basements in these areas can lead to the following problems:

- Dependence on pumps to manage flow from perimeter drains;
- Illegal cross connections (i.e. perimeter drains) are tied to the sanitary system; and
- Excessive flow in the storm system (e.g. from perimeter drains that are essentially “draining” the swamp).

In the absence of a geotech report requirement, the City can amend the Subdivision & Development Servicing Bylaw and/or OCP Bylaw to provide stronger clauses that limit basements in designated areas with supporting inspection/enforcement to prevent the aforementioned problems from occurring.

4.9 Education

The City of Prince George recognizes the value of providing education material to better inform developers, contractors, and property owners of the requirements within the Subdivision & Development Servicing Bylaw and associated Design Guidelines and how to achieve them. The City has already produced some development related educational material but understands that there are still gaps, where additional information should be provided. In particular the City sees the need to produce lot grading related information similar to the Lot Grading Guidelines provided by the City of Edmonton.[12]

Lot grading information would be particularly useful in the communication of cross drainage easement agreements and the need to maintain backyard swales throughout development and occupancy. After development this becomes a civil matter between two property owners, but issues are often brought to the City and the City would benefit from improved public information.

As the development of individual homes or duplexes are exempt from the Subdivision & Development Servicing Bylaw, lot grading of individual properties would be better addressed in the Building Bylaw.

[12] https://www.edmonton.ca/programs_services/documents/ResidentialGuidelines.pdf March 2021

4.10 Maintenance

The success of the Design Guidelines is dependent on a good supporting maintenance program. For instance, sediment traps that are shown in the Design Guidelines will only be successful if they are periodically cleaned of the collected sediment. In addition, a regular storm maintenance program that includes street sweeping, catch basin sump cleaning and ditch cleaning will also help remove sediment from the system, protect natural assets and reduce the frequency and cost for sewer and pond cleaning.

The Storm Sewer Bylaw defines service connections as “the pipe which may include an inspection chamber or clean out connecting a storm sewer to the drainage system constructed upon private property.” Section 3.8.3 of the Subdivision & Development Servicing Bylaw states “Provide cleanout on service line at location indicated” but does not provide any more details. The Design Guidelines do not make any reference to clean-outs.

4.11 Grades

The City’s Design Guidelines (DG) state that the maximum velocity in an unlined ditch shall be 1 m/s. The DG states that on steep slopes, grade control structures may be used to reduce velocities, but they do not state a maximum slope for ditches. With respect to sewers the DG state that where design velocities are supercritical or in excess of 2 m/s, special provision shall be made to protect against displacement of sewers by erosion or shock. No upper limit to flow velocities or grades in storm sewers is defined. However, when supercritical flow does occur (where steep grades are utilized) the designer shall provide appropriate analysis and justification and make provisions in the design to ensure that structural stability and durability concerns are addressed. Flow throttling or energy dissipation measures to prevent scour will be required to control the flow.

4.12 Cover

The City’s DG states that “storm sewers shall be installed at a depth lower than the frost line that is generally at a depth of about 2.2 m and be able to service properties on both sides of the roadway”. This is significantly deeper than other municipalities, such as the City of Waterloo which have a minimum cover of 1.5 m. The DG do not specify a maximum depth of cover, just stating that pipes deeper than allowable for Class III pipe must be specially designed for their specific conditions. The City has conducted a study related to depth of cover in other municipalities and is considering reducing the amount of cover due to climate change.

4.13 Catch Basins

The City of Prince George’s DG do not mention the need for bike friendly catch basins or manhole covers. City of Surrey requires bicycle friendly top/side inlet style catch basins on all arterial roads per their standard drawings. These types of inlets can also help with snow and leaves.

The City of Prince George’s DG state that catch basins shall be provided at upstream end of radius at intersections and at low points. They go on to state that low points are not to be located within curb returns at intersections. The City of Vancouver’s Engineering Design Manual goes a bit further by specifying that catch basins are not to be located in painted cross walks or curb ramps. The Vancouver manual specifies that catch basins are to be located at the beginning of the curb return or higher side of crosswalk.

The City of Prince George’s Subdivision and Development Servicing Bylaw provides a reference drawing for a corrugated steel catch basin. A concrete catch basin would have a greater lifespan, on average, particularly in corrosive soils.

4.14 Application

The Design Guidelines are only effective if they are actually applied. The City can help promote application by:

- Mandating adherence of the Design Guidelines within the Subdivision and Development Servicing Bylaw;
- Having enough well-trained staff to review designs by designers, contractors, and developers; and
- Educating developers, designers, contractors, and City staff on the requirements within the Design Guidelines, Subdivision and Development Servicing Bylaw and Storm Sewer Bylaw.

4.15 Miscellaneous

The City's Subdivision and Development Servicing Bylaw and Design Guidelines do not provide standard drawings or a process for utility disconnects.

5. Development Contributed Assets

As per the City's Subdivision & Development Servicing Bylaw and Drainage DCC Bylaw, development is required to construct and/or contribute to the construction of stormwater assets. In this section we will outline issues related to development contributed stormwater assets and full life-cycle costs for these assets.

As previously mentioned, the Design Guidelines state that developers must provide an O&M manual for any newly constructed stormwater pond. However, the Design Guidelines do not require estimated O&M costs to complete the recommended activities within the O&M manual. The Design Guidelines should be amended to require the provision of O&M cost estimates for any new ponds.

5.1 Life Cycle Costs for Development Contributed Stormwater Assets

The life cycle costs of various stormwater assets are provided in the following table to assist the City when approving developments and to assist with planning for ongoing maintenance after the assets are taken over by the City. Descriptions of the various columns are described below.

- 2021 Unit Cost: Cost to construct the asset on a per unit basis (e.g. $ per metre or $ per pond)
- Annual maintenance cost: Average cost per year to inspect, clean and repair the asset on a per unit basis
- ESL: Estimated Service Life
- Cost/unit (1 life cycle): The total capital and maintenance costs for an asset over its estimated service life
- LCC/unit (100 years): The life cycle costs include the total capital and maintenance costs for an asset over a 100-year span. It could represent multiple life spans. The goal is to normalize costs between assets with different life spans.

The cost estimates were consolidated from various stormwater asset management plans completed for Canadian municipalities. The cost estimates in the table do not include monitoring costs (e.g. water quality sampling or flow monitoring).

Table 17 Life Cycle Costs for Typical Stormwater Assets

Asset Type	Details	Unit	2021 Unit Cost	Annual Maintenance Cost ($/Uni	ESL (years)	Cost/unit (1 life cycle)	LCC/unit (100 years)
Drainage Pipe	Gravity - PVC - 250 mm	m	$492	$0.70	80	$548	$685
Drainage Pipe	Gravity - PVC - 300 mm	m	$564	$0.70	80	$620	$775
Drainage Pipe	Gravity - PVC - 375 mm	m	$636	$0.70	80	$692	$865
Drainage Pipe	Gravity - PVC - 450 mm	m	$708	$0.70	80	$764	$955
Drainage Pipe	Gravity - PVC - 525 mm	m	$780	$0.70	80	$836	$1,045
Drainage Pipe	Gravity - PVC - 600 mm	m	$876	$0.70	80	$932	$1,165
Drainage Pipe	Gravity - Conc - 675 mm	m	$936	$0.70	80	$992	$1,240
Drainage Pipe	Gravity - Conc - 750 mm	m	$1,080	$0.70	80	$1,136	$1,420
Drainage Pipe	Gravity - Conc - 900 mm	m	$1,104	$0.70	80	$1,160	$1,450
Drainage Pipe	Gravity - Conc - 1050 mm	m	$1,284	$0.70	80	$1,340	$1,675
Drainage Pipe	Gravity - Conc - 1200 mm	m	$1,584	$0.70	80	$1,640	$2,050
Drainage Pipe	Gravity - Conc - 1350 mm	m	$1,848	$0.70	80	$1,904	$2,380
Drainage Pipe	Gravity - Conc - 1500 mm	m	$1,980	$0.70	80	$2,036	$2,545
Drainage Pipe	Gravity - Conc - 1800 mm	m	$2,124	$0.70	80	$2,180	$2,725
Drainage Pipe	Gravity - Conc - 2100 mm	m	$2,520	$0.70	80	$2,576	$3,220
Culvert	CSP 400-450 mm	m	$570	$0.70	30	$591	$1,970
Culvert	CSP 525 mm	m	$650	$0.70	30	$671	$2,237
Culvert	CSP 600 mm	m	$700	$0.70	30	$721	$2,403
Culvert	CSP 675 mm	m	$722	$12.50	30	$1,097	$3,657
Culvert	CSP 750 mm	m	$745	$12.50	30	$1,120	$3,733
Culvert	Conc 900 mm	m	$1,104	$12.50	80	$2,104	$2,630
Culvert	Conc 1050 mm	m	$1,284	$12.50	80	$2,284	$2,855
Culvert	Conc 1200 mm	m	$1,584	$12.50	80	$2,584	$3,230
Culvert	Conc 1350 mm	m	$1,848	$12.50	80	$2,848	$3,560
Culvert	Conc 1500 mm	m	$1,980	$12.50	80	$2,980	$3,725
Culvert	Conc 1800 mm	m	$2,124	$12.50	80	$3,124	$3,905
Culvert	Conc 2100 mm	m	$2,520	$12.50	80	$3,520	$4,400
Ditch		m	$50	$5.00	50	$300	$600
Biofiltration Swale		m	$500	$83.33	25	$2,583	$10,333
Infiltration Trench		m	$380	$83.33	25	$2,463	$9,853
Rain Garden		m	$500	$83.33	25	$2,583	$10,333
Catch Basin		Ea	$3,500	$45.00	80	$7,100	$8,875
Manhole		Ea	$5,000	$32.50	80	$7,600	$9,500
Dry Detention Pond		Ea	$150,000	$1,000	50	$200,000	$400,000
Wet Detention Pond		Ea	$250,000	$1,000	25	$275,000	$1,100,000

6. Risk Assessment

Risk can be defined as a product of the probability of asset failure (PoF) and the consequences of asset failure (CoF) or criticality as shown below.

Risk = Probability of Failure × Consequence of Failure

AECOM developed a network level risk assessment and prioritization methodology that considers condition, capacity, and criticality (e.g. potential impact of failure). The risk prioritization methodology was developed starting with the risk framework within the 2009 RIVA Business Process Maps and then refined based on available information/data and in consultation with Prince George staff.

The tables below show the prioritization methodology, or scoring system, used to determine the risk of the City's Stormwater Assets for each main asset type. The scoring system is based on a scale of 1 to 10 where 10 represents the highest risk. 50% of the risk score is based on an asset's probability of failure and 50% of the risk score is based on an asset's consequence of failure.

Table 18 Risk Scoring Methodology: Stormwater Mains and Culverts

PoF/CoF Weighting		Sub- Weighting		Description	Score	Data source
50%	Probability of Failure	35%	Flow Deficiency	insufficient capacity for 5 yr design storm	10	WDP
				none	0	
		25%	Repair history	> 1 repair	10	Cityworks
				1 repair or multiple inspections	5	
				none	0	
		40%	Condition	0 remaining ESL or found to be in bad condition	10	GIS
				0-10 yr remaining ESL	8	
				10-20 yr remaining ESL	6	
				20-30 remaining ESL	4	
				30-40 remaining ESL	2	
				> 40 yr remaining ESL	0	
50%	Conse quence of Failure	35%	Pipe Flow	≥ 900 mm	10	GIS
				750	8	
				675	6	
				600	5	
				525	4	
				450	3	
				375	2	
				≤300 mm	1	
		25%	Zoning (bylaw 7850 - class)	Business, Industrial, Commerical, Utility, site specific	10	GIS
				recreation & Institution	6	
				residential	4	
				rural	2	
		20%	Downstream receiving environment (catchment)	Immediately discharges to a fish/inferred fish bearing channel/body downstream	10	GIS
				Eventually flows to a fish bearing body (ie farther downstream)	5	
				No fish habitat before Fraser/Nechako	2	
		20%	Cover surface	arterial	10	GIS
				collector	6	
				local	4	
				lane	3	
				non-road surface	1	

Table 19 Risk Scoring Methodology: Pump Stations

PoF/CoF Weighting		Sub-Weighting			Score	Data source
50%	Probability of Failure	30%	Redundancy	No back-up pump	10	Condition assessment report
				Back-up pump	0	
		35%	Condition - pump	Condition assessment score ≤50	10	GIS & Condition assessment report
				Condition assessment score 50-60	8	
				Condition assessment score 60-70	6	
				Condition assessment score 70-80	4	
				Condition assessment score 80-90	2	
				Condition assessment score >90	0	
		35%	Condition - facility	Condition assessment score ≤50	10	
				Condition assessment score 50-60	8	
				Condition assessment score 60-70	6	
				Condition assessment score 70-80	4	
				Condition assessment score 80-90	2	
				Condition assessment score >90	0	
50%	Conse quence of Failure	50%	Flow (size)	≥ 200 hP	10	GIS
				>100 hP	7	
				>50 hP	5	
				25-50	4	
				10-25	3	
				5-10	2	
				<5	1	
		25%	Adjacent Land Use	ICI (industrial commerical institutional); environmentally sensitive area	10	GIS
				multi-residential	7	
				residential	4	
				agricultural/ park	3	
				undeveloped/forest	0	
		25%	Adjacent cover surface	arterial	10	GIS
				collector	6	
				local	4	
				lane	3	
				non-road surface (eg park)	1	

Table 20 Risk Scoring Methodology: Channels

PoF/CoF Weighting		Sub-Weighting			Score	Data source
50%	Probability of Failure	100%	Condition	known problem area	10	WDP
				none	0	
50%	Conse quence of Failure	35%	Flow (down stream culvert)	≥ 900 mm	10	GIS
				750	8	
				675	6	
				600	5	
				525	4	
				450	3	
				375	2	
				≤300 mm	1	
		25%	Zoning Class	Business, Industrial, Commerical, Utility, site specific	10	GIS
				recreation & Institution	6	
				residential	4	
				rural	2	
		20%	Downstream receiving environment (catchment)	Fish bearing/infered fish	10	GIS
				Eventually flows to a fish bearing channel (ie farther downstream)	5	
				No fish habitat before Fraser/Nechako	2	
		20%	Adjacent surface (<20 m)	arterial	10	GIS
				collector	6	
				local	4	
				lane	3	
				non-road surface	1	

Table 21 Risk Scoring Methodology: Catch Basins

PoF/CoF Weighting		Sub-Weighting			Score	Data source
50%	Probability of Failure	50%	Issue	known problem area; multiple maintenance visits	10	Cityworks
				none	0	
		50%	Condition	0 remaining ESL or found to be in bad condition	10	GIS
				0-10 yr remaining ESL	8	
				10-20 yr remaining ESL	6	
				20-30 remaining ESL	4	
				30-40 remaining ESL	2	
				> 40 yr remaining ESL	0	
50%	Conse quence of Failure	35%	Land Use	Business, Industrial, Commerical, Utility, site specific	10	GIS
				recreation & Institution	6	
				residential	4	
				rural	2	
		25%	Downstream receiving environment (catchment)	Immediately discharges to a fish bearing channel/body downstream	10	GIS
				Eventually flows to a fish bearing body (ie farther downstream)	5	
				No fish habitat before Fraser/Nechako	2	
		40%	Cover surface	arterial	10	GIS
				collector	6	
				local	4	
				lane	3	
				non-road surface	1	

Table 22 Risk Scoring Methodology: Storm Storage Basins/Ponds

PoF/CoF Weighting		Sub-Weighting			Score	Data source
50%	Probability of Failure	100%	Condition (pond assessment)	Poor	10	Detention Pond Inspection report 2014
				Fair	6	
				Unknown	age (see below)	
				Good	2	
				Brand New	0	
		100% (if condition unknown)	Age	> 25 year	10	GIS
				20-25 yr	8	
				15-20	6	
				10-15 yr	4	
				2-10 yr	2	
				< 2 yr	0	
50%	Conse quence of Failure	35%	Storage Capacity	large (capacity > 10,000)	10	GIS
				medium (1000-10,000)	6	
				small <1000 m3	3	
		20%	Zoning	Business, Industrial, Commerical, Utility, site specific	10	GIS
				recreation & Institution	6	
				residential	4	
				rural	2	
		25%	Downstream receiving environment (catchment)	Immediately discharges to a fish bearing channel/body downstream	10	GIS
				Eventually flows to a fish bearing body (ie farther downstream)	5	
				No fish habitat before Fraser/Nechako	2	
		20%	Cover surface within 50 metres	arterial	10	GIS
				collector	6	
				local	4	
				lane	3	
				non-road surface	1	

Table 23 Risk Scoring Methodology: Inlets

PoF/CoF Weighting		Sub-Weighting			Score	Data source
50%	Probability of Failure	50%	Repair history	> 1 inspection	10	Cityworks
				others	0	
		50%	Condition	0 remaining ESL or found to be in bad condition	10	GIS
				0-10 yr remaining ESL	8	
				10-20 yr remaining ESL	6	
				20-30 remaining ESL	4	
				30-40 remaining ESL	2	
				> 40 yr remaining ESL	0	
50%	Conse quence of Failure	35%	Pipe Flow	≥ 900 mm	10	GIS
				750	8	
				675	6	
				600	5	
				525	4	
				450	3	
				375	2	
				≤300 mm	1	
		25%	Zoning	Business, Industrial, Commerical, Utility, site specific	10	GIS
				recreation & Institution	6	
				residential	4	
				rural	2	
		20%	Classification of Channel	Fish presence/fish inferred channel (immediately downstream)	10	GIS
				Within a catchment that has fish (farther downstream)	5	
				No fish habitat before Fraser/Nechako	2	
		20%	Cover surface	arterial	10	GIS
				collector	6	
				local	4	
				lane	3	
				non-road surface	1	

The City has one dam, the Shane Lake Dam. The risk scoring of the dam was based on the 2020 Shane Lake Dam Failure Consequences Classification Report. The dam was given the following risk scores:

- PoF: 4, since beaver activity could cause a risk failure

- CoF: 10, since dam failure could threaten downstream property and human safety

The data and risk scoring framework was entered into Innovyze's InfoAsset Planner to calculate the risk for the various stormwater assets. These scores can be used to inform sustainable infrastructure management within the City through prioritization of inspection, maintenance, rehabilitation, and renewal of linear and non-linear stormwater infrastructure. The outputs of the model could also be used as inputs to the City's asset management system Powerplan, GIS and into any MS-Excel file. The City will be provided an Excel file with PoF, CoF and risk score by AssetType and AssetID.

The assets are given a risk score from 0 to 10, where:

- Very low risk: 0-2;
- Low risk: 2-4;
- Moderate risk: 4-6;
- High Risk: 6-8; and
- Very high risk: 8-10.

The risk scores for the City's stormwater assets by type can be seen in the following figures.

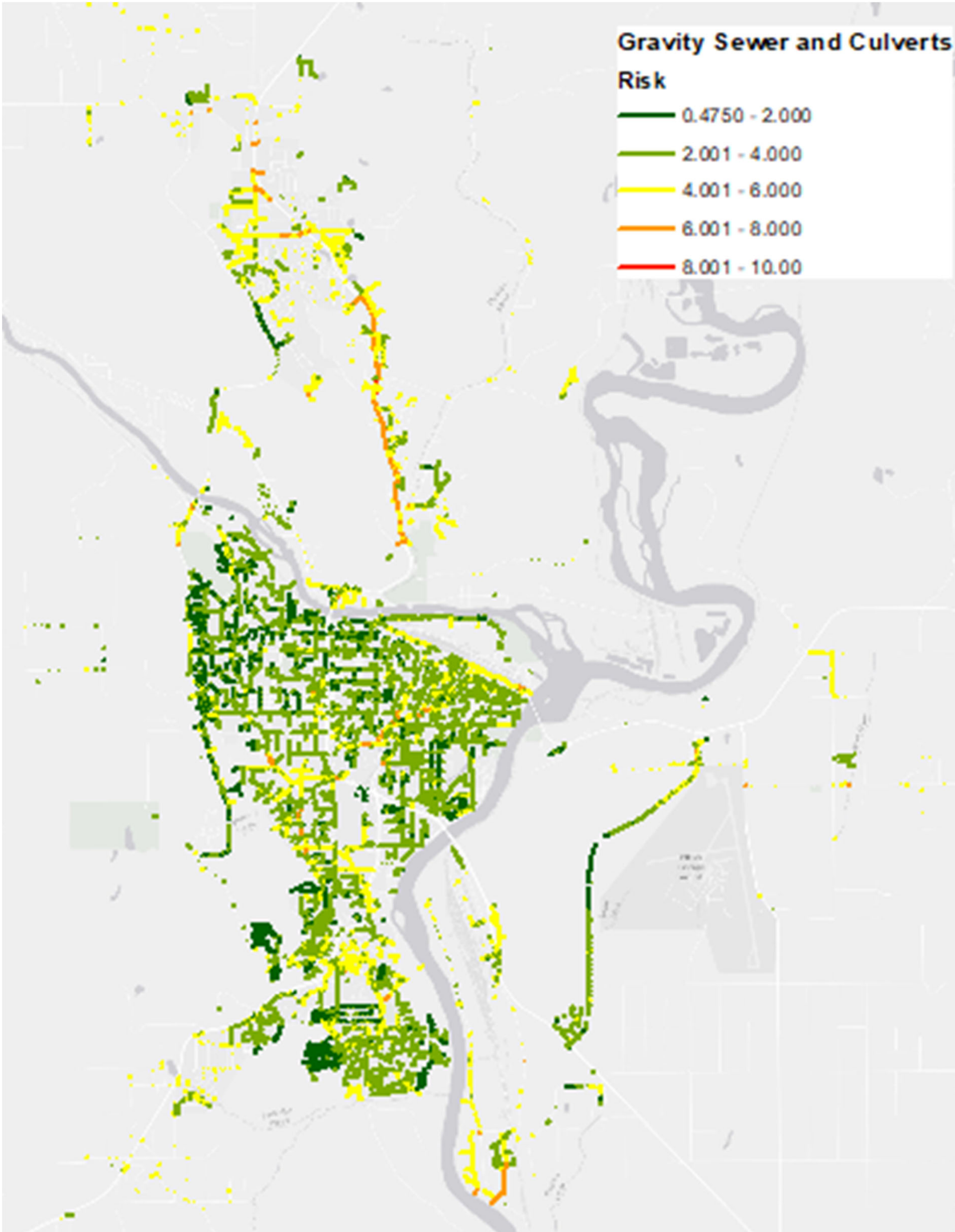

Figure 11 Risk Score for Sewer Mains and Culverts

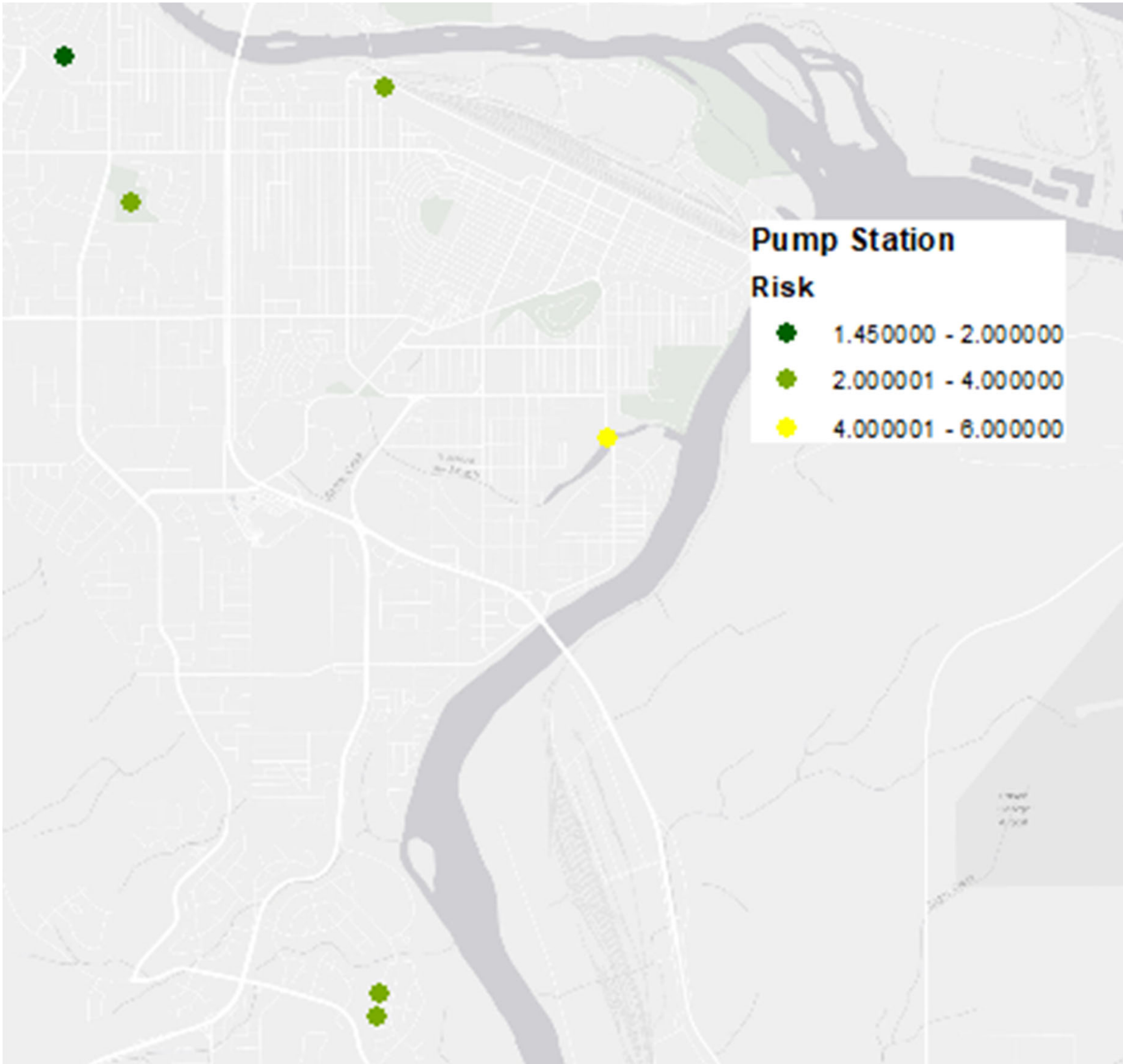

Figure 12 Risk Score for Pump Stations

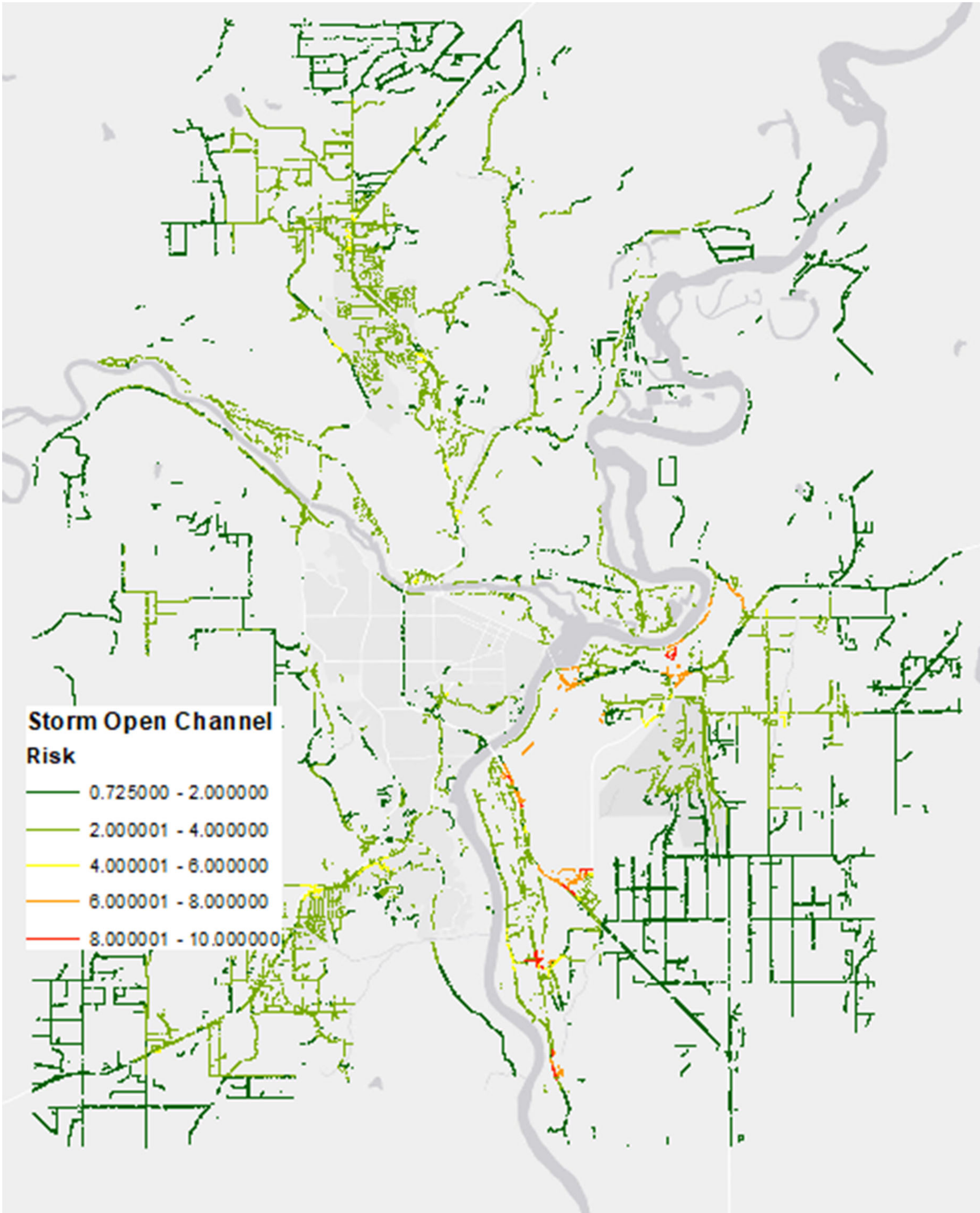

Figure 13 Risk Score for Channels

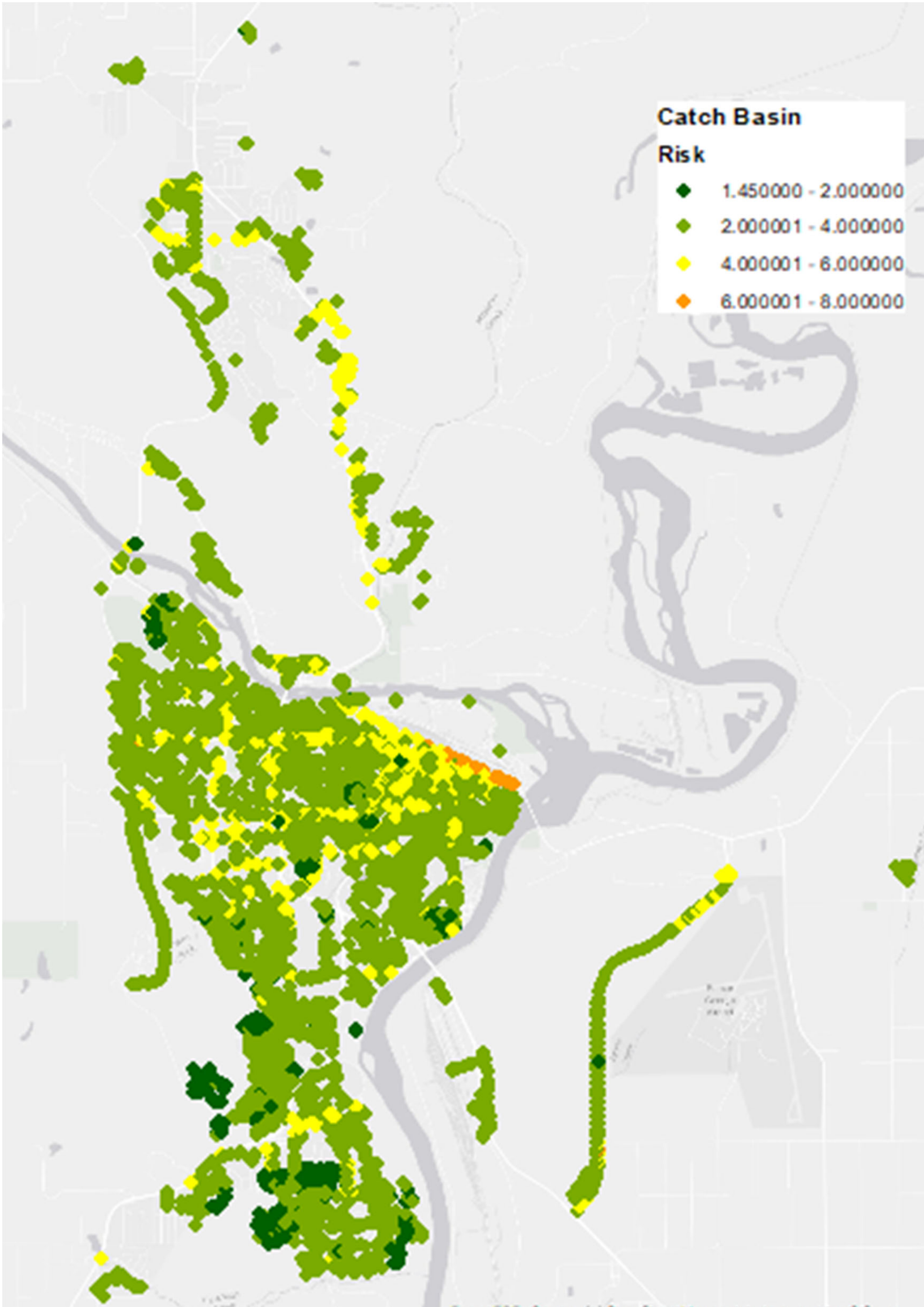

Figure 14 Risk Score for Catch Basins

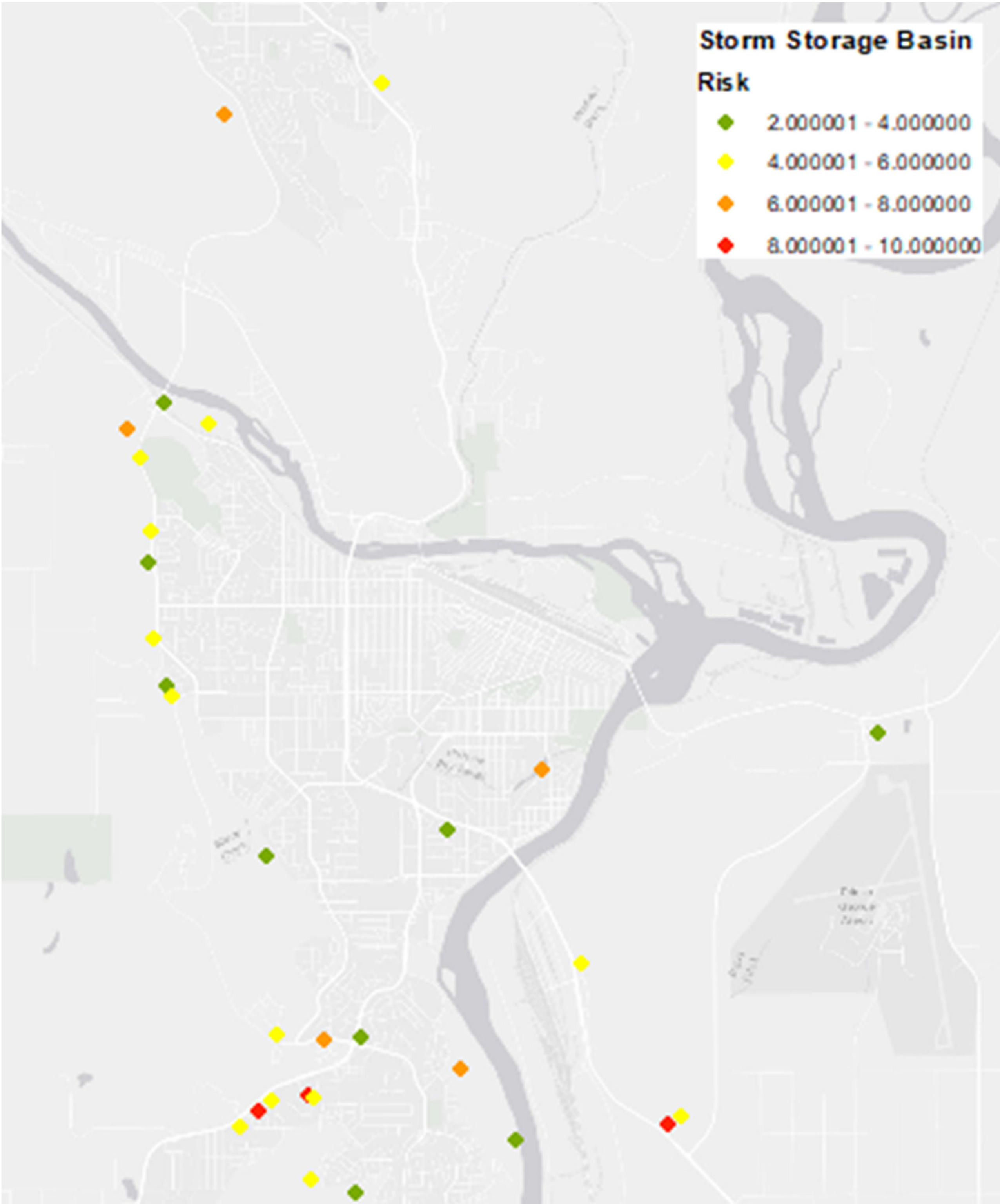

Figure 15 Risk Score for Detention Ponds (e.g. Storm Storage Basin)

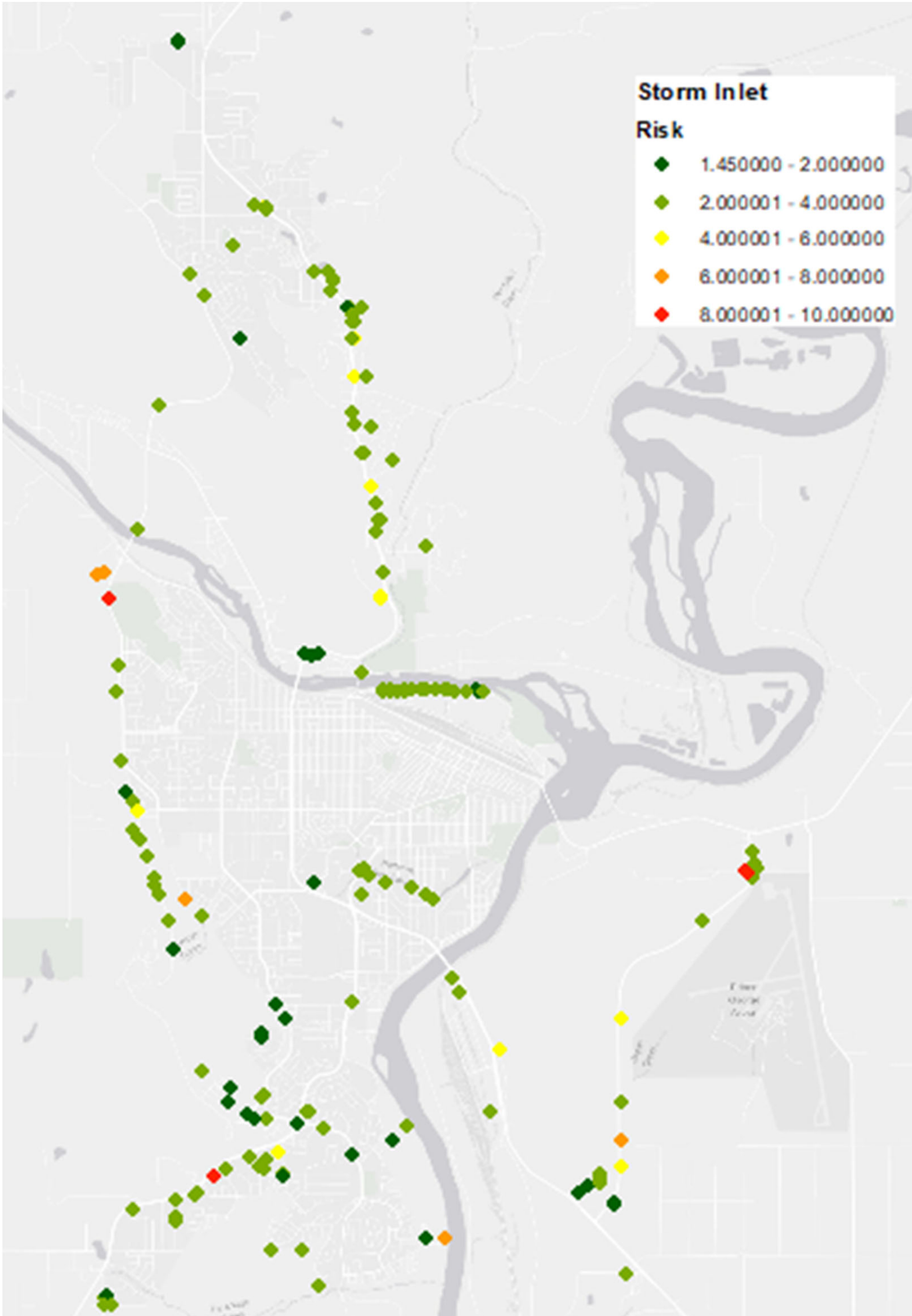

Figure 16 Risk Score for Inlets

The figure below shows the risk score for each of the discharge points. The risk score for discharge points was derived from the asset immediately upstream of the discharge point.

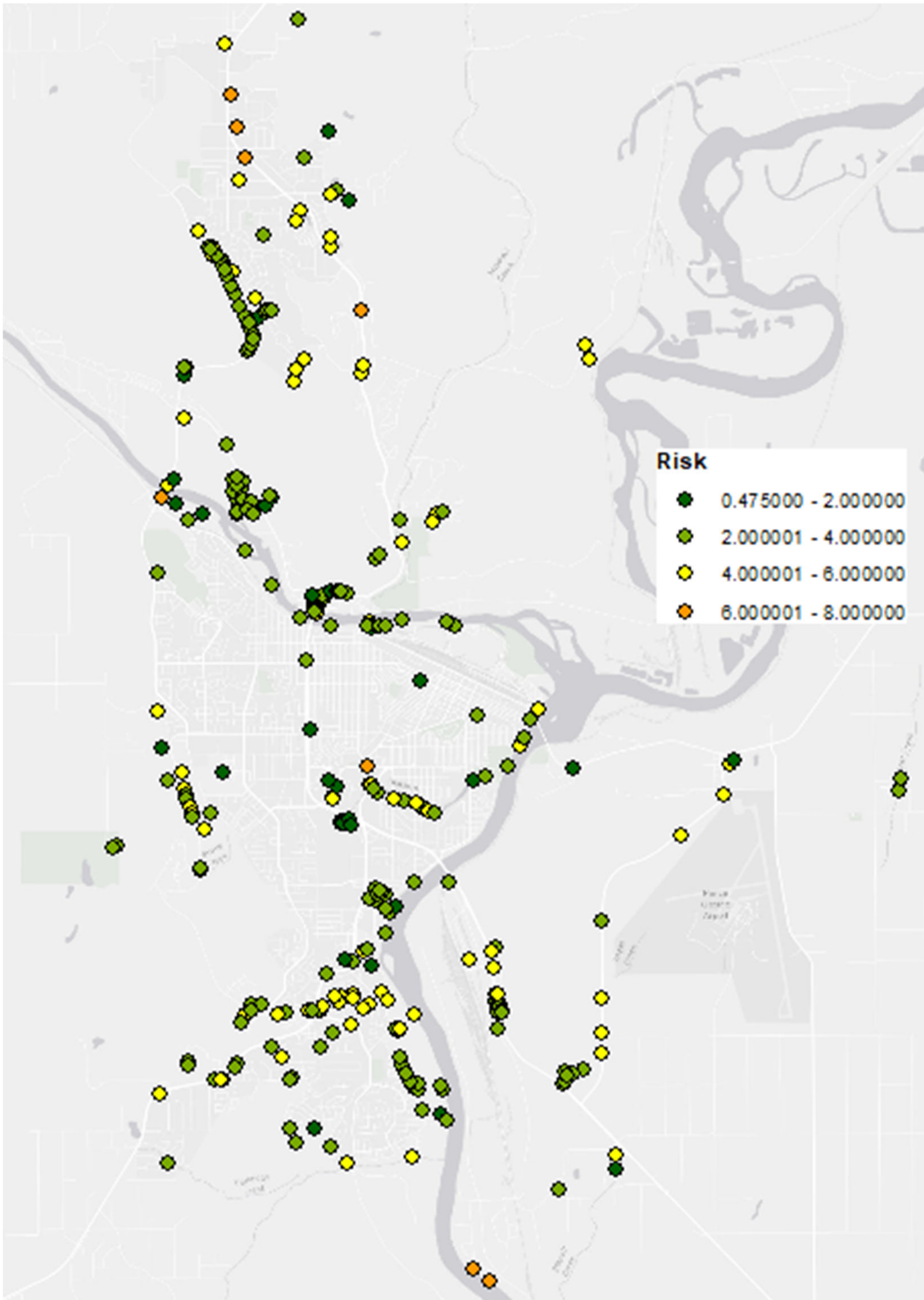

Figure 17 Risk Score for Discharge Points

7. Condition Assessment

7.1 Overview

Condition assessment is one of the primary steps utilized prior to performing maintenance, rehabilitation, or replacement activities. In sewers, the most commonly used inspection technique is the Closed-Circuit Television (CCTV). The results from this inspection are used to evaluate the internal condition of the pipeline to determine the structural and operational condition.

The North American Sewer Service Companies (NASSCO) developed the Pipeline Assessment Certification Program (PACP) standard, which is currently utilized by municipalities across Canada and the United States (US). In PACP, each defect is assigned a code, where each defect code has a specific condition grade ranging from 1 to 5.

Similarly, NASSCO has developed a standard to evaluate vertical sewer assets including manholes and catch basin. The Manhole Assessment Certification Program (MACP) has a similar methodology and defect categorization for evaluation. These assets are inspected using panoramic camera to generate unfolded 360-degree image of the inspection from rim to channel/bench, where applicable.

The condition grades are assigned for two group defect categories, the structural and operational (service). The grades and definitions are listed below (Table 24).

Table 24 PACP Condition Grades

Grade	Definition
5	Most significant defect grade
4	Significant defect grade
3	Moderate defect grade
2	Minor to moderate defect grade
1	Minor defect grade

Assigning defect grades are dependent on the quality of the defect coding and inspection. While PACP has a Pipe Rating Index formula (weighted average formula) to grade the inspected segments, many cities and municipalities are driven by the maximum score from each defect group.

The interpretation of the grade computed based on the observed defects is as follows (Table 25):

Table 25 Inspected Segment Grade Interpretation

Grade	Definition
5	Immediate attention needed
4	Poor; will be become grade 5 in near future
3	Fair; moderate defects
2	Good; the pipe has not begun to deteriorate
1	Excellent; no to minor defects

These grades are most commonly translated into the Likelihood of Failure (LoF). When a pipe's LoF is combined with its CoF to generate overall risk, the City can use the information to prioritize subsequent inspections, repairs, or renewal.

Establishing a program that would annually inspect pipelines and manholes/catch basins will aid in accomplishing three main objectives. The first relates to structural condition deficiencies and forms the basis for updating overall system upgrading requirements (short- and long-term). The second identifies re-inspection frequencies associated with sewer infrastructure that has no short-term upgrading requirements. The third is to identify portions of the infrastructure that have specialized cleaning requirements such as intruding lateral removal, root growth that cannot be removed by non-mechanical sewer cleaning equipment, etc.

7.2 Condition Assessment Tools

7.2.1 Closed Circuit Television (CCTV)

CCTV is a method used to record videos for underground pipelines. It is used to inspect pipelines that can be too small or dangerous for humans to enter. In their early stages, CCTV cameras were winched between two manholes to record the condition of the pipeline. Over time, CCTV cameras were mounted on top of a crawler or a float. Operators were able to control the movement of the robot, as well as that of the camera, from far distances. The camera records the inner-surface condition of the pipeline and supplies information above the flow line. Later, experts use the recorded video to interpret, comment on, and make conclusions about the pipeline's condition based on a standard (e.g. PACP). Although some sophisticated technologies have been introduced for sewer inspection, CCTV is still the most commonly utilized technique in North America.

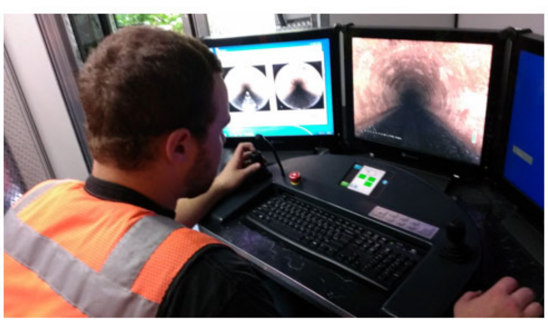

Figure 18 CCTV Inspection

7.2.2 Zoom-in Camera

Zoom-in cameras provide still imagery and/or recorded video. Unlike the conventional CCTV camera, a zoom camera remains stationary and records the data where it is installed. The camera is lowered to the manhole while it is mounted on a pole, crane, truck, or tripod. Then it can record the data by zooming in the camera. The distance coverage along the pipeline is highly dependent on the capability of the camera and the internal condition of the pipe. Generally, a zoom-in camera can provide information between 30 to 50 m from the location where it is installed (this is dependent on the actual internal environment of the asset being assessed).

7.2.3 Laser Profiler

The laser profiler is a technology that is able to detect and quantify the changes in the vertical and horizontal shape of pipelines, known as the deformation of a pipeline. It can also feed the operators with a profile of the interior pipeline wall.

There are two types of laser profilers: a two-dimensional (2-D) laser profiler and a three-dimensional (3-D) laser profiler (see Figure 19). The 2-D laser profiler technology is based on a ring of light, generated from a laser, around the wall of the pipeline. A camera, usually a CCTV camera, which is attached on the same crawler, detects the ring of light, and stores the laser image for further analysis. Using CCTV alone, the operator may not observe any deflection along the pipeline while analyzing the recorded video.

The 3-D laser uses laser point beams, which have a receiver and a two-way transmitter. The output of the inspection is a 3-D plot of X, Y, and Z coordinates of the pipeline (point cloud). The point cloud data captures the full pipeline segment and the true cross section of the pipeline, unlike the 2-D laser profiler, which utilizes single-data acquisition. The extracted 3-D representation of the pipe shows its real cross section regardless of the divergence angle from the centerline of the pipeline.

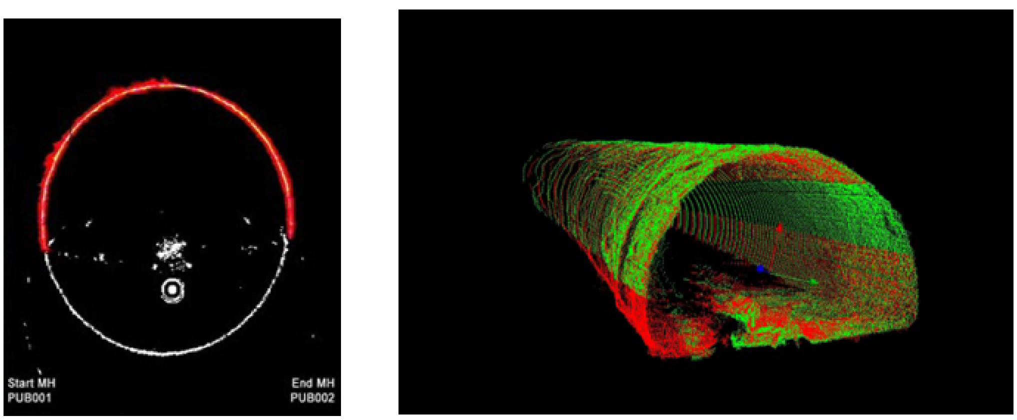

Figure 19 2D and 3D Laser Profiler Outputs (acquired from Redzone Robotics and AET Robotics)

7.2.4 Sonar

Sonar is an application of acoustical technologies. It is based on the implementation of sound energy where the magnitude of the frequency is higher than humans can hear. Sound beams travel through the inspected material. The waves reflect whenever there is a change in the density of material. Some of the reflected waves pass through the new medium, whereas others return to the surface. The image produced by the sonar sensor is affected by the selection of the acoustic frequency. When the acoustic frequency increases, the penetrating power decreases. The sonar sensor is mainly utilized below the flow line to measure the volume of any settled deposits.

7.2.5 Multi Sensor Robots

A robot with multiple sensors can be used in a single inspection to obtain numerical information, where applicable.

SewerVue Multi Sensor

SewerVue includes multiple sensors including CCTV, laser, and pipe penetrating radar (PPR) (see Figure 20). The latter applies the theory of a radar system, where an antenna produces high-frequency radio waves. PPR is applied in-pipe, so the signal will penetrate the pipe's wall to the surrounding soil. The system can operate using two or three antennas that are able to detect several frequencies to evaluate the surroundings and the structure of the pipe itself. The SewerVUE robot, which applies the concept of PPR, can provide information about the wall's thickness, rebar's alignment, cover, and the condition of the pipe's liners for nonferrous pipe materials. The robot is also equipped with CCTV and LIDAR technologies.

Figure 20 SewerVue Multi-Sensor

Redzone Multi Sensor

There are a variety of sensors deployed by Redzone Robotics to study the condition of sewers (see Figure 21) by deploying a variety of technologies and sensors. The selection of a robot is dependent on the size, technology used and access requirements. In general, the majority of the robots host multiple sensors including laser, sonar, and CCTV.

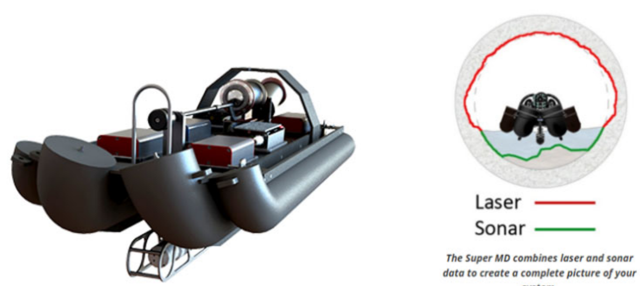

Figure 21 Super MD by Redzone Robotics

Typically, these multi-sensor inspections are used to inspect large pipelines, culverts, or any critical linear asset to maximize the data collection which will improve engineers' informed decisions.

7.2.6 Manhole Panoramic Inspection

Vertical sewer assets, such as catch basins and manholes, are usually inspected using Panoramic cameras to produce unfolded images to help in assessing the asset. The camera is carried by a tripod and lowered through the manhole to record the internal condition of the asset. Some advanced cameras can also develop a 3D reconstructed point cloud interactive model to increase the level of information for the inspected asset.

Figure 22 Manhole Panoramic Inspection Results

7.3 Condition Assessment Frequency

Generally, the frequency of inspecting sewers ranges between 1 to 30 years. The frequency is typically driven by three main parameters which are the vulnerability, condition, and its consequence of failure. Pipelines in poor condition with a moderate or high consequence of failure could be prioritized for inspection in the next 1 to 3 years.

While prioritizing sewer inspections is usually dependent on previous CCTV data, the City could initially rely on a reliable desktop model to infer the probable condition of the assets. The desktop model can be developed using existing asset data (age, material, etc.). This was done as part of the risk model described in the previous section.

7.4 Approximate Cost Estimate

The cost of inspections differs based on the technology and whether the City conducts the inspection themselves or hires a contractor. Table 26 shows high level cost estimates of camera inspection, excluding an engineering firm analysis of the inspections. Multi sensor applications costs vary significantly depending on the technology and size of the asset.

Table 26 Condition Assessment Costs (CCTV and Panoramic)

Tool	Rate
Pipeline CCTV Inspection	$5 to $15/m
Manhole Panoramic Inspection	$200 to $250/manhole

7.5 Prince George's Condition Assessment Program

Storm Sewers

The City does not have a comprehensive storm sewer inspection program. The City typically only inspects its storm sewers by CCTV as part of construction or to address urgent issues. However, it is recommended that the City inspect approximately 5% of its storm sewer system per year. That would result in each sewer being inspected, on average, every 20 years, which is common good practice. The City has recently purchased a CCTV camera (a Rausch with a lateral launch camera) and software (ITPipes) that can integrate with the City's computerized maintenance management system, Cityworks. This should assist with implementing a condition inspection program for storm sewers.

When a sewer is inspected will depend on its condition and criticality. The City will need to inspect the entire system once to establish a baseline condition and help establish future inspection priorities. In the absence of existing condition information, the City can determine CCTV priorities based on risk scores determined in the previous section. It would not be efficient to inspect sewers in exact order of risk as that would involve jumping from one area of the City to another. But the City could be divided into zones where higher risk pipes are grouped together.

In the short-term, the City could use the risk model scores to prioritize and "trigger" sewer inspection. In the future, once the system has been inspected by CCTV, the City can use PACP scores for prioritizing and triggering inspections.

In order to complete a high-level cost-benefit review of a planned maintenance approach we have leveraged historical data from the City. NWWBI data shows that the City experienced one emergency storm sewer repair for every 100 km of storm sewer in 2019. As the City's system ages, this number will likely increase. The City has had some recent storm sewer failures: the Victoria Street sinkhole that cost $38,000 to repair and the Winnipeg Street sinkhole that cost over $1 million to repair. At an estimated cost of $10 per metre, it would cost $100,000 per 100 km to CCTV the system. Note that inspections are typically done on a 20-year cycle, on average. So, the annualized cost of sewer inspection is $5,000 per 100 km. CCTV inspections would allow the City to identify and address issues in a planned manner (see following section on asset longevity) which is less costly than making emergency repairs once a sinkhole has formed.

In summary, our high-level estimate based on current benchmarking data predicts that spending $5,000 per 100 km on preventative maintenance would avoid many of the economic, social, and environmental costs associated with emergency repairs. There are other advantages to a CCTV program which includes better planning of renewal needs and being able to extend the life of the assets through less costly interventions that can be applied to an asset before it has completely deteriorated and can only be entirely replaced.

Culverts

There are typically three types of culvert inspections:

- External visual inspection to look for erosion, blockages, headwall deterioration etc.;
- Walk through internal inspection of large culverts, and
- CCTV internal inspection.

Currently the City of Prince George uses summer students to do external cross culvert inspections. Critical culverts should be inspected annually. As with storm sewers the prioritization and "triggers" for culvert inspection can be refined once the City has completed initial inspections of all its culverts. Also, it would not be efficient to inspect culverts in exact order of risk as that would involve jumping from one area of the City to another. But the City could be divided into zones where higher risk culverts are grouped together.

Pump Stations

Short staffing in the plant operations staff has reduced regular visual inspections of pump stations from weekly to monthly. More frequent inspections are conducted when possible. The pump station near Hudson Bay Wetland has the highest risk and should be the first pump station to receive additional inspections, when possible.

The City last completed a condition assessment of all its pump stations in 2018. Regular condition assessments (e.g. every 5 years) are recommended. More frequent condition assessments can be triggered by issues found during the City's monthly inspections.

Ditches

Ditches need to be inspected and cleaned periodically, including vegetation control and ditching. Ditch inspections can be done in conjunction with other work such as culvert inspection or street sweeping. If the ditch inspection is done in conjunction with another activity then the prioritization of the inspection will likely be determined by that other activity. However, if ditch inspection is done on its own then the "open channel" risk scoring can be used to identify priorities. As previously mentioned, it would not be efficient to inspect ditches in exact order of risk as that would involve jumping from one area of the City to another. But the City could be divided into zones where higher risk ditches are grouped together.

Ponds

Ponds need to be inspected for blockages, sediment accumulation, debris, erosion, vegetation (including invasive species), safety, and deterioration of hard assets such as headwalls and fences. Many of the inspections will be regular (i.e. annual inspection after spring melt) but some more detailed inspections may be triggered by sediment accumulation or asset failure. The City currently visits its stormwater ponds annually and does more thorough assessments periodically. The last condition assessment of the ponds was completed in 2019. It is recommended to complete condition assessments every 5 years.

Catch Basins

Catch basins can have three types of inspections:

- Structural condition assessment to determine if and when repairs need to be done;
- Grate inspection to determine if there are blockages that need to be addressed to allow full flow; and
- Sump inspection to determine the amount of accumulated sediment and when it needs to be cleaned.

Some municipalities inspect and clean their catch basin sumps annually in the spring to remove accumulated road sand and other debris. Grate inspections will typically happen if a problem has occurred or if there is a known "problem" catch basin that needs to be inspected prior to storms or snow melt. Structural condition assessments which happen less frequently could be conducted based on age and/or risk.

Outfalls

Many municipalities try to inspect their outfalls to creeks and other water bodies annually for blockages, erosion and evidence of spills or contamination. The City could prioritize the inspection of its outfalls based on the risk score given to "discharge points".

Creeks

Some municipalities try to inspect their creeks through an annual "walking of the creek", to look for issues such as erosion. Flagging found issues such as erosion would help the City determine priorities, along with fish classification, for inspections. The biggest challenge with prioritizing creek stretches for inspection is that the creeks in the City's GIS are broken down into large segments (e.g. > 100 m) so shorter sections of creek cannot be easily modeled. As mentioned above under "outfalls", the City should be inspecting outfall locations within creeks.

8. Asset Longevity

There are different technological options for extending the life of existing assets (e.g. cathodic protection) but there are also other options such as implementing optimal maintenance practices, rehabilitation interventions and a risk-based asset management approach to extend asset longevity.

At the asset management level, failure risk reduction is achieved by either reducing the probability of failure or the consequence of failure (or both). This is most often achieved by a capital or maintenance expenditure that must be compared with the savings associated with risk reduction. Treatment options and associated costs to reduce asset failure risk must consider the type of asset and local conditions. The selection of an appropriate treatment can either be a manual process or can be automated through a computerized Optimized Decision Making (ODM) process which the City currently utilizes, called Powerplan.

Treatments can be selected to address Performance Deficiencies and Operational Deficiencies. These categories are further described as follows.

8.1 Performance Deficiencies

The rehabilitation of sewer infrastructure to address the risk exposure associated with performance deficiencies can be placed into two broad categories:

- Renovation; and
- Replacement.

Renovation can be defined as methods in which the sewer is improved by incorporating the original sewer host pipe. The best example of this is the use of cured-in-place pipe (CIPP) technology for spot repairs or full segment relining. Renovation technologies utilize the existing sewer and involve minimal to no excavation. The City utilizes this method of renovation regularly for its sanitary sewers.

Replacement can be defined as methods by which the pipe is replaced entirely from manhole-to-manhole or in spot locations. This is typically done by utilizing either minimal or traditional excavation techniques.

The three aspects of performance deficiencies that must be considered include:

- Structural Integrity;
- Materials Deterioration (pipe fabric decay by corrosion, abrasion, etc.); and
- Hydraulic Capacity.

A hydraulic model study is typically required to identify hydraulic capacity performance issues, while a condition assessment is required to identify structural integrity and material deterioration performance issues. All performance (capacity) deficiencies can be rectified by replacement methods. Structural integrity and materials degradation may be rectified by renovation methods; however, the greater the deficiency, the less cost effective the renovation technique may be. The evaluation of replacement versus renovation must be made on a case-by-case basis.

Renovation of sewer infrastructure implies rehabilitation by trenchless methods that utilize the existing sewer as part of the process. Several treatment options to address structural or material deficiencies are outlined as follows:

- Pure Trenchless Categories
    - Stabilization (grouting technologies)

- Full Segment Renovation (lining)
- Trenchless Point Repair

- Minimum Excavation / Replacement Categories
    - External Point Repair
    - Full Segment Renewal
    - Augmented Renovation (lining with external repair)

8.1.1 Stabilization

These technologies stabilize the structure and arrest the deterioration process or specific defect but do not structurally enhance the existing sewer structure. Stabilization repairs for small diameter domestic sewers can employ a variety of chemical grouts (e.g. acrylamide, polyurethane) injected with remote sealing packer technology. Other means of stabilization could occur from personnel-accessible locations in larger diameter sewers (i.e. from a nearby manhole) to enable a localized internal repair of the pipe by manual application. Minor defects such as infiltration or cracking within the sewer that are typically limited to 5% to 10% of the total segment length may be repaired using stabilization methods such as spot patching, pressure grouting, or chemical grouting. While stabilization as a rehabilitation technique is typically a very low capital cost with minimal surface disruption, it usually has a very short effective design life. Chemical grouting is generally used in North America to address infiltration related deficiencies for pipes that are not personnel-accessible (less than 600mm diameter) or to prepare pipes for relining in areas with excessive infiltration. Other traditional stabilization methods such as localized patching or the re-pointing of bricks, require personnel entry and are therefore limited to larger diameter sewers (greater than 1,200mm), or to personnel-accessible sewers (close to a manhole, 600mm to 900mm diameter).

8.1.2 Full Segment Renovation

Full segment renovation can be used to address defects distributed throughout the segment or to address several defect clusters. Full segment renovation is effective in addressing material degradation and pipe wall defects including cracks, fractures, spalling, or holes (where there is no voiding of the backfill). In diameters greater than 1200mm and where deformation is excessive (greater than 10% loss of cross section), the constructability and cost effectiveness should be reviewed on a case-by-case basis. Work for smaller diameter pipe is typically carried out by cured-in-place pipe (CIPP) methods. Larger diameter pipe may warrant review of alternate technologies such as segmental liners or short pipe relining.

8.1.3 Trenchless Point Repair

Trenchless Point Repair (TPR) provides an effective means of addressing localized pipe defects where there is minimal loss of structural integrity. A TPR is normally assigned to pipe wall defects including cracks, fractures, spalling, or holes (where there is no voiding of the backfill). The benefit of using a TPR is that there is minimal surface disruption and the sewer can be repaired in a fraction of the time of traditional excavation-based repair methods. Key limitations include diameter (less than 1200mm), defect length (less than 10m), and deformation (less than 10% loss of cross section). Typically, the use of point repair technologies is limited to 3 or 4 localized instances or 20% to 30% of total length in a given manhole-to-manhole segment and the complete absence of defects in between the repair areas.

8.1.4 External Point Repair

External Point Repair (EPR) is used to address severe localized defects where trenchless point repairs are not technically feasible to be constructed. As with trenchless point repairs, typically the use of point repair technologies is limited to 3 or 4 instances or 30% to 40% of total length in a given manhole-to-manhole segment and the complete absence of defects in between the repair areas.

8.1.5 Full Segment Renewal

Full Segment Renewal is used to address severe defects distributed throughout the segment length or to address several defect clusters. The nature of the defects renders relining technologies either technically infeasible or of an unacceptable construction risk.

Renewal involves the replacement of the existing sewer and this can be accomplished using minimum excavation (pipe bursting, tunnelling, directional drilling, etc.) or traditional open-cut installation techniques. The following figure identifies an example performance deficiency in which a Full Segment Renewal treatment would be appropriate.

8.1.6 Augmented Full Segment Renovation

In some cases, a combination of the previous treatments would provide the most suitable solution. The most common example would be when an EPR is required to rectify a single severe defect (i.e. hole with a void, collapsed section, or obstruction in the main) that prevents Full Segment Renovation. Once the EPR is complete, the trenchless work (full or point) proceeds. Similarly, the use of a stabilization treatment can be used to prepare a pipe for relining.

8.1.7 Cost Estimates

High level cost estimates for different treatment options are provided in the following table.

Table 27 Cost Estimates for Sewer Treatment Options

Intervention	From (mm)	To (mm)	Unit Cost	Unit	Mobilization
EPR	0	524	$2,000	Each	$6,500
EPR	525	99,999	$2,500	Each	$7,500
Replace	0	374	$800	m	
Replace	375	599	$850	m	
Replace	600	1,049	$70	m	
Replace	1,050	1,499	$1,300	m	
Replace	1,500	1,800	$1,800	m	
Replace	>1,800		$2,800	m	
TPR	0	374	$1,125	Each	$2,500
TRP	375	599	$1,550	Each	$3,000
TPR	600	9,999	$2,000	Each	$3,500
Stabilize	0	749	$1,000	Each	$1,500
Stabilize	750	9,999	$2,000	Each	$3,000
Line	0	449	$515	m	
Line	450	749	$775	m	
Line	750	899	$915	m	
Line	900	1,349	$1,400	m	
Line	1,400	9,999	$2,000	m	

EPR = External Point Repair
TPR = Trenchless Point Repair

8.2 Operational Deficiencies

Operational defects such as deposits and roots can reduce the operational performance of sewers and can impact the ability to assess structural integrity, particularly in cases where operational defects prevent a complete CCTV inspection. It may be necessary to assign several treatments in order to restore operational performance and to facilitate a complete inspection. Several treatment options can be utilized to restore operational performance, as identified through the Condition Assessment process, and are outlined as follows:

- **Clean and Re-inspect** - In the event that a complete inspection is not obtained or that 20% of the pipe cross-section is full of deposits, the sewer needs to be cleaned. Cleaning the sewer should facilitate the ability to obtain a complete CCTV inspection.
- **Obstruction Removal** - Intruding obstructions can reduce the cross-sectional area of the sewer. Obstructions should be removed if there is a cross-sectional loss of 20% or greater or when it prevents a complete CCTV inspection.
- **Root Removal** - Used to address root masses in the pipe. Root removal is required if the cross-sectional loss of the sewer is 20% or greater or when it prevents a complete CCTV inspection.
- **Solid Debris Removal** - Used to address heavy encrustation, calcified debris, asphalt, or concrete deposits in the pipe. Solid debris removal is required to restore the operational performance if there is a cross-sectional loss of 20% or greater or when it prevents a complete CCTV inspection.

8.3 Relining Storm Sewers and Environmental Considerations

Typically, the main environmental concern of lining is that it is an outdoor plastic manufacturing process (installing and curing), which is a less controlled environment when compared to regular manufacturing that could happen in a factory. Further information about environmental considerations with the relining of storm sewers are outlined in Section 4.7.

8.4 City of Prince George Considerations

The City is already taking important steps that help asset longevity (e.g. asset management, maintenance management, relining, spot repairs, sediment removal etc.).

Old corrugated steel pipe (CSP) from amalgamated areas do not have asphalt coating and are showing signs of deterioration, whereas more recent installations of CSP have asphalt coating. The City could look at relining some of the older CSP, especially the deep culverts to extend their life. Note that some of these pipes may be too deteriorated or have hydraulic capacity issues that will necessitate full segment renewal.

The most important steps that the City can take to extend the longevity of its stormwater assets are:

- Change the list of allowable materials that can be used in new construction, particularly in areas with corrosive soils. Some cities no longer allow CSP to be used for sewers or cross culverts. Over the long run CSP can be more costly than other materials such as concrete because it has a shorter life span.
- Inspect the entire stormwater system to identify cost-effective rehabilitation opportunities before the assets become too deteriorated and the more costly treatment of full renewal is the only option.

Choosing the right treatment option for a given asset will also depend on the consequence of failure. Some assets, such as rural residential driveway culverts that are not a fish bearing channel can be allowed to run to failure. However, allowing the failure of a fish-bearing culvert or a large sewer under an arterial roadway would be costly from an economic, social, and environmental perspective. With high risk assets, the City can justify the cost of inspection, preventative maintenance, and rehabilitation such as stabilization or relining.

Appendix A : LID Interview Transcripts

AECOM Canada Ltd.
410-250 York St.
London, ON, N6A 6K2
Canada

T: 1-519-673-0510
www.aecom.com

Project Name:	Prince George ISMP	Date of Meeting:	December 14th, 2021
		Time:	11:00 – 12:00
		Project #:	60628231
Attendees:	Bill Trenouth Ph.D, P.Eng., CAN-CISEC – AECOM Water Resources Engineering Aaron Ward – City of Thunder Bay Engineering Dept.	Location:	Conference Call
		Prepared By:	Nick Szendrey
Regrets:			
Regarding:	LID implementation for the City of Prince George / Thunder Bay Stormwater Plan		

Minutes of Meeting

Discussion

Thunder Bay stormwater plan

- Done by EOR.
- Key thing: push for Green Infrastructure (GI)
- From a Climate Change (CC) resiliency perspective, T-Bay notes that this is their “buffer” against CC.

LID:

- Identified 550 location on public lands where LID could go.
- A table in Volume 2 of their SWM MP – identifies locations, approx. size, etc.
- The above table has been key to in leveraging third-party funds to build their projects to date.
- They have an eight-year program (500K per year) for the next 5 years to do LID with the federal government
- T-Bay is fiscally conservative as well, but this let’s them leverage external funds.
- Accessed over 5 million dollars to date, including funding up to 8 years from now as well
- 20 facilities have been built since the SWM MP was approved.
- Because their LID is mapped out, this helps them capitalize on opportunities when they do construction.
- Winter sand: a key consideration. **Need pre-treatment**…still working on how to do this
- OGS is useful for sand, floatables, etc.

- Thunder Bay has three divisions involved in LID maintenance: roads (culverts, etc.), environment (CBs and pipes), parks (landscaping)
- Cleaning of rock inlets needs to be contracted out, since no one wants to do those things
- Winter: as the snowbank melt, they leave behind a ton of junk.
- Two sites sampled: by a grad student
- Lakehead University: Brant Muir. Monitored three LID sites around T-Bay. Check online!
- 90% are bioretention/biofiltration – very similar
- Infiltration trenches are the third type
- 7-8-foot frost depth. Sub drains within the frost zone. No problems
- Keep the features offline. Provide full-time construction inspection. Understand what your material suppliers are capable of. You need to start with a washed sand.
- Public buy-in: hit the public repeatedly with the same messaging.
- Need consistent, simple messaging. “Keep it Superior”, is the example T.B uses. Public approval for this is key.
- People understand the word “flooding”, but they don’t understand “water quality”.
- T-Bay has their own “Residential Rain Garden Program”, where they cover 100% of the cost up to $500 to build rain gardens on private property.
- 1.5-2-hour webinar is mandatory. This is common among municipalities with a subsidiary program.
- They have evening tours of LID features – private rain gardens are more popular than the municipal ones

Post-meeting Notes

Thunder Bay has created a progressive approach towards LID involving:

1. Identifying a detailed list of potential locations for retrofit/greenfield opportunities.
2. This led to the ability to leverage third party funds to begin working with LID.

This seems to be a common approach for fiscally conservative municipalities wishing to be progressive. Mapping out LID locations has allowed them to capitalize.

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T: 1-519-673-0510
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Date: December 22, 2020

Time: 9:30 – 10:30

Project #: 60628231

Location: Conference Call

Attendees: Bill Trenouth Ph.D, P.Eng., CAN-CISEC – AECOM Water Resources Engineering

Darlene Conway – Senior Engineer, SWM Projects Ottawa
Karine Bertrand - P.Eng,. Project Engineer, Stormwater Rehabilitation
Laurent Jolliet – City of Ottawa Engineering Dept.

Prepared By: Nick Szendrey

Regrets:

Regarding: LID implementation for the City of Prince George / City of Ottawa SWM / LID in Ottawa

Minutes of Meeting

<u>Quick background/overview – Darlene</u>

Why is Ottawa undertaking SMW retrofits/and LID program?
Focus on ROW bioretention, although the City is moving into other LID types
Most of Ottawa's DT core has NO water quality/quantity control
City has planned ROW retrofits for many areas over the next 20 years, based on reconstructions, etc.

*Ottawa took the approach of discussing several examples of recent LID implementation – highlighting success/failures/challenges to aid Prince George on their journey.

Sunnyside Avenue– Karine
Constructed in 2015
Monitoring wells in the features; water typically draws down in ~10 hours
City has lots of tight soils, so what Ottawa has capitalized on are areas with sandy soils, or soils where they can do infiltration
Project involved bump outs (traffic calming). 0.5 ha area
Native soil infiltration rate is 43mm/h
Ottawa plans on replicating the bump outs in future projects
Biggest challenge city has had is getting water into the LID (inlet design). Therefore, bump outs have been great for getting the water into the LID.
Features include secondary (side) inlet for backup. They don't work super-well.

Other lessons learned: grading of bioretention bump outs, etc. had to be redone to comply with AODA requirements. Plants had to be removed and work had to be redone, which was a problem.
Next lesson: bump outs changed the turning radius. In the winter, the snow made it hard to see the turn. This led to damage to the curb and the garden. Concrete was poured over the biomedia at the affected corner to protect the LID feature.
Side inlets haven't been working (due to design). Careful design consideration is key, especially for inlets; this has been a recurring topic across several interviews.
Primary inlet: "We have not found the optimal design". The river stone inlets are cleaned twice per year (spring and summer), but they are still silting up and leading to bypass. Next attempt is to lower the river stone inlets, so water can pass over if things are silted up.
Overflow CB's need to be set low enough that a plough won't grab them

Performance: 70% runoff volume reduction, but this has decreased recently (possibly from siltation at the inlets leading to bypass).
Bypass has been noticed through the beehive riser rings
Average drawdown time is 6.5 hours, design drawdown time is 48 hours

Winter monitoring was completed – facilities worked in the winter during melt events. Drawdown still observed – way below the 48 hours drawdown time. In general, the facility still works in the winter.

Plantings – lots of trial and error. Half of the plants trialed failed in the bioretention facilities. For Ottawa, tall grasses have worked best ((Heavy Metal Switch Grass). Native drought-tolerant species have worked best. They are lower maintenance as well. Canada anemone. Water every week for first 1-2 years during the dry season. Coneflowers did not work.

More Lessons:
Inlet maintenance underestimated
Gardening volunteers have been awesome for "adopting" some of the gardens and doing weeding, cutting back plants, and doing light maintenance. If Prince George can do the same, they should collaborate with any naturalist, pollinator or related club. This is done through the City's "adopt a road" or "adopt a park" program. Historically, these revolved around picking up litter, for example. It has taken some work to evolve this to capture gardening work using community members.

Detailed construction specs – more details needed. There is a learning curve for everyone – not just the city, but the consultants and contractors too. Even for small things like sub-drain placement, contractors need hand holding
City comment: no issues with operation or challenges with freezing for the facility monitored.
Frost depth is recognized to be 1.8 m (minimum depth of cover for water mains)

<u>Stewart Street – Laurent</u>

Located in urban core of City.

Context: 2.2m of extra asphalt width. Based on this, they narrowed the road, implemented GI and built a bike lane. Soils were good – sandy ("Sandy Hills" is name of neighborhood). CDA = 2.4 ha

Narrowed the ROW width 2.2 m (0.9m of one side of the road, 1.3m on the other). Continuous subdrain on either side of the road.

Lesson learned: verify the CDA with DEM, site visit and Google Streetview.
I:P ratio up to 20:1.
Problem: we did not have enough width to work within the ROW. When it is too narrow, we do not have enough ponding depth not enough freeboard. Also, for a small feature people may not notice it and we have had people drive through them
For Stewart street, they used a corrugated interior pipe → big problem for fluching. Not maintainabel. Use 30-45 degree bends at access points.
Underdrain invert elevations hsould be surveyed – as built survey required
Overflows. Need to be 150 – 300mm above base of filter bed
Plastgic underdrains → not good. Use metal made traffic rated CB overflows.
Curb inlet – clogs with debrsi (leaves). These inlet types do not allow for enough depression.

Lessons:
specify the planting window
Use tall grass – help stop people from stepping through the gardens
Use plants that are shade tolerant when planting beneath trees
Avoid garden edging
Check existing garbage pickup practices – do people throw bags in the boulevard?
Grading – always a struggle. When you are tight for space, it is even harder. (dirt on sidewalks, etc.)
"When it is flat, it is hard"
Do private property owners blow their leaves? If so, they will end up in your boulevard bioretention/gardens. This will fill your garden and block your inlets, etc. They will also smother your vegetation. When there are lots of trees around, expect to do fall maintenance.
Landscape contractors (private property) drove through the facility and did some damage.
Detailed as-built required.
LID needs to consider street layout/topology (Peel streetscape toolbox, City of Toronto LID design guidelines.

Biomedia:
Consultants are learning. Finding good contractors is also a challenge. We need to be extra clear on the drawings to make sure there is no confusion. This includes the biomedia. Contractors will still get it wrong – P index, etc. Need to do a hand-mix first, followed by trial run, etc.

CB details are also a challenge.

Coordination between departments = we are still working out some of the details. They ARE SWM facilities, so responsibility rests with SWM operations.

Other projects (high GW table; monitoring pending)

- Chapel Hill Park 'n Ride – Darlene

Surface bioretention: the focus is more challenging conditions: tight soils (5 mm/h)
Adjacent to a highly eroded creek (Mud Creek, no SWM controls)
GW table is very high as well. "If we can't infiltrate, we will filter and provide peak flow control"

LID implementation is not just driven by MECP RVCT, but also by subwatershed studies and response to developer comments that “you can’t do anything because of XYZ challenges”.

Hemmingwood Way – Laurent

To facilitate implementation, the City has developed a hydrology guideline.

Another bioretention project. 14.5m boulevard, but not a very busy street
Located in SW quadrant of City
6 bioretention cells (bump outs) in the suburban core of the City

Site also had very high groundwater levels (seasonally they are above the bottom of the facility).

Pre-drilled holes in the CBs were again a problem on this street (like Stewart St.)

City has guidelines for “challenging” areas – area with clay, high GW, etc. it is still in draft, but has been put out to the development industry for comment

City is working on a screening tool (GIS-based tool) to make sure that they take advantage of road retrofit projects and select the best dozen or so candidates for retrofit implementation.

Something in the infrastructure master plan (online)? Darlene will check with the hydro g guidelines.
City also looking at

- **Post-meeting Notes**
  - Ottawa provided several slideshows regarding this information to AECOM, to coincide with this interview.

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Project Name:	Prince George ISMP	Date of Meeting:	January 6th, 2021
		Time:	11:00 – 11:20
		Project #:	60628231
Attendees:	Nick Szendrey, B.Eng. - AECOM Water Resources EIT	Location:	Conference Call
	Alan Mangory, Senior Drainage Engineer, City of Edmonton		
		Prepared By:	Nick Szendrey
Regrets:			
Regarding:	LID implementation in the City of Edmonton		

Minutes of Meeting

Discussion: - Not yet majorly promoting LID in Edmonton. The city is very behind in comparison to surroundings like Calgary. - Some experience/success with bioswales in cold climate. This is the LID Alan has seen achieved successfully. - Edmonton has begun to slowly promote bioretention in areas of playgrounds, or areas where flooding is common.
▪ **Closing Remarks**
▪ **Post-meeting Notes** Alan emphasized finding a way to work with Calgary, or a way to achieve their guidance. Calgary has shown to be the most productive and progressive with LID in Alberta. This is where Prince George can find the most useful and relevant information to aid in their LID journey.

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Project Name: Prince George ISMP

Date of Meeting: January 6th, 2021
Time: 12:00 – 12:45
Project #: 60628231
Location: Conference Call

Attendees: Nick Szendrey, B.Eng. - AECOM Water Resources EIT

Paul Javor, MSc, P.Eng., City of Sudbury

Prepared By: Nick Szendrey

Regrets:

Regarding: LID implementation in the City of Sudbury / General LID information

Minutes of Meeting

Introduction

- LID in Sudbury is developing. Current problem – bedrock eliminates infiltration
- Blasting is commonly used to deal with any development
- Areas without bedrock have very swampy conditions so another problem for infiltration. These issues combine to make LID difficult.

Winter Control Practices and Difficulties Associated

- Paul tries to talk about winter control practices with everyone
    - Everyone uses salt they use sand they use sand on 80% of roads (5% salt,95% sand mix). The quantity of sand used is extremely large.
- Bio-soils with collection pipes, seeing some attention but high standards of quality
- No water balance, it is all runs off in Sudbury; high water table
- They look at biofiltration – swales with perforated pipes underneath
- Problem is sand clogging; a need for pre-treatment is extreme.
- Attempts that haven't worked out:
        - No attempts, some approval; everyone fears the sand – even the highly progressive LID organizations.
- Some subdivisions with 100% infiltration, no outlet, very specific geography. varying geography is a massive challenge in the city, and a big consideration when thinking LID.

In Prince George, Similar winter practices exist; using sand, quite as much. Still, Sudbury could be a good comparable location.

Why sand? Sand is cheaper and prevents harming aquatic life, they have long winters and they can have a snow packed road

- Most practitioners from southern Ontario and no one knows the impact of so much sand. He is really stressing how detrimental it is. The climate is not the problem. This is good information, as Sudbury uses a significant greater quantity of sand in road treatment compared to any other municipality in this study. Prince George should take this advice into key consideration, especially if they wish to implement LID on sand routes. Focus on pre-treatment.

- OGS very useful in Sudbury to take out the particles - gritty road sand.
- Only LID concepts with plans approved in Sudbury. No major progress down this road.

Slow development:

- 400 lot subdivisions with 20-40 builds a year – (Sudbury development rate)
- Tough to find people dealing with road sand b/c they are usually not progressive municipalities.

Closing Remarks

- Paul builds large OGS (biggest there are) for retrofits on Ramsy lake, etc. lots of cast in place chambers 50x20x30 ft, doubled one of these (two side by side)
-

No community outreach; however, a conservation grant was achieved to look at one LID in a community parking lot… indirectly the city funds this (as they pay the conservation)

- LID Maintenance is limited by public without equipment. So how does one truly eliminate the maintenance issue by allowing community programs to do it for the city?

Post-meeting Notes

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Project Name:	Prince George ISMP	Date of Meeting:	January 7th, 2021
		Time:	11:00 – 12:00
		Project #:	60628231
Attendees:	Bill Trenouth Ph.D, P.Eng., CAN-CISEC – AECOM Water Resources Engineering Nick Szendrey, B.Eng., AECOM Water Resources EIT Bert Van Duin - Drainage Technical Lead, Development Planning. Infrastructure Planning, Water Resources. City of Calgary	Location:	Conference Call
		Prepared By:	Nick Szendrey
Regrets:			
Regarding:	LID implementation in the City of Calgary / Considerations and recommendations for Prince George		

Minutes of Meeting

Introductions

- *Bert offers to have Prince George contact him at the City of Calgary to come in (post COVID), to discuss and see things for themselves.*

- Bert's journey is ongoing, still in the process of trying to sort out rather than seeing the optimal distribution of grey/green infrastructure.

Discussion

- Source control practice documents Bert created are still quite relevant today (found on city website).
- Specific LID used in Calgary, driven by the need for volume runoff control from hydrogeological modification perspective
- Approach: not necessarily an infiltration type of hydrology – more evapotranspartive
  - Approaches most effective with this perspective are:
    - Capture of runoff, rainwater harvesting or SW capture in larger storm ponds
    - Very large ponds in Calgary reflecting pre dev flow rates (small?)
    - Irrigation from ponds back onto the land is used, interesting!
    - Making a clear distinction between bioretention and raingardens

- Raingardens used as landscape approach
- Alberta water quality perspective… targets are geared towards removal of large particles (>75um)
- With that, pilot projects over the last decade
  - Originally starting with bioretention
  - ALDP collaboration talk about w Leta (good work with rain gardens and demonstrating their performance)
- Bert mentions the current scope of updating their SWM strategy, starting to move towards not wanting conditions in communities to get worst (flood control perspective and water quality loading perspective)
- Phosphorous management plan in beau river
- Source water protection – surface water based i.e. water is coming from the mountains; starting to drive discussions more but has not translated into hard guidelines or targets making it difficult to go after constituents other than sediment b/c of where provincial guidelines are at and municipalities wanting to do the absolute minimum.
- They are not near a wholesale LID level. More so, a hydrological level; but even then, industry pushes back.
- **Their approaches – the need for proper pre-treatment is incredibly important. Sand being used in Prince George makes it important there specifically should they go down this route.**
  - While we use salt for de icing, they use sand, grit, etc. more often. This poses a massive challenge
  - Looking at things from a water balance perspective, avg annual basis expressing water runoff volumes, moisture conditions, and an appreciation towards the landscape/engineering world

Questions

- **Q**. Bill - "You draw a hard line between bioretention and rain gardens; wondering when you say that, what is the driver behind saying and acknowledging that?"
  - **Answer:** the distinction is a terminology functionality perspective, ppl mixing up different practices that are functionally different.
    - Bioretention; looked at from a treatment perspective
    - Rain gardens: runoff volume control perspective. Loadings I/P ratio being pushed as important – they are fundamentally different
  - When you are dealing with people, clear terminology is extremely important.

- **Q**. Bill **-** "You mentioned hydro modification of the hydro cycle; do you look at seasonal variation… 60% of runoff is in a 2 week period in the spring in southern Ontario; in the winter, seasonally high GW is natural to see very little infiltration… under these types of conditions.. if it is natural to see seasonally high variations, do you look at it with this much granularity?"

  - **Answer:** NO, pre-dev. runoff is largely associated with the spring conditions. He has considered it more of a perspective of looking at it from wetlands impacting steams.
  - Lots of cattle terrain growing, like small stream land in Ontario; for the wetlands, he has been talking about more about mimicking hydro period since it fits more towards impacts on nesting birds and such rather than the streams
    - For the streams; can you potentially push more flow through them but still stick within the cumulative stress type environments b/c naturally there would have been very little flow going through them in the later part of the summer: still, pre-development runoff volumes are still very small ; still 3-5% max of what the precipitation would be… thus it is putting a high demand on doing that volume control.
    - With the tight clay soils as well, they are cautious of not trying to curate unrealistic expectations of what he calls "deep infiltration" that may result in

seepage issues into ex basements, or sanitary sewer; or cause slope stability issues.
- #1 consideration was driven by these acknowledgements
- Keep in mind, here in Alberta, a lot of work has been done pertaining to public health safety aspects b/c harvesting and re use approaches are quite attractive – lots of unique and good research done beyond what most jurisdictions have done thus far. They are simply waiting for Alberta PHS to publish what is needed.
    - When this becomes available, he feels that people will start looking at the guiding document on this. All of our stormwater will have wastewater signatures; So, they have really been putting a lot of emphasis on how we deal with this.
    - Largely what we see from storm ponds and inadvertent cross connections lead to the above. And it doesn't take a lot to see the clear signature. In some areas they wonder about exfiltration and infiltration processes (exfiltration from sanitary).

- **Q**: How does sand usage on roads affect LID implementation today (types etc,)?
    - **Answer**: pre-treatment is paramount; still trying to sort out the best way to do this. Leaning towards using something like a sump as part of the inlet and getting away from riprap. Expectations and maintenance make it not work long term.

        - Challenge they have in Calgary is being a community with CBs with no sumps in them (removed in 40s/50s).
        - leads to issues with high sediment loading to river, over 90% into beau river comes from storm, saturated system and sands/gravels in conveyance issues
        - Protecting LID becomes a component of this
    - The option as well may involve closing off certain features in the winter months.
        - Calgary would rather not for logistical issues.
        - Turning pump off slows flow but lets sediment through
        - They don't use OGS b/c the top freezes over in the winter, so sediment goes through them
    - Still resolving.

- Q: Bert, you talked about freezing; with respect to LID features, has Calgary had issues with winter performance and functioning?
    - **Answer**: lot of myths from a winter perspective says Bert… Says the biggest issue pertaining to winter is the vegetation.
    - Calgary is in a harsh environment with shanooks, huge temp swings and so it can get very dry.
    - Being able to find vegetation that can survive is a tough journey.
        - Many landscape industries don't understand what is needed so it's a challenge. This has led Bert to setting artificial conditions with an extremely low pallet for species that would survive. Creates an internal balance between the need for high permeability and the ability for moisture retention to sustain vegetation.
- **Question**: Speaking with struggles of plant selection; has the city had to overcome issues with respect to material availability and need to modify the specs of the LID?
- **Question**: have there been challenges with training/onboarding contractors especially for larger retrofit projects?
    - Degree of implementation is relatively so low, so they deal with a vary narrow list of contractors who think they can do it.

- Progress on supply constraints – some of the suppliers are from the Calgary area so it makes their life easier. (mentioned some standard that they are working on/updating testing protocols and such for contractors).
- Bert says some reliable suppliers are now available but what's still missing is the specializing of including nutrients effectively. Controlling leaching, etc. should be kept in mind.
  - Huge need for education with all the turnover (on all levels!)
  - Prince George should keep an eye on what they are doing in Alberta in terms of education efforts.
  - Interior BC shows lots of interest in their education methods. Looking to put more on the web as well.
  - Bert really highlights modules; on storm cells, and other LID types for use. Modules discuss treatment requirements, maintenance, etc. Find these on the City of Calgary website

Q: online sources about implementation/monitoring of LIDs that you can share?

- **A:** UofCalgary / Alberta on things like this – papers published with this info.
- This past summer LID inspection project looking at 30 bio retention, soil cell, swale implemented over past decade, but report hasn't been released; he will share with Prince George, but it might be after completion of this work.

Q: The City of Ottawa highlighted some bumpouts, biosoil retrofits, etc. Ottawa highlighted people putting junk in them, driving in the bioretention cells, leaves being blown in. Any similar experiences in Calgary? How can these issues be mitigated?

- **Answer**: Similar experiences yes, trying to address them in their LID modules to minimize potential impacts. One thing to keep in mind is seeing a diff between green field installations and retrofit installations. Having to do with catchment condition (stabilized, etc), potential for high sediment loadings going into them.
  - Greenfields vs retrofits establishment; vegetation growth, practices, etc.
  - Hard to establish vegetation when water and contaminants are already going through them
    - Mentions construction sediment overloading bioretention's.
    - ESC in winter months.

  - *Cognisant of difference between retrofit vs greenfield will help handle this problem discussed in the question*
  - Operation people need to be involved EARLY!
  - Design with maintenance in mind.

This leads to new challenges

  - Challenges with interactions between engineering and parks departments. Engineers create LID and then push them to parks department to maintain. Funding for departments does not properly consider this! Working with so many levels in a municipal workplace creates a difficult environment in this sense. One department cannot typically do all the work for LID which is the main issue.
  - Bert touches on turnover in municipalities. Need some dedication to some aspects of LID to avoid training/retraining.

Closing Remarks

- Bert mentions keeping up with climate change as an issue.
- Wants to see finished product and says to let prince George chat with him if they please. He is happy to help in all aspects!

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Project Name:	Prince George ISMP	Date of Meeting:	January 8th, 2021
		Time:	11:00 – 12:00
		Project #:	60628231
Attendees:	Nick Szendrey, B.Eng. - AECOM Water Resources EIT	Location:	Conference Call
	Leta Van Duin, B.Sc. Executive Director Alberta Low Impact Development Partnership	Prepared By:	Nick Szendrey
Regrets:			
Regarding:	LID implementation in the City of Calgary / Considerations and recommendations for Prince George/ LID technical guidance		

Minutes of Meeting

Information from Leta

Considerations:

- Everybody is fixated on bioswales, but their role should probably be less prominent.
- Not about doing LID just to do LID, they want to solve a problem. Need to do things for specific reasons
- Thinking about how you want to do maintenance, going to sumps – how will u get the sediment out of the things
- is it an ancillary benefit to implementation of SWM? Then focus energy to the correct locations. Otherwise, the approach should be different…

Example cases:

- OGS are great for sediment removal If its all you care about; but if you are also trying to get nutrient removal, urban heat islands, air quality, etc, suddenly the scale is tipped towards vegetation practice.
- Driving political imagination.
- New vs existing development – things change. With new development, you could implement as you build. With old, a step back may need to be taken to move forwards.

- Specifically: ditches are go-to options because people understand them. Some additional infiltration from the increase in uncompacted soil volume, and increased slope to a regular ditch.
  Soil uptake processes, volume attenuation, providing adequate treatment (if at all).
  How much, and what did you improve?

- Not working in the private realm means not enough performance; you won't get what is required this way.

- *Background: Flood in 2013 caused province to influx money to monitor and demonstration on these topics, this is why Calgary is a step ahead*

- Rain gardens for flood attenuation. On lot/site rain gardens are like mini dry ponds and the province is beginning to recognize it. *Rain gardens have been a topic of conversation across all interviews completed in this municipal scan.*
    - Risk around maintenance and filling things in, but still worth doing.

- **Calgary doesn't have incentivizing programs yet** because of how they bill for stormwater and such. its not a line item; so how do u incentivize it? Saskatoon/Victoria has looked at these programs. too soon though, but maybe in the future.

Education/Testing:

- Leta has completed 12 residential development sites to work on construction aspects, worker/resident attitude towards LID, etc… Bigger community sites completed to educate.
    - Landscape architects think they know but in terms of detailed design they have a high degree of handholding. Leta says there are construction videos and residential practices coming out "imminently" that we could reference.
    - Leta wishes to begin working with some form of landscaper certification program to help educate companies on LID requirements/needs, to improve success rate.
    - Residential landscaping community is not used to dealing with "elevation". This is an issue that arises, when you request specific heights for aspects of LID. A way around this is simplifying terms used. For example, calling these gardens and cells "bathtubs" really helped contractors understand what to construct.
    - Calling things pollinator habitats, biodiversity, flood mitigation helps sell LID to people; they can wrap their head around the good in these terms.

Good examples of LID to look towards:

- Currie barracks in Calgary – medium/high density communities, which are limited by downstream pipe size; so very highly motivated (land value), to minimize the pond size and meet the capacity.
- LID is everywhere here. Automatic irrigation, "literally a menu of options when you bought homes." Rain gardens and barrels. Story: high value land = may be easier to achieve LID
- green conveyance, bioretention through the community towards a central amenity feature which is the pond but also is the park. There are outlets for varying storm sizes into underground storage. Long story short – get creative! Budget helps.

LID in the Winter:

- Pilot project from the university where they plow literally on top of the LID and Leta has been monitoring it but in general it works out fine. The snow doesn't affect this functioning much at all.

Bioretention and Vegetation:

- Inlets are weak points of bioretention – Leta has a good handle on the vegetation. She says she did a review for the CSA standard for vegetation. She created a very generic list of vegetation that can be used.

- The plant pallet u can use is narrow but generally is universal across the country! Climate typically affects media selection rather than plant selection. It may be a struggle to find vegetation combined with inlet methods that work, but once this is achieved it should be smoother sailing.
- For residential rain gardens Leta recommends using a typical loam – rather than 1/3 topsoil, 1/3 compost and 1/3 sand (typical garden mix more easily obtainable).
- meeting local conditions in texture is key. Regular loam is good for rain gardens because we can rely on soil structure, not texture.
- Correctly considering soil structure will lead to success with rain gardens. Finding a soil structure that works for Prince George may be a unique process, as conditions likely are not the same where Leta has typically worked.
- For bioretention: Focus on surviving the drought season each year.

Suppliers:

- Leta has found one supplier does the correct bioretention media across Alberta. She thinks its because there aren't enough projects that require it… (they do have multiple locations though). But there are the correct media available and its possible to achieve. the demand just needs to exist to make it more accessible, as companies haven't been given a reason to make the correct mixtures. They don't use sandy media for bioretention.

More examples:

- Blvd retrofit in red deer where they stripped the sod and added plants at the stripped sod height to buy several inches of absorptive capacity during large rain events. Very simple, not conventional but simple!
- Mowed every week, etc. Requires a good amount of maintenance. This is still a simple way to think LID and head down this path.

- There's nothing really close to a wholesale solution. Prince George needs to find what works for them.

Closing Remarks

- Leta feels like she has a good understanding of making these LID work in terms of getting in done correctly in the field. She has experience. It would warm her heart to help communities like Prince George properly implement them. She is very knowledgeable on the subject.
- Leta can help with vegetation lists
- Leta doesn't want to be called in after something is built incorrectly; She wants to help early in the process to stop people from doing it wrong and keep them thinking LID rather than scare themselves away.
- Leta says to look at modules highlighting resilient landscaping practices. Big believer in this; fascinating for engineers, big problems to solve, etc.
- Just volume control you're after? Fancy LID are not the way to go; keep it simple!

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Project Name: Prince George ISMP

Date of Meeting: January 8th, 2021

Time: 13:00 – 13:30

Project #: 60628231

Location: Conference Call

Attendees: Bill Trenouth – AECOM Water Resources Engineering, Ph.D, P.Eng., CAN-CISEC

Ian Boland, C.E.T – City of Peterborough Senior Watershed Project Manager

Prepared By: Nick Szendrey

Regrets:

Regarding: LID implementation in the City of Peterborough

Minutes of Meeting

Discussion Points:

Peterborough has no LID in the ROW yet. They do have LID in parking lots but have struggled in implementing these.

Permeable Pavers: turnstone and some bioswales.

Rear yard infiltration swales – primary form of LID in new subdivisions. This is because no easements, no protections required. The problem: Survival of vegetation.

Want to implement a SWM fee/a credit to help ensure maintenance and protection of these LID.

Standard 18.5m XS – most common XS in a subdivision ROW. This is what they wish to use going forward.

Cleantech: come a long way, but expensive.

Peterborough is confident in what they want in terms of LID going forward; which is a limited style of LID. Prime focus is to standardize the process, in order to facilitate maintenance and reduce costs.

will look at underground chambers where it makes sense, but for the most part it will be a standardized bioswale/retention unit used going forward. Will also be using Filterra, but they are expensive.

Parking lot LID: problems are partly design. The grass is not growing, and they see more traffic than they should. They have become very compacted. Did not expect the traffic they saw.

- No standing water so they are working, they suppose.
- But the grass looks poor. It was done because it was suggested, but no one really knew about it/how to do it. Contractor was not trained.
- **We can all learn from this**

Peripheral bioswales: they are wet almost 100% of the time. They are below the water table – which is a problem. They might function as a filter, but they are not infiltrating. Designer did not look at the hydrology data. These are internal City projects.

BIG ONE: experience and training. Will be a direct relation to success with LID.

GreenUp = they had a couple of different raingarden installation programs (SUN) Sustainable Urban Neighbourhoods programs. They went into two neighbourhoods and installed 15 rain gardens. Rain gardens are “nice to have”, but not really rain gardens.

Rain garden subsidy in the city … involves taking some measurements of rooftops, finding downspouts, etc. There is an online calculator. If you meet the min requirements you can get $500 to build a rain garden. Initially, you are required to go to training, which Greenup supplied. **Training is required. This helps ensure success!**

ROW bioretention = City engineers ask the residents “do you want plants or sod?” We have though about maintenance a lot. We have tried to work it into the design. The expectation is that these will be cleanout once per year, in accordance with our current maintenance cycle. Peterborough uses salt and sand.

Peterborough engineering construction group still likely complains about these things… extra cost, project delays, etc. However, we’ve bene through enough training to know that these things must go in, and how to do it. Grumblings will quiet down over time.

Peterborough currently has a requirement to infiltrate 15mm.

- new (within the last year or two). Responsibility lie withing Ian’s department – they look after the OGS units, ponds, etc. They need to get up to speed with the O&M of LID too. They want to get to the point where minor inspections are done by public works department. The biggest driver to get this done is the new system wide ECA from the MECP.

Ian has some limited experience with winter operation – if they are not properly designed, they may not function in the winter.

- For Permeable Pavement, snow melts a lot quicker. Not using as much salt, etc.

Drivers:

- System wide ECAs
- Water quality – we have a couple of sensitive fisheries creeks with brook trout (Fisher and Jackson Cr.). We have a lot of small streams that mean a lot to people.
- Water quantity – we had big flood in 02 and 04, and that is driving it as well. LID alone cannot solve it alone, but it could help
- Strong environmentally-minded community – vocal residents. The university drives this as well.
- CC is a driver too.

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Project Name:	Prince George ISMP	Date of Meeting:	January 28th, 2021
		Time:	9:00 – 10:00
		Project #:	60628231
Attendees:	Bill Trenouth – AECOM Water Resources Engineering, Ph.D, P.Eng., CAN-CISEC Adrienne Sonnes – City of London Stormwater Engineering Division	Location:	Conference Call
		Prepared By:	Nick Szendrey
Regrets:			
Regarding:	LID implementation in the City of London / Considerations for Prince George BC		

Minutes of Meeting

Discussion

Implementation:
City of London (CoL) pushing the "third pipe" (EES) system, as they have a hard time allocating budget to look after rain gardens. City staff don't have time or resources to weed roadside ditches.

- CoL still puts rain gardens in subdivisions in retrofit projects. They will do it for retrofits and when soil conditions allow it.
- The expectation is that the homeowner will look after the feature. Sod is the default option. If they want a garden, CoL will include one at no cost to the homeowner.
- At first this was a flop – people were interested in the plantings, but they didn't get taken care of, so now the City (and its consultants) tend to steer homeowners toward sod, unless there is a real demand for plantings.
- Consultants are expected to meet/discuss with property owners what their LID preference would be.

City has not had any icing complaints about LID infiltrating in the winter. When properly designed (e.g. With subdrain) there does not appear to be any winter maintenance concerns.

Standards development:
This has been a big struggle.
Moving forward, City wants to have design standards. This includes standards for pre-treatment.
Standards would like to be developed in-house and based on City implementation experience so far
City would probably accept three main LID feature types, although this has not been officially decided:

City preferred types are dependent on land use topology. Very preliminary list:

- EES
- Infiltration gallery
- Bioretention (with sod as a default)
- Amended topsoil (looking at providing some sort of credit but not there yet)

City of London has a long-standing and relatively modest SWM utility fee, and is looking at the possibility of offering a credit for amended topsoil and other green infrastructure approaches

Structurally supported soil systems (e.g. Silva cells) tend to come into play when there are forestry requirements. Forestry is not 100% comfortable with irrigating trees using SW currently, so these systems are not on the short list above.

Logistical/Management/Communication
Tracking these things is also a problem from an asset management perspective. Location, maintenance needs, timing, level of effort, etc.

Internal silos – this has also been an issue. For implementation, we have tailored our approach to cater to the teams that work well with us.

For pre-treatment, City would accept more than one type. But we need to understand how it works, what level of maintenance is required, and what is the surrounding land use context

City has complete street standards, but note is not at the point where the standards have extended to include design guidance/details for various LID options and associated appurtenances.

Working with Western University has worked very well for the City – both parties have both from the relationship and the City has improved it's understanding of LID. *If Prince George has the opportunity to work with a local university partner as part of their implementation process it is encouraged that they do so.*

The best learning tool City has had is doing retrofit and pilot projects through the infrastructure renewal program (IRP). IRP in London brings together water, trans and sewer groups, and is run by construction admin. This has brought all these groups together to work, and it has greatly improved communication. City has seen good support internally through this process for virtually all aspects of LID implementation.

Sewers and Parks departments: have been awesome. They have asked us "just tell us what to do". They tell us what they can take on, and they want to be supportive, but they are limited due to their budgets, etc.

City stormwater engineering is still working with roads to enhance the collaborative relationship as it pertains to implementation. Roads is not yet a core part of the implementation process and they need to be brought into the fold, SWED continues to work with them in this regard (with things like street sweeping, for example).

Public Education:

Public education: people who are interested in LID are seeking it out anyway. It is a bit of a struggle with the public and people have their own attitudes regarding LID (both positive and negative), and education will not always change that.

Local gardeners have “seedy Saturday” which the City attends, and City staff attend the London Home Show too. These are outreach avenues where we talk directly to homeowners. City also has a dedicated webpage to educate/provide LID and stormwater resources

Fusion Landscaping - City is hosting a FLP training session in Winter 2021 to build a local market of landscape contractors qualified to build water-sensitive landscape installations (rain gardens and other low-tech LID). SEE LINK: https://horttrades.com/fusion

City of London also has a stormwater rate reduction for private sites. They get a reduction if they implement LID.

- **Post-meeting Notes**

Appendix B : Plant and Tree Lists for the City of Prince George

BOULEVARD, RESIDENTIAL OR NATURAL AREAS RECOMMENDED TREE LIST

This guide provides information on trees that are recommended for use within boulevards, residential, or natural areas in Prince George.

Elm trees in the Prince George Millar Addition neighbourhood.

RECOMMENDED TREE LIST

The following list of tree species are recommended for use in Prince George given their suitability for the local climate and planting in locations which include:

- Boulevards or areas adjacent to roadways (B),
- Natural Areas using native or semi-native trees (N),
- Planter beds or Small Yards (P),
- Residential lots (R), or
- the Bowl Area or other Sheltered Sites (*).

The enclosed tables provide detailed information on each tree species such as their size at maturity, leaf colour, characteristics, salt tolerance, and bear resistance.

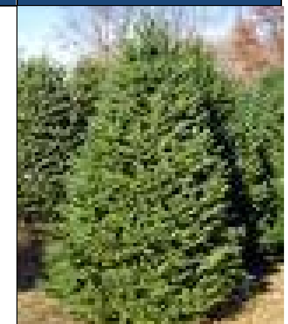
SPECIES NOT RECOMMENDED

A list at the end of this guide identifies tree species which are not recommended for use or should be used with caution.

STREET TREES

A list of recommended street trees is also available in a separate document through the City of Prince George.

Evergreen Trees (Coniferous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Needle Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Balsam Fir Abies balsamea	B, N, R	10-15m Ht. 3-6m W.		Low	High	• Dense symmetrical habit and dark green colour • Medium size with smooth bark, soft/flat needles • Generally insect/pest free • Prefers moist, well-drained soil with shelter from strong winds • Not pollution tolerant	
White Fir Abies concolor	B, N, R	20-25m Ht. 5-8m W.		Low	High	• Larger fir with dense habit that is conical to columnar in shape • Foliage often has a bluish tinge • Prefers moist, well-drained soil • More adaptable than most firs	
Subalpine Fir Abies lasiocarpa	N, R	10-25m Ht. 4-10m W.		Low	High	• Similar to a Balsum Fir (Abies balsamea)	

Tree Use:
B – Boulevard N – Natural Area P – Planter/Small Yard R – Residential * Bowl Area/Sheltered Site

Evergreen Trees (Coniferous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Needle Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Rocky Mt. Juniper Juniperus scopulorum *'Cologreen'* *'Gray Ice'* *'Medora'* *'Moonglow'* *'Witchita'*	P, R	4-10m Ht. 1-3m W.		Low	High	• Nice evergreen for small areas • Upright forms vary from a narrow 'Skyrocket' to the fuller 'Witchita' or 'Moonglow' • Colours range from bright green to intense blue • Drought tolerant once established • Prefers full sun	
Weeping Larch Larix decidua *'Pendula'*	P, R	6m Ht. 4m W.		High	High	• Unique specimen tree with strong weeping habit • Soft green needles that turn bright yellow in fall and shed in winter • Prefers a sunny site with moist soil	
Siberian Larch Larix siberica	N, R, S	20m Ht. 15m W.		High	High	• Deciduous with large pyramidal shape • Soft green foliage turns yellow in fall and shed in winter • Requires a sunny site with moist, well-drained soil • Looks especially nice in group	

Tree Use:
B – Boulevard N – Natural Area P – Planter/Small Yard R – Residential * Bowl Area/Sheltered Site

Evergreen Trees (Coniferous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Needle Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Norway Spruce Picea abies *'Pendula'* + others	B, P, R	25-30m Ht. 10-15m W.		Medium	High	• Large graceful spruce with weeping branches • Bright green foliage • Very hardy • 'Pendula' is a small weeping form suitable as a feature tree in large beds or a planter	
White Spruce Picea glauca *'Densata'* *'Conica'* *'Jean's Dilly'*	N, P, R	30m Ht. 15m W.		High	High	• Large native spruce with bluish green foliage • 'Densata' Black Hill Spruce is more compact & tolerant of drier soils • 'Conica' is very compact, with dwarf forms suited to planters & ornamental beds	
Colorado Spruce Picea pungens *'Bakeri'* *'Fat Albert'* *'Hoopsii'* + others	B, N, P, R	30m Ht. 15m W.		High	High	• Available in many sizes & forms from columnar to weeping • Best known for vivid blue colour • More drought tolerant than other spruce • Allow room for spread & best uniform growth	

Tree Use:
B – Boulevard N – Natural Area P – Planter/Small Yard R – Residential * Bowl Area/Sheltered Site

Evergreen Trees (Coniferous)

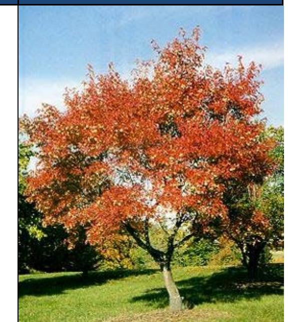
Latin Name/ Common Name	Tree Use	Mature Height/ Width	Needle Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Eastern White Pine Pinus strobus *'Pendula'*	B, P, R	15m Ht. 7m W.		Low	High	• Long bluish green needles give it a soft look • Long purple cones are attractive • Requires sun and moist, well-drained soil • 'Pendula' is a smaller weeping cultivar used as a feature plant	
Scots Pine Pinus sylvestris	B, N, R	15m Ht. 8m W.		Low	High	• Pyramidal shape when young, becoming more spreading with age • Bluish green needles & orange brown bark • Hardy and adaptable • Prefers a sunny site	
Douglas Fir Pseudotsuga menziesii	N, R	20m Ht. 10m W.		Low	High	• Large evergreen with a conical shape • Nice dark green needles • Interesting cones • Requires moist, well-drained soil • Requires a large area	

Tree Use:
B – Boulevard N – Natural Area P – Planter/Small Yard R – Residential * Bowl Area/Sheltered Site

Evergreen Trees (Coniferous)							
Latin Name/ Common Name	**Tree Use**	**Mature Height/ Width**	**Needle Colour**	**Salt Tolerance**	**Bear Resistance**	**Characteristics**	**Photo**
Cedar Thuga occidentalis *'Brandon'* *'Skybound'* *'Techney'* + others	P, R *	2-4m Ht. 1m W.		Low	High	• Upright cedars • Symmetrical, conical form • Used for hedging or as a windbreak • Best in sheltered location • Requires a moist, well-drained soil	

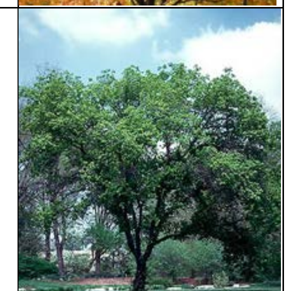
Tree Use:
B – Boulevard **N** – Natural Area **P** – Planter/Small Yard **R** – Residential ***** Bowl Area/Sheltered Site

Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Amur Maple Acer ginnala *'Compactum'* *'Embers'*	P, R + Shrub Beds	2-6 m Ht. 2-5m W.			Medium	High	• Multi-stemmed habit • Can be shaped by pruning • Adaptable & hardy • Bright red fall colour • Fits into almost any landscape	
Norway Maple Acer platanoides *'Crimson King'* *'Columnar'* *'Prairie Splendor'* *'Easy Street'* + others	B, R, *	8-15m Ht. 5-9m W.			High	High	• Various forms from upright to spreading • Several burgundy leaved cultivars • Green leaved cultivars turn bright yellow in fall • Prefers moist soil, but will tolerate other soils • Very few pests problems	
Red Maple Acer rubrum *'Autumn Blaze'* *'Columnare'* *'Northwood'* *'Red Sunset'* +others	B, R	15m Ht. 6-10m W.			Low	High	• Beautiful specimen tree • Dense canopy with strong symmetrical branches • Glossy green leaves turn brilliant red in fall • Prefers moist acidic soil • Shade tolerant when young	

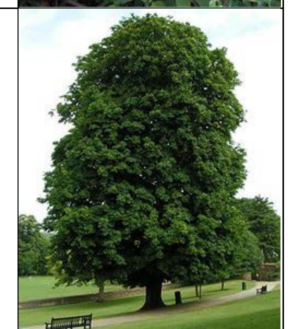
Tree Use:
B – Boulevard N – Natural Area P – Planter/Small Yard R – Residential * Bowl Area/Sheltered Site

Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Sugar Maple Acer saccharum *'Adirondack'* *'Legacy'* *'Green Mt.'* *'Unity'* +others	B, R, *	15m Ht. 12m W.			Low	High	• Good upright dense, oval shape • Green leaves in summer turn orange/gold in fall • Outstanding gray bark • Not good for restricted growing areas due to canopy spread and surface roots	
Tatarian Maple Acer tataricum	B, R	7-8m Ht. 8-10m W.			Low	High	• Small wide spreading graceful form • Similar to Amur Maple but larger • Nice specimen tree for small yard • Bright red fall colour • Adaptable & drought tolerant	
Purple blow Maple Acer truncatum *'Pacific Sunset'*	R, P, *	9m Ht. 8m W.			Low	High	• Similar to Amur Maple (Acer ginnala), but not as hardy • New growth is red/purple, attracts birds • Very nice fall colours • Use in sheltered sites	

Tree Use:
B – Boulevard   N – Natural Area   P – Planter/Small Yard   R – Residential   * Bowl Area/Sheltered Site

Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Ohio Buckeye Aesculus glabra	B, N, R, *	8-10m Ht. 6-8m W.			Low	Medium	• Low headed, rounded form • Has prickly nuts that could be a nuisance in yards • Nice orange fall colour • Requires moist soil • Best in natural areas	
Horse Chestnut Aesculus hippocastanum	B, R, *	15-20m Ht. 10-15m W.			Low	Medium	• Dense oval crown • Showy white flower clusters in spring • Spiny nuts in the fall are not edible • Not much fall colour • Requires moist soil	
Serviceberry Amelanchier x grandiflora *'Autumn Brilliance'*	N, R, P	8m Ht. 5m W.			Low	Medium	• Often multi-stemmed or small tree • Showy white flowers in spring • Sweet reddish purple edible berries • Outstanding fall colour • Attracts birds	

Tree Use:
B – Boulevard **N** – Natural Area **P** – Planter/Small Yard **R** – Residential ***** Bowl Area/Sheltered Site

Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
River Birch Betula nigra *'Heritage'*	N, B, R	15m Ht. 15m W.			Low	High	• Nice oval shape • Beautiful exfoliating bark for winter interest • Available in single stem or clump forms • More pest-resistant than other birches • Adaptable to various site conditions	
Paper Birch Betula papyrifera *'Prairie Dream'* *'Chickadee'* *'Snowy'*	N, R	12-15m Ht. 5-10m W.			Medium	High	• Prefers heavy watering & well-drained soil • Outstanding white bark • Susceptible to pests during prolonged drought • Not suitable as a street tree	
Weeping Birch Betula pendula *'Dalcarlica'* *'Purple Rain'* *'Tristis'* *'Youngii'*	B, P, R	6-12m Ht. 5-8m W.			Low	High	• Similar to Paper Birch but with a weeping form • Very graceful • Cutleaf has finely dissected leaves • 'Youngii' Birch is smaller and useful where space is limited • 'Purple Rain' has striking purple foilage	

Tree Use:
B – Boulevard N – Natural Area P – Planter/Small Yard R – Residential * Bowl Area/Sheltered Site

Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Caragana Caragana arborescens *'Pendula'* *'Walker'*	P, R	2m Ht. 1.5m W.			Low	High	• Top grafted shrubs that make interesting feature trees • Showy yellow flowers • Bright green foliage • Weeping Branches with thorns • Drought tolerant	
Hackberry Celtis occidentalis *'Prairie Pride'*	B, N, R	20m Ht. 15m W.			Low	Medium	• Elm-like in size & form • Large tree that is tough & adaptable for urban use • Berries attract birds • Not much fall colour • Drought tolerant	
Pagoda Dogwood Cornus alternifolia *'Argentea'*	P, R, *	4-6m Ht. 4-6m W.			Low	Medium	• Horizontal branching creates a layered effect • Nice for a Japanese style garden & for planters • Showy white flowers • Red/purple fall colour • Shade-tolerant	

Tree Use:
B – Boulevard **N** – Natural Area **P** – Planter/Small Yard **R** – Residential ***** Bowl Area/Sheltered Site

Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Morden Hawthorn Crataegus x mordensis *'Toba'* *'Snowbird'*	P, R	5m Ht. 5m W.			Low	Medium	• Small flowering trees with red fruit • Some thorns • Some pest problems • 'Toba' has pink flowers & 'Snowbird' has white	
Russian Olive Elaeagnus angustifolia	B, R	8m Ht. 8m W.			Medium	High	• Can be grown as a large shrub or trained as a single stemmed tree • Small yellow flowers, silvery small fruit, & 4" sharp thorns • Prefers a dry site • Avoid waterways – can be invasive	
White Ash Fraxinus Americana *'Autumn Blaze'* *'Autumn Purple'* *'Skyline'*	B, R	13-15m Ht. 12m W.			Low	High	• Nice shade tree & better structure than Green Ash • Fall colours range from yellow, orange & purple • Prefers moist well-drained soil but is adaptable • Salt tolerant • 'Autumn Blaze' hardy to zone 3	

Tree Use:
B – Boulevard **N** – Natural Area **P** – Planter/Small Yard **R** – Residential ***** Bowl Area/Sheltered Site

Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Manchurian Ash Fraxinus mandshurica *'Mancana'*	B, R	12m Ht. 6m W.			Low	High	• Upright oval trees with lacy foliage • Yellow fall colour • Tolerant of various soil types • Some potential pest problems that proper care & site selection could alleviate • 'Mancana' is a seedless variety	
Green Ash Fraxinus pennsylvanica *'Patmore'* *'Prairie Spire'* *'Rugby'*	B, R	15-18m Ht. 7-10m W.			Low	High	• Hardy & adaptable (but has been overused) • Develops poor structure if not pruned regularly when young • Yellow fall colour • Seedless male cultivars are preferred	
Butternut Juglans cinera	B, R, *	12-18m Ht. 10-12m W.			Medium	High	• Beautiful, wide spreading shade tree • Interesting compound leaves • Oily, edible nuts attract squirrels • Requires deep, rich soil	

Tree Use:
B – Boulevard N – Natural Area P – Planter/Small Yard R – Residential * Bowl Area/Sheltered Site

Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Black Walnut Juglans nigra	B, R, *	15-22m Ht. 15m W.			Low	Medium	• Upright high headed tree with nice foliage • Long lived • Nuts are attractive to squirrels • Roots produce a compound that is toxic to other plants	
Amur Maackia Maackia amurensis	B, P, R	6-9m Ht. 6-7m W.			Low	High	• Small graceful tree good for a small yard • Fragrant, yellowish flowers in spring • Golden bark • Low maintenance & adaptable • Virtually pest-free	
Ironwood Ostrya virginiana	B, R, *	10-13m Ht. 7-10m W.			Low	High	• Oval to rounded tree that is tough, adaptable & shade tolerant • Attractive foliage turns yellow in fall • Bark is showy & seeds attract birds • Avoid wet soils	

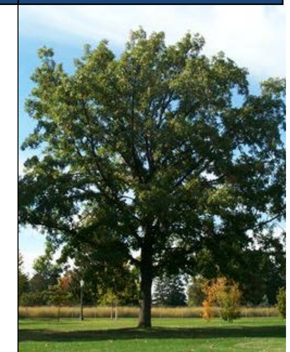
Tree Use:
B – Boulevard **N** – Natural Area **P** – Planter/Small Yard **R** – Residential ***** Bowl Area/Sheltered Site

Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Amur Cork Tree Phellodendron amurense *'Macho'* *'Shademaster'* *'His Majesty'*	B, R	7-9m Ht. 7-9m W.			Low	Medium	• Unique & beautiful tree that should be used more • Graceful, spreading habit • Nice foliage with fall colour • Interesting bark • Use male cultivars to avoid fruit which is messy and attracts bears	
Swedish Columnar Aspen Populus tremula 'erecta'	B, N, R	12m Ht. 2m W.			Medium	High	• Growing in popularity due to it's beautiful columnar habit • Tough, adaptable & fits into restricted spaces • Nice fall colour, no fluffy seeds & non aggressive roots	
Northern Pin Oak Quercus ellipsoidalis	B, R	15m Ht. 12m W.			Low	Medium	• Broad, oval habit • Very stately appearance typical of Oaks • Cold hardy Pin Oak • Rich, green foliage with red to coppery fall colour	

Tree Use:
B – Boulevard **N** – Natural Area **P** – Planter/Small Yard **R** – Residential ***** Bowl Area/Sheltered Site

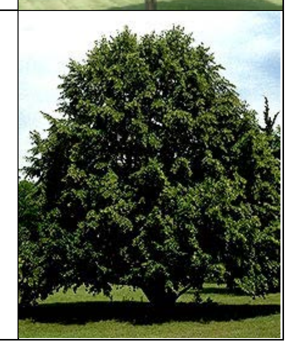
Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Bur Oak Quercus macrocarpa	B, R	20-24m Ht. 9-12m W.			Medium	Medium	• Very hardy native Oak • Interesting bark, leaves & acorns • Adaptable tree & tolerant of urban conditions • Requires large area to reach it's full potential • Birds & squirrels love the acorns	
Red Oak Quercus rubra	B, R	18-21m Ht. 9-12m W.			High	Medium	• One of the faster growing Oaks • Large & very stately tree • Tolerant of most soils except high pH • Fall colour ranges from red to coppery-brown • Leaves often remain on the tree for winter	
White Willow Salix alba *'Tristis'* *'Vitellina'*	N, R	15m Ht. 12m W.			Low	High	• Beautiful tree with colourful yellow new growth • 'Tristis' has a weeping habit • Not for the small yard • Willows drop branches constantly & have very aggressive roots • Best used in larger natural areas	

Tree Use:

B – Boulevard N – Natural Area P – Planter/Small Yard R – Residential * Bowl Area/Sheltered Site

Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Laurel Leaf Willow Salix pentandra *'Prairie Cascade'*	N, R	10-13m Ht. 10m W.			Low	High	• Fast growing tree with shiny green foliage • Use in large, natural areas • Requires moist, wet soils • 'Prairie Cascade' is a hybrid with golden new stems & a weeping habit	
Japanese Tree Lilac Syringa reticulate *'Ivory Silk'*	B, P, R	8-9m Ht. 7-8m W.			Medium	High	• Small tree with oval crown • Very attractive creamy white flower clusters • Nice specimen for small yard or large planter • Tough tree for urban conditions • Probably underused	
Linden sp. Tilia Americana Tilia cordata Tilia x flavescens Tilia mongolica *Various species*	B, P, R	10-30m Ht. 7-15m W.			Medium	High	• Pyramidal to oval in form • Very nice structure & branching habit • Nice foliage with yellow flowers • Very tidy tree & requires little pruning • Tilia americana is larger than other Tilia's	

Tree Use:
B – Boulevard N – Natural Area P – Planter/Small Yard R – Residential * Bowl Area/Sheltered Site

Shade/Ornamental Trees (Deciduous)

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Elm Ulmus Americana *'Brandon'* *'Liberty'* *'Valley Forge'* *'New Harmony* *'Discovery'*	B, R	20m Ht. 15m W.			Low	High	• Nice specimens at City Hall & the Millar addition • Lovely vase-shape with arching branches • Yellow fall colour • Dutch Elm disease (DED) has wiped out entire Elm population in much of North America • Use DED-resistant varieties	

Other Tree Species **not recommended for use** or should be **used with caution**, include the following:

- **Poplar & Willow species** – Suitable for natural areas only as root systems are invasive.
- **Manitoba Maple/Box Elder (Acer negundo)** – Self-seeding and root systems are invasive.
- **Silver Maple (Acer saccharinium)** – Hazardous and messy with brittle branches. Root systems are also invasive.
- **Black Ash (Fraxinus nigra)** – Not recommended given pest problems with Black Ash cultivars.
- **Flowering Crabs (Malus species)** – Crab trees produce fruit and are attractants to bears. Fruit must be removed immediately upon ripening for harvest or disposal (composting not recommended as the odour is attractive to bears).
- **Mayday & Chokecherry (Prunus padus)** – Prunus species produce fruit and are attractants to bears. Black knot disease is prominent in some prunus species.
- **Mountain Ash (Sorbus aucuparia/decora)** – Mountain ash trees produce fruit and are attractants to bears. Fruit can also be messy on hard surfaces.

Revision Date: February 21, 2019

Tree Use:
B – Boulevard N – Natural Area P – Planter/Small Yard R – Residential * Bowl Area/Sheltered Site

SALT TOLERANT PLANTS RECOMMENDED LIST

CITY OF PRINCE GEORGE

This guide provides information on salt tolerant plant species that are recommended for use along sidewalks, roadways, or other paths that are maintained with deicing salts in winter.

Maple trees along Queensway in Prince George.

SALT TOLERANT PLANTS

Winter maintenance of sidewalks, roadways, and trails in Prince George often includes the use of deicing salt which can be fatal to many of the plant species. Salt spray and excess salt in the soil can also cause branch dieback, stunted growth, and overall vigor.

The following list of plant species are recommended for use in landscaped areas that will be impacted by deicing salts. Note: All high salt tolerant plant species are listed in **bold**.

Latin Name	Common Name	Salt Tolerance
Shade & Ornamental Trees (Deciduous)		
Acer ginnala	Amur Maple	Medium
Acer platanoides	**Royal Red Maple**	**High**
Betula papyrifera	Paper Birch	Medium
Larix sp.	**Larch**	**High**
Populus tremuloides 'Erecta'	Swedish Columnar Aspen	Medium
Quercus macrocarpa	Bur Oak	Medium
Quercus rubra	**Red Oak**	**High**
Syringa reticulata 'Ivory Silk'	Ivory Silk Tree Lilac	Medium
Tilia americana	American Linden	Medium

Latin Name	Common Name	Salt Tolerance
Evergreen Trees (Coniferous)		
Picea abies species	Norway Spruce	Medium
Picea glauca species	White Spruce	High
Picea pungens species	Colorado Blue Spruce	High
Pinus nigra	Austrian Pine	High
Ornamental Deciduous Shrubs		
Berberis thunbergii	Japanese Barberry	High
Cotoneaster species	Cotoneaster	High
Philadelphus species	Mock Orange	Medium
Potentilla species	Potentilla	High
Rhus species	Sumac	High
Rosa rugosa	Hardy Shrub Rose	High
Spiraea x vanhouttei varities	Bridlewreath Spiraea	Medium
Ornamental Evergreen (Coniferous) Shrubs		
Juniperus species	Juniper	High
Pinus mugho	Mugho Pine	High
Perennials		
Alchemilla mollis	Lady's Mantle	High
Artemisia schmidtiana 'Silver Mound'	Silver Mound Artemesia	Medium
Coreopsis verticullata 'Moonbeam'	Moonbeam Tickseed	Medium
Dianthus pulmarius	Pinks	High
Euphorbia griffithii 'Fireglow'	Fireglow' Griffith's Spurge	Medium
Hemerocallis 'Stella de Oro'	Stella De Oro Daylily	Medium
Heuchera micrantha var.	Palace Purple Coral Bells	Medium
Hosta plantaginea	Plantain Lily	Medium
Iberis sempervirens	Evergreen Candytuft	Medium
Iris sibirica 'Caesar's Brother'	'Caesar's Brother' Siberian Iris	Medium
Liriope spicata	Creeping Lilyturf	Medium
Sedum spectabile 'Autumn Joy'	Autumn Joy Stonecrop	Medium
Stachys byzantina	Lamb's Ears	Medium
Ornamental Grasses		
Calamagrostis x acutiflora	Karl Foerster Feather Reed	High
Elymus arenarius	Blue Lyme Grass	High
Festuca glauca 'Elijah Blue'	Elijah Blue Fescue	Medium

MINIMIZING SALT INJURY

The following practices are recommended to help avoid injuries to plant material and grass from deicing salt:

- Place temporary winter barriers such as burlap or fencing along landscaped areas
- Avoid the use of deicing salt and apply the salt to hard surface areas after the snow has been removed
- Avoid storing shoveled snow on planting beds
- Alter drainage patterns to avoid the accumulation of salt runoff into landscaped areas
- Flush landscaped areas heavily with water in spring to help move any salt through the soil

CITY OF PRINCE GEORGE

RECOMMENDED STREET TREE LIST

This guide provides information on tree species which are recommended for use as street trees in Prince George.

RECOMMENDED TREE LIST

Street tree environments contain some of the most extreme growing conditions with confined spaces, heat, salt spray, pollution, poor drainage, and vandalism or damage. The following list of street tree species are recommended for Prince George given their suitability within locations that include:

- Raised Planter Beds (S), or
- At grade Street Tree Wells (W).

The enclosed tables provide detailed information on each tree species such as their size at maturity, leaf colour, characteristics, salt tolerance, and bear resistance. Note: Some species may also be available in a columnar form which is suitable for narrow sidewalks.

Street trees in front of the Wood Innovation & Design Centre in PG.

SPECIES NOT RECOMMENDED

A list at the end of this guide identifies tree species which are not recommended for use or should be used with caution.

BOULEVARD, RESIDENTIAL & NATURAL AREA TREES

A list of recommended trees for boulevards, residential, and natural areas is available in a separate document through the City of Prince George.

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Norway Maple Acer platanoides *'Crimson King'* *'Columnar'* *'Prairie Splendor'* *'Easy Street'* + others	S, W	8-15m Ht. 5-9m W.			High	High	• Various forms from upright to spreading • Several burgundy leaved cultivars • Green leaved cultivars turn bright yellow in fall • Prefers moist soil, but will tolerate other soils • Very few pests problems	
Red Maple Acer rubrum *'Autumn Blaze'* *'Columnare'* *'Northwood'* *'Red Sunset'* +others	S, W	15m Ht. 6-10m W.			Low	High	• Beautiful specimen tree • Dense canopy with strong symmetrical branches • Glossy green leaves turn brilliant red in fall • Prefers moist acidic soil • Shade tolerant when young	
Weeping Birch Betula pendula *'Dalcarlica'* *'Purple Rain'* *'Tristis'* *'Youngii'*	S	6-12m Ht. 5-8m W.			Low	High	• Similar to Paper Birch but with a weeping form • Very graceful • Cutleaf has finely dissected leaves • 'Youngii' Birch is smaller and useful where space is limited • 'Purple Rain' has striking purple foilage	

Tree Use:
S – Sidewalk Raised Planter Bed **W** – Sidewalk Tree Wells at grade

Latin Name/ Common Name	**Tree Use**	**Mature Height/ Width**	**Summer Leaf Colour**	**Fall Leaf Colour**	**Salt Tolerance**	**Bear Resistance**	**Characteristics**	**Photo**
Amur Maackia Maackia amurensis	S	6m Ht. 6m W.			Low	High	• Small graceful tree good for a small yard • Fragrant, yellowish flowers in spring • Golden bark • Low maintenance & adaptable • Virtually pest-free	
Swedish Columnar Aspen Populus tremula 'erecta'	S, W	12m Ht. 2m W.			Medium	High	• Growing in popularity due to it's beautiful columnar habit • Tough, adaptable & fits into restricted spaces • Nice fall colour, no fluffy seeds & non aggressive roots	
Japanese Tree Lilac Syringa reticulate *'Ivory Silk'*	S, W	7m Ht. 5m W.			Medium	High	• Small tree with oval crown • Very attractive creamy white flower clusters • Nice specimen for small yard or large planter • Tough tree for urban conditions • Probably underused	

Tree Use:

S – Sidewalk Raised Planter Bed **W** – Sidewalk Tree Wells at grade

Latin Name/ Common Name	Tree Use	Mature Height/ Width	Summer Leaf Colour	Fall Leaf Colour	Salt Tolerance	Bear Resistance	Characteristics	Photo
Linden sp. Tilia cordata Tilia mongolica *'Corinthian'* *'Greenspire'* *'Morden'* *'Harvest Gold'* + others	S, W	15m Ht. 5-10m W.			Medium	High	• Well-structured tree requiring little pruning • Beautiful foliage & fragrant flowers • Usually pyramidal in form, but some more upright forms may be available • Very tidy tree – an Arborist's favourite	

Other Tree Species **not recommended for use** or should be **used with caution**, include the following:

- **Box Elder or Manitoba Maple (Acer negundo) -** Not very pollution, salt, and drought tolerant.
- **Sugar Maple (Acer saccharum)** – Not very pollution, salt, and drought tolerant.
- **Ohio Buckeye (Aesculus glabra)** – Not very pollution, salt, and drought tolerant. Produces nuts.
- **Hackberry (Celtis occidentalis)** – Large tree that requires room and is susceptible to disease.
- **Morden Hawthorne (Crataegus mordenensis)** – 3" thorns present a risk to pedestrians.
- **Russian Olive (Eleagnus angustifolia)** – Poor form, brittle branching system, and drainage issues can occur.
- **Black Ash & Patmore Ash (Fraxinus species)** – Overabundant in PG and pest concerns are present.
- **Butternut (Juglans cinera)** – Produces nuts, it is not compatible with urban soils, and is susceptible to fungus.
- **Flowering Crabs (Malus species)** – Crab trees produce fruit and are attractants to bears.
- **Burr Oak (Quercus macrocarpa)** – Too large for a street tree environment and branches are at a 90 degree angle.
- **Mayday & Chokecherry (Prunus padus)** – Produces fruit and are attractants to bears. Black knot disease is prominent.
- **Mountain Ash (Sorbus aucuparia/decora)** – Produces fruit and are attractants to bears.
- **Redmond Linden (Tilia americana 'Redmond')** – Too large for a street tree environment.
- **Elm (Ulmus americana)** – Too large for a street tree environment and roots can be aggressive.

Appendix C : PG Airport Precipitation

Existing IDF Curve

		Recurrence (years)						
		2	5	10	20	25	50	100
Periods	5 min	4.5	6.5	8.1	10.0	10.7	13.0	15.8
	10 min	6.1	8.6	10.6	12.8	13.6	16.3	19.4
	15 min	7.0	9.9	12.3	15.1	16.1	19.5	23.5
	30 min	8.2	11.7	14.4	17.4	18.5	22.0	26.1
	1 h	9.8	13.6	16.6	19.9	21.0	24.8	29.1
	2 h	11.7	15.5	18.7	22.5	23.9	28.8	34.6
	6 h	16.7	21.5	25.4	29.8	31.4	36.8	43.0
	12 h	20.8	26.1	30.4	35.2	36.9	42.7	49.4
	24 h	27.5	34.2	38.6	42.9	44.3	48.5	52.8

IPCC Climate ChangeScenarios

RCP 2.6

		Recurrence periods (years)						
		2	5	10	20	25	50	100
Periods	5 min	4.9	6.9	8.7	10.8	11.6	14.1	17.3
	10 min	6.6	9.2	11.3	13.8	14.7	17.7	21.3
	15 min	7.6	10.6	13.2	16.2	17.4	21.1	25.8
	30 min	8.9	12.5	15.5	18.8	20.1	23.9	28.6
	1 h	10.7	14.6	17.8	21.5	22.8	27.0	32.0
	2 h	12.7	16.5	20.0	24.1	25.8	31.0	37.9
	6 h	18.2	22.9	27.2	32.1	33.9	39.8	47.3
	12 h	22.7	27.8	32.5	37.8	39.8	46.2	54.5
	24 h	30.0	36.7	41.4	46.3	47.9	52.9	57.8

RCP 4.5

		Recurrence periods (years)						
		2	5	10	20	25	50	100
Periods	5 min	4.9	7.1	8.9	11.0	11.7	14.2	17.2
	10 min	6.7	9.4	11.6	14.1	14.9	17.8	21.2
	15 min	7.7	10.8	13.5	16.5	17.5	21.2	25.6
	30 min	9.0	12.8	15.8	19.2	20.3	24.0	28.6
	1 h	10.8	14.9	18.2	21.9	23.1	27.1	32.1
	2 h	12.8	16.9	20.5	24.6	26.1	31.2	37.6
	6 h	18.4	23.5	27.9	32.7	34.5	40.0	47.2
	12 h	22.9	28.5	33.3	38.7	40.6	46.4	54.4
	24 h	30.3	37.5	42.3	47.4	49.0	53.4	57.9

RCP 8.5

		Recurrence periods (years)						
		2	5	10	20	25	50	100
Periods	5 min	5.1	7.5	9.5	11.8	12.6	15.4	18.9
	10 min	7.0	9.9	12.4	15.1	16.1	19.3	23.2
	15 min	8.1	11.4	14.5	17.7	18.9	23.0	28.2
	30 min	9.4	13.5	17.0	20.6	21.9	26.2	31.3
	1 h	11.3	15.8	19.6	23.5	24.9	29.6	35.0
	2 h	13.4	17.8	22.0	26.5	28.1	33.9	41.7
	6 h	19.3	24.8	29.9	35.2	37.1	43.6	51.4
	12 h	24.0	30.1	35.8	41.6	43.6	50.8	59.1
	24 h	31.7	39.6	45.6	50.9	52.8	57.9	62.8

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