INTEGRATED INFRASTRUCTURE CAPITAL PLAN (IICP)

Prioritized Stormwater System Capital Plan

Prepared for:

The City of Castlegar

August 2018

Submitted by:

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Report for

Integrated Infrastructure Capital Plan (IICP)
Prioritized Stormwater System Capital Plan

Prepared for

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1.0 INTRODUCTION

Climate change is an important issue for British Columbia. One of the most serious impacts of climate change is the increase of extreme events – warm days and precipitation. Climate forecasts suggest that the province will experience temperature increases by mid-century, relative to historical average, of between 2 to 4°C. It is anticipated that the number of heavy precipitation events will increase in frequency and magnitude and there will be a shift in the seasonal pattern of occurrence. These changes will result in more droughts, floods and increased extreme weather events potentially resulting in catastrophic infrastructure failure. This change in climate will also likely result in decreased infrastructure service-life. For example, an increased frequency of freeze/thaw events will degrade roads and the increased frequency and magnitude of extreme precipitation events will result in floods and potential infrastructure damage due to undersized drainage capacity.

Incorporation of climate change into asset management and master plans has so far been limited, with the vast majority of new infrastructure continuing to be designed using established codes or history-based, asset-specific environmental criteria. The impacts of climate change will increase infrastructure replacement and maintenance costs as we move forward. The climate-related challenges that communities face are compounded by the maintenance, monitoring and replacement costs of aging infrastructure.

The objective of this report is to provide a risk-based approach and an intuitive process to integrate climate change with asset management into the capital planning process for the City's stormwater infrastructure.

1.1 Background

In 2010, a PIEVC Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment was completed for the City of Castlegar's stormwater infrastructure. The intent of this PIEVC Protocol was to improve the community's understanding of the context for developing local climate change adaptation strategies. To date, the results of this assessment have not been incorporated in any City plan. The City of Castlegar recently received funding under the Strategic Priorities Fund for the development of an Asset Management and Climate Change Prioritization Framework that incorporates the PIEVC results for the City's linear infrastructure assets.

The primary outcomes from this assignment are:

- To establish an understanding of the existing stormwater system by creating a reliable and accurate hydraulic model;
- To create a prioritized list of renewal (condition) and capacity (growth) projects that embraces a triple bottom line approach and addresses all legislation/regulations, aging infrastructure and future growth (asset management plan) and has considerations for a changing climate;

- Conduct a climate change vulnerability assessment and create a scenario where these results are integrated with the asset management plan;
- Identify the funding requirements needed to meet the City's risk and service level requirements for infrastructure investment on an average annual basis;
- Utilize results to inform an integrated capital plan for roads, water, drainage and sanitary sewer; and
- To provide sufficient knowledge transfer to allow City staff to adopt and utilize the decision-making process for capital planning and infrastructure investment decision-making.

1.2 Technical Memoranda

Four (4) technical memoranda were completed throughout this study to inform the overall strategy. Each section of the master plan is derived from previous analyses discussed in these memoranda.

For readability, only summary information from each technical memorandum is provided in this report where required to support the capital plan. However, for convenience a reference note is provided in key sections for the location of the related technical memorandum to allow the reader access to more information, if desired. Furthermore, some key findings from the technical memoranda are also included in order to support conclusions. **Table 1.1** below lists the technical memoranda; they are located within **Appendix A.**

Table 1.1 - List of Technical Memoranda

	Description
1	Design Criteria and Analysis
2	Hydraulic Modelling Results
3	Storm Sewer Capacity Risk Assessment Methodology
4	Storm Sewer Condition Risk Assessment Methodology

1.3 Community Context

The City's vision for the community is to create a resilient, financially sustainable and healthy community through sound fiscal management, smart growth development, and wise asset reinvestment. The goal of this vision has been incorporated into this plan.

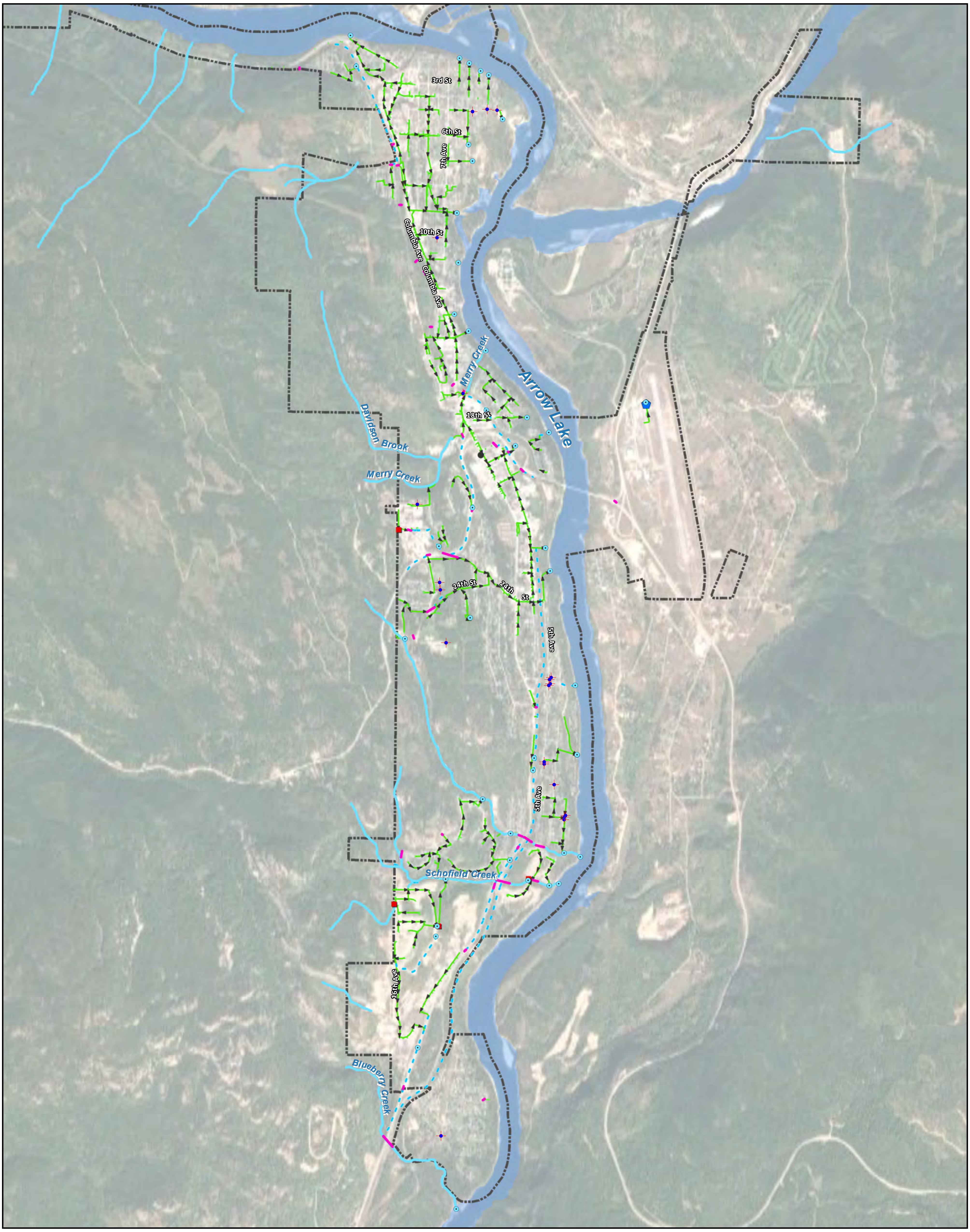
1.4 Current Storm Sewer Infrastructure

The City sits along and drains into the Columbia River. The City's water supply is also taken from the Columbia River upstream of the City's boundary. Other creeks, notably Merry Creek and

Schofield Creek, drain to the river through the City's storm drain system. The City relies on an underground collection system made up of approximately 43 km of pipe which gathers the surface water and conveys it to the creeks or the Columbia River.

Figure A shows the existing storm system, along with key physical features such as the creeks.

The total estimated replacement value for the existing stormwater assets (piped network only) is approximately $30 million based on the asset management assessment. These replacement costs include the existing collection system components such as mains and manholes, drywells, catch basins, and some ditches. It does not provide a valuation of the major receiving/conveyance systems such as Merry Creek, Schofield Creek and Blueberry Creek.



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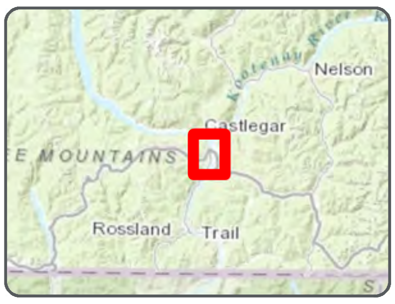
City of Castlegar

Integrated Infrastructure
Capital Plan (IICP)

Existing Storm System

Legend

- ✦ Dry Well
- ⊙ Outfall
- ■ Headwall
- ⬟ Oil/Silt Separator
- ● Storage Basin
- ▬ Culvert
- ▬ Watercourse
- ─ Catch Basin Lead
- ─► Gravity Main
- - - Ditch / Overland Flow Path



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Metres

N

Coordinate System:
NAD 1983 UTM Zone 11N

Scale:
1:32,000

Data Sources:

Data provided by -
City of Castlegar
Urban Systems

Project #: 0841.0099.01
Author: BP
Checked: SS
Status: ~ DRAFT ~
Revision: A
Date: 2017 / 11 / 28

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FIGURE A

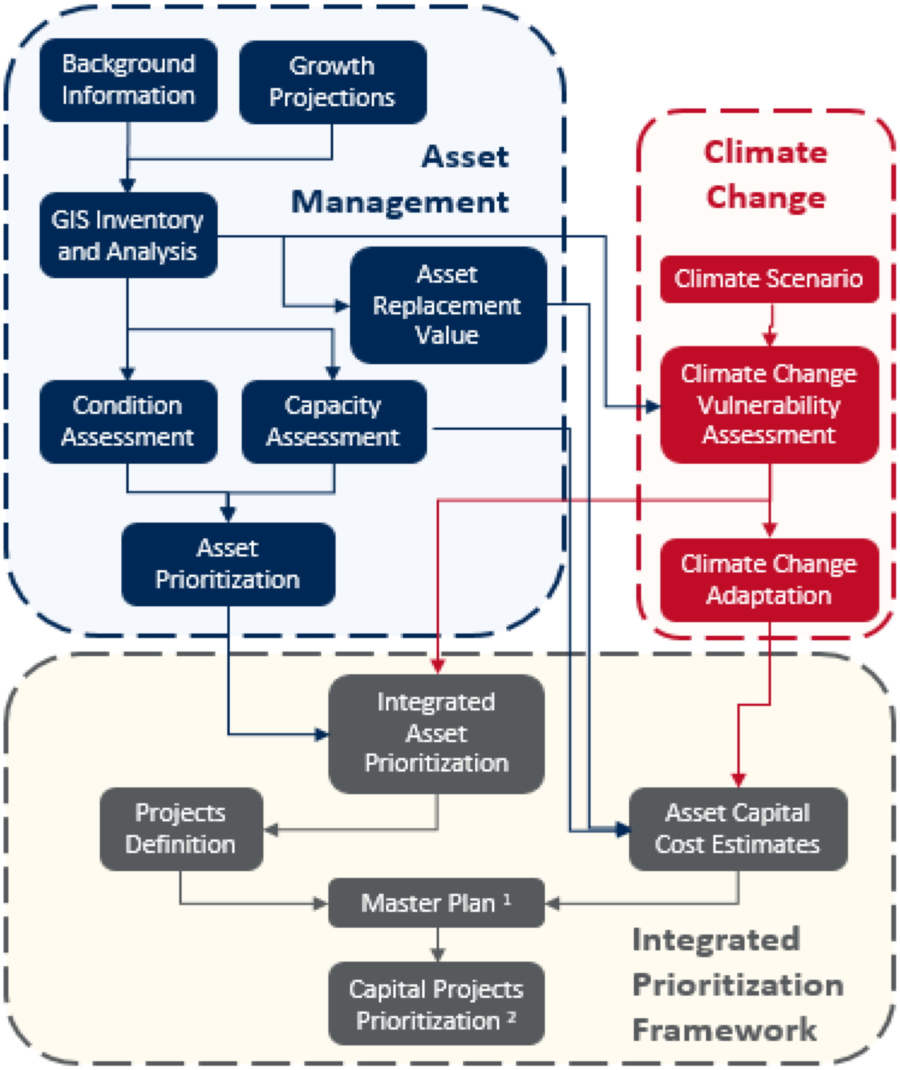
U:\Projects_KEL\0841\0099\01\D-Drafting-Design-Analysis\GIS\Projects\MXD\Current\Figure A - Existing Storm System Overview.mxd Last updated by bpauls on November 28, 2017 at 2:11:39 PM

1.5 Guiding Approach

The approach to integrating climate change into the asset management risk assessment is to first assess pipe performance on flows in an existing conditions scenario followed by a future conditions scenario in an asset management capacity context. Upon completion of this, climate change parameters will be added into the model and a sensitivity analysis will be completed.

The asset management risk assessment typically tells us how to prioritize these capacity-related upgrades so that pipes that present the highest risk can be upgraded first. In order to consider climate change, these scenarios were analyzed again using the climate parameters discussed below in **Section 4.6**. Figure B below illustrates the methodology and integration of climate change.

Figure B – Integrating Climate Change into Asset Management



2.0 ASSET MANAGEMENT RISK ASSESSMENT

Each drainage system consists of the following components:

1. The Minor System – underground pipes and culverts that are designed to convey flows from rainfall events with a specified return frequency (in this case, 1:10 years).
2. The Major System – surface flood paths, roadways, swales and water courses that are designed to convey flows from rainfall events with a specified return frequency (in this case, 1:100 years).

The methodology for the minor system is broken down into three parts:

Assessment of the Likelihood of Failure

Assessment of the Consequence of Failure

Risk Score

The capacity risk scores for the minor system will be used in conjunction with condition risk scores to help guide the prioritized infrastructure capital replacement process. The risk assessment tells us how to prioritize these capacity and condition related upgrades so that pipes presenting the highest risk can be upgraded first.

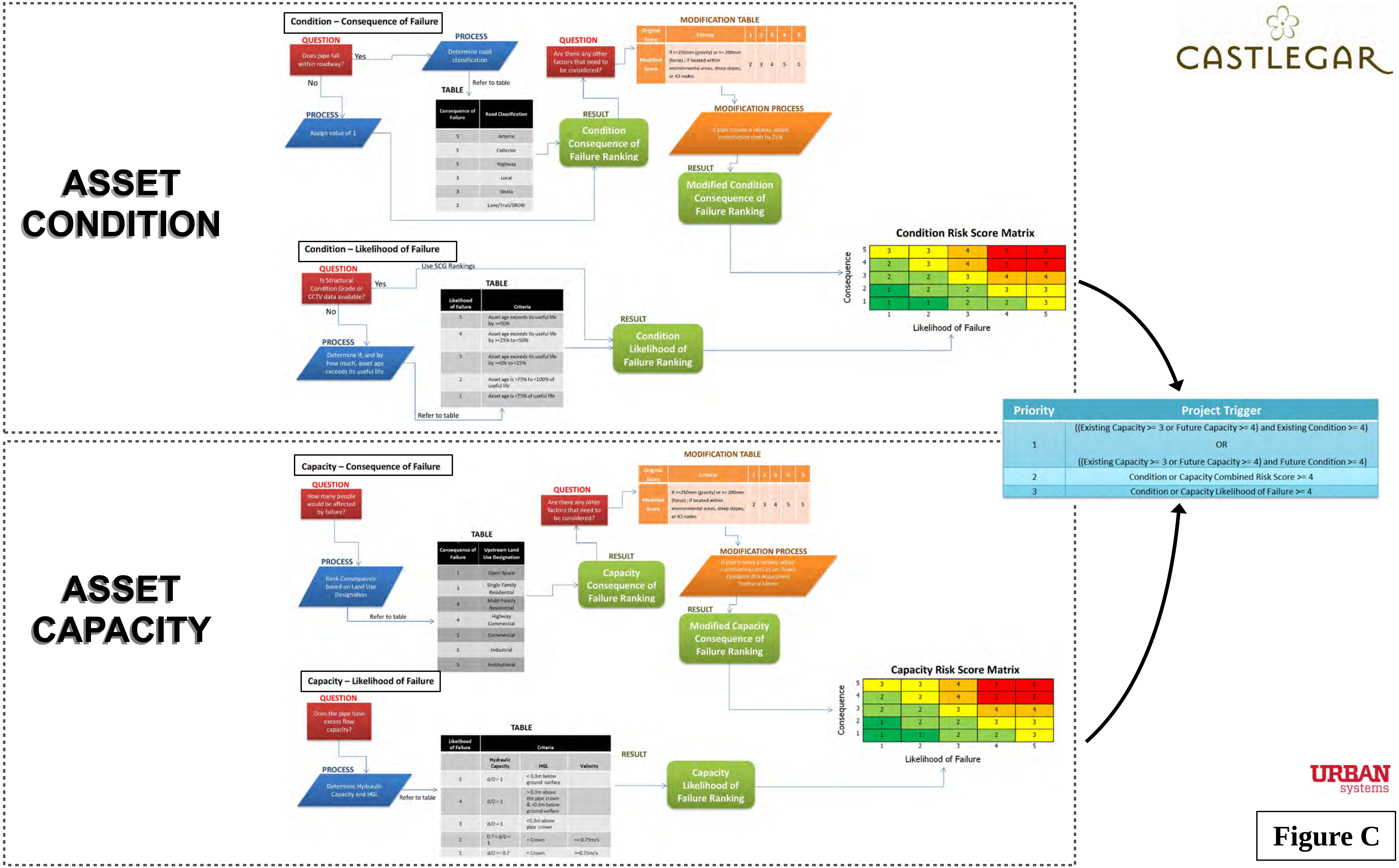
A vulnerability assessment of the major storm system was also completed as part of the PIEVC report.

A more detailed look at the major system was not part of this study, but it is recommended. To understand risk associated with the major system, it is important that the City identifies areas of localized flooding and the overland flow routes using detailed site topography. Likely causes of localized flooding could be caused by pipe blockages, poor inlet capacity or poor boulevard grading.

For this type of assignment, the City would require a high-quality LiDAR dataset. A Geographic Information System (GIS) would be used to create a surface model derived from the LiDAR. The surface model would be fed into ArcHydro (a hydrologic GIS extension) to determine the overland flow path of water leaving any surcharging manholes. The surface model would also be used to locate potential storage depressions along the flow paths. Depression volumes would be compared with flow volumes to determine if the flow from the manholes could be contained by the depressions. Flow paths and depressions can be prioritized for risk based on the type of land use impacted.

CASTLEGAR ASSET RISK EVALUATION PROCESS - a combination of condition & capacity; consequence & likelihood

STORM



ASSET CONDITION

Condition – Consequence of Failure

QUESTION: Does pipe fall within roadway?

Yes → PROCESS: Determine road classification → Refer to table

No → PROCESS: Assign value of 1

TABLE

Consequence of Failure	Road Classification
5	Arterial
5	Collector
5	Highway
3	Local
3	Strata
2	Lane/Trail/SROW

RESULT: Condition Consequence of Failure Ranking

QUESTION: Are there any other factors that need to be considered?

MODIFICATION TABLE

Original Score	Criteria	1	2	3	4	5
Modified Score	If >=250mm (gravity) or >= 200mm (force) ; if located within environmental areas, steep slopes, or ICI nodes	2	3	4	5	5

MODIFICATION PROCESS: If pipe crosses a railway, adjust construction costs by 25%

RESULT: Modified Condition Consequence of Failure Ranking

Condition – Likelihood of Failure

QUESTION: Is Structural Condition Grade or CCTV data available?

Yes → Use SCG Rankings

No → PROCESS: Determine if, and by how much, asset age exceeds its useful life. → Refer to table

TABLE

Likelihood of Failure	Criteria
5	Asset age exceeds its useful life by >=50%
4	Asset age exceeds its useful life by >=25% to <50%
3	Asset age exceeds its useful life by >=0% to <25%
2	Asset age is >75% to <100% of useful life
1	Asset age is <75% of useful life

RESULT: Condition Likelihood of Failure Ranking

Condition Risk Score Matrix

Consequence \ Likelihood of Failure	1	2	3	4	5
5	3	3	4	5	5
4	2	3	4	5	5
3	2	2	3	4	4
2	1	2	2	3	3
1	1	1	2	2	3

ASSET CAPACITY

Capacity – Consequence of Failure

QUESTION: How many people would be affected by failure?

PROCESS: Rank Consequence based on Land Use Designation → Refer to table

TABLE

Consequence of Failure	Upstream Land Use Designation
1	Open Space
3	Single Family Residential
4	Multi-Family Residential
4	Highway Commercial
5	Commercial
5	Industrial
5	Institutional

RESULT: Capacity Consequence of Failure Ranking

QUESTION: Are there any other factors that need to be considered?

MODIFICATION TABLE

Original Score	Criteria	1	2	3	4	5
Modified Score	If >=250mm (gravity) or >= 200mm (force) ; if located within environmental areas, steep slopes, or ICI nodes	2	3	4	5	5

MODIFICATION PROCESS: If pipe crosses a railway, adjust construction costs as per Sewer Condition Risk Assessment Technical Memo

RESULT: Modified Capacity Consequence of Failure Ranking

Capacity – Likelihood of Failure

QUESTION: Does the pipe have excess flow capacity?

PROCESS: Determine Hydraulic Capacity and HGL → Refer to table

TABLE

Likelihood of Failure	Criteria		
	Hydraulic Capacity	HGL	Velocity
5	d/D = 1	< 0.3m below ground surface	
4	d/D = 1	> 0.3m above the pipe crown & >0.3m below ground surface	
3	d/D = 1	<0.3m above pipe crown	
2	0.7 < d/D < 1	< Crown	<= 0.75m/s
1	d/D <= 0.7	< Crown	>=0.75m/s

RESULT: Capacity Likelihood of Failure Ranking

Capacity Risk Score Matrix

Consequence \ Likelihood of Failure	1	2	3	4	5
5	3	3	4	5	5
4	2	3	4	5	5
3	2	2	3	4	4
2	1	2	2	3	3
1	1	1	2	2	3

Priority	Project Trigger
1	((Existing Capacity >= 3 or Future Capacity >= 4) and Existing Condition >= 4) OR ((Existing Capacity >= 3 or Future Capacity >= 4) and Future Condition >= 4)
2	Condition or Capacity Combined Risk Score >= 4
3	Condition or Capacity Likelihood of Failure >= 4

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Figure C

2.1 Methodology

The risk assessment for the minor system was completed with a focus on the two primary drivers of pipe failure: **condition** and **capacity**. For each of these drivers, the risk assessment was broken down into three parts:

1. Likelihood of failure (i.e., probability)
2. Consequence of failure (i.e., severity of environmental, social, and economic impacts)
3. Assignment of total risk scores (after modification, if any, and combination of scores)

Once risk scores were assigned, *prioritization of assets* could be completed according to which assets had the highest combined risk scores.

Definitions of each of these parts and assignment of risk scores for use in the risk assessment are provided below.

2.2 Risk Due to Pipe Capacity

Likelihood of Failure: The likelihood of failure due to capacity was assessed by analyzing the hydraulic capacity, HGL, and the depth of water level above ground surface as completed in the storm system hydraulic model. How criteria specifically correlate to likelihood of failure is described in **Technical Memorandum #3.**

Consequence of Failure: The consequence of failure is a function of the population density and cost of flooding (based on land use type). Risk scores are assigned a range from 1 to 5, with 1 indicating an insignificant consequence of failure and 5 indicating a severe consequence of failure. How criteria specifically correlate to consequence of failure is described in **Technical Memorandum #3.**

2.3 Risk Due to Pipe Condition

Likelihood of Failure: The likelihood of condition-based failure is driven by the Structural Condition Grade (SCG) of the asset. In this case, SCGs were not available and so for pipes and non-pipe assets, the asset was assigned a risk score based on its age. Asset age directly relates to the principles of asset management and tangible capital asset inventories. In some cases, operator knowledge of the condition of a pipe was used instead of asset age. To exemplify the sensitivity of pipe age to the overall risk score, we provided two additional risk scenarios – one extended service lives by 25% and the other by 50%. These scenarios allow the City to easily observe the financial impact of choosing to take on more or less risk related to timing of asset replacement. Risk scores range from 1 to 5, with 1 indicating a low likelihood of failure and 5 indicating a high likelihood of failure. How criteria specifically correlate to likelihood of failure is described in **Technical Memorandum #4.**

Consequence of Failure: The consequence of failure is driven by two key factors: the cost to restore service and cover third-party liability (potential financial consequence) and the actual location of the infrastructure (potential population, land use and traffic disruption consequence). How criteria specifically correlate to likelihood of failure is described in **Technical Memorandum #4.**

This study also considered a primary driver of failure consequence to be whether a pipe is located within a road and if so, what the associated road classification is, as this indicates the level of traffic disruption that may occur due to failure. The cost to repair a storm main break is closely linked to the type of road (and associated volume) that might be damaged as a result; for example, a failure within an arterial road presents greater traffic control and road reconstruction requirements than a failure within a local road. The City's GIS data set was used to analyze if a pipe is physically located within a road and if so, what the road classification and volume is.

2.4 Modification of Consequence Risk Scores

Due to their larger size or nearby surroundings, some storm sewer mains present an increased level of consequence of failure. For this risk assessment, consequence risk scores were increased by one (with no score greater than five) for pipes that met certain requirements regarding:

- **Pipe diameter**: higher consequences for pipes carrying larger flows
- **Proximity to Industrial, Commercial, or Institutional (ICI) land use**: higher economic consequences if flooding occurs in these areas
- **Proximity to an environmentally sensitive area:** higher environmental consequences if adjacent to, or crossing, a sensitive watercourse, within an OCP designated ESA, or within a steep slope area

2.5 Combining Risk Scores

The combined risk score incorporates the likelihood of failure score and consequence of failure score into a single score ranging from 1 to 5, with 1 indicating a low risk and 5 indicating a high risk. In cases where video evidence or manual investigation proves that a storm main has already failed, the combined risk score will be automatically set to 5.

By combining risk scores, the social (land use) and economic (cost to restore service) impacts of pipe failure are considered. This methodology is the basis of this plan. Additional infrastructure planning techniques were also applied to further narrow the list of asset replacements by incorporating desired levels of service and combined asset risk scores. These are discussed in the following sections.

To illustrate this methodology and for convenient reference, a pullout schematic (**Figure C**) is included with this document. It shows how the methodology is applied; once familiar with the definitions, the schematic should be an effective tool for the City to use for visualizing the process.

2.6 Climate Change Scenario

Drainage infrastructure capacity is sensitive to changes in surface flow rates, which can be impacted by a variety of climate variables – either individually or combined. Condition impacts are also related to surface flow, but are a function of the amount of abrasives and debris carried with it. Given these considerations, the potential responses to climate change are as follows:

- Changes to flow rates (design loads) from natural, upstream catchments due to changes in rainfall and snowmelt (a function of snow accumulation, temperature, wind, solar radiation, soil moisture, and rain-on-snow events).
- Changes to flow rates (design loads) from urban catchments due to changes in rainfall intensities, durations, and frequencies.
- Changes to sediment and debris loading within natural streams due to changes in soil moisture, stream flow rates, and vegetation.

The climate risk and vulnerability assessment for the drainage infrastructure was conducted using two methods:

1. Estimating the impact on service life due to failure mechanisms influenced by projected climate changes, and
2. Conducting hydrologic and hydraulic analyses of the drainage system using design storms generated from projected IDF curves to evaluate capacity.

CLIMATE CHANGE RISK ASSESSMENT - METHODOLOGY

The climate change risk assessment focuses on developing the likelihood that a future change in climate variables will result in a material change in the processes that cause reduced capacity and/or reduced service life for each stormwater asset. This approach has been taken since it is often the combination of climate variables, rather than a single climate variable, that contributes to the impact that each process has on an asset's capacity and/or longevity.

In keeping with the likelihood scoring method outlined for the asset management risk assessment (1-5 scale), weighted likelihood scores were developed for the climate change risk assessment. This was done using the following methodology:

1. Identify processes that impact an asset's capacity and/or service life. These are called "failure mechanisms" for the purposes of this assessment since, over time, these contribute to an asset's ultimate failure.
2. Determine the climate variables that impact each identified process.
3. Obtain the baseline value for each climate variable.
4. Obtain the projected values (or projected change in values) for each climate variable for applicable time periods. In this case, the time periods are:
    - Baseline (1961-1990)
    - 2050s (2040-2069)

5. Assign a likelihood score to each climate variable change. Scoring is an integer from 1 to 5, with 1 being very unlikely and 5 being very likely.
6. Assign "climate contribution scores" to reflect the contribution that the projected change in each climate variable associated with each process has on that process. A scoring range of -2 to +2 was used, with the allowance of decimal fractions within that range. A score of -2 indicates that the projected change in the subject climate parameter significantly impacts the process but reduces or perhaps even reverses the reduction in capacity and/or service life. A score of +2 also significantly impacts the process but increases the reduction in capacity and/or service life. Note that this process relies heavily on engineering judgement based on experience.
7. Calculate the weighted likelihood for each failure process using the climate variable likelihood scores and weighting them by the absolute value of the corresponding contribution scores.

*Note that the projected climate values are based on the PCIC ensemble of SRES AR4 - A1 runs. These represent the "business as usual" approach which means increasing concentrations of greenhouse gases at current rates.

FAILURE MECHANISMS

Four failure mechanisms were identified for the climate risk analysis – two which impact condition, and two which impact capacity. These are listed in Table 2.1.

Table 2.1: Drainage Infrastructure Failure Mechanisms

Failure Mechanism	Condition	Capacity	Comments
Soil acidification - exterior pipe corrosion	X		*function of soil type (sand, gravel); pipe material (ferrous metals)*
Streamflow - High Flowrate		X	*loads for culverts, bridges, and trunk storm sewers*
Streamflow - With Sediment	X		*abrasive wear in culverts and trunk storm sewers*
Surface stormwater runoff		X	*sanitary inflow and storm sewer loads*

CLIMATE VARIABLES

The following climate variables were selected for the storm sewer climate change risk assessment based on the identified failure mechanisms.

Climate Variable	Rationale
Precipitation - High Intensity (10 Y; 15 min)	This rainfall event has the potential to generate high flow rates for the minor drainage systems within urbanized areas.
Precipitation - High Intensity (100 Y; 12 hr)	This rainfall event has the potential to generate high flow rates for the major drainage systems within urbanized areas.
Precipitation - Spring Season (MAM)	Springtime rainfall events can impact surface flow rates from natural, upstream catchments. This is especially true if the rainfall occurs on a “ripe” snowpack.
Temperature - Average Annual	Provides an indication of potential changes to plant growth and wildfire conditions. A change in both could affect the amount of material available as debris.
Temperature - Extreme High	Provides an indication of potential changes to wildfire conditions. A change could affect the amount of material available as debris as well as peak runoff from upland catchments.
Temperature – Springtime High (MAM)	High springtime temperatures can trigger rapid snowmelt events.
Soil Moisture – Annual Fluctuation	Changes to soil moisture can potentially impact slope stability, which in turn can impact the amount of sediment and debris available with natural streams. Increased bed loads could increase wear of culverts and storm sewers carrying these flows.
Soil Moisture – Fall Season (SON)	Autumn soil moisture plays a role in spring runoff rates and volumes from natural, upland catchments.
Snow Accumulation – Spring Season (MAM)	This is the critical time for snowmelt, and high accumulations during this period increase the likelihood of high flow rates from natural upstream catchments.
Streamflow - Average Annual Maximum	Key capacity indicator for major system drainage infrastructure that conveys runoff from upland catchments.
Freeze/Thaw Cycles - Annual	Repeated freeze/thaw cycles can affect soil stability along and above stream channels. Changes could affect the amount of sediment in the streams.
Incident Solar Radiation - Spring Season (MAM)	This climate variable has a significant impact on snowmelt. Changes could influence peak runoff from upland catchments.

CLIMATE CHANGE RISK ASSESSMENT – RESULTS

The weighted likelihoods for each of the identified failure mechanisms are provided in Table 2.2. The table also includes the baseline and projected values for the identified climate variables, their assigned likelihoods, and corresponding failure mechanism contribution scores.

Table 2.2: Climate Change Risk Assessment Analysis

Storm Sewers/Culverts		**Climate Parameters**											
		Temperature - Average Annual	Temperature - Spring Season High (MAM)	Temperature - Extreme High	Precipitation - Spring Season (MAM)	Precipitation - High Intensity (10 Y; 15 min)	Precipitation - High Intensity (100 Y; 12 hr)	Soil Moisture - Fall Season (SON)	Snow Accumulation – Spring Season (MAM)	Incident Solar Radiation - Spring Season (MAM)	Annual Number of Freeze/Thaw Cycles	Streamflow - Average Annual Maximum	Soil Moisture Content - Annual Fluctuation
Baseline		1.8	8.0	36.7	214.4	48.0	4.0	511.7	0.5	182.0	70.0	1.5	94.1
Baseline Units		°C	°C	°C	mm	mm/hr	mm/hr	mm	m	W/m^2	count	L/s/ha	mm
Projected Change (2050s) in Baseline Units		4.1	10.8	40.0	236.0	62.2	4.7	502.1	0.3	174.0	68.6	1.4	109.6
Projected Change (2050s) from Baseline (%)		127%	35%	9%	10%	30%	18%	-2%	-40%	-4%	-2%	-5%	16%
Climate Variable Change Likelihood		5	5	4	5	4	4	3	4	3	2	2	3
Failure Mechanism	**Weighted Likelihood**	**Climate Contribution to Failure Mechanism (-2 to +2)**											
Soil acidification - exterior pipe corrosion	0.8	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Streamflow - High Flowrate	2.0	0.0	2.0	0.0	2.0	0.0	2.0	-0.1	-1.0	-0.1	0.0	2.0	0.0
Streamflow - With Sediment	2.3	2.0	2.0	2.0	2.0	1.5	2.0	-0.1	-1.0	-0.1	-0.1	2.0	1.0
Surface stormwater runoff	4.0	0.0	0.0	0.0	0.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0

Note that capacity is most at risk due to increased surface stormwater runoff. However, infrastructure that conveys stream flows are at medium risk – both in terms of capacity (high flow rate) and condition (sediment abrasion). These weighted risk scores were used to establish climate change adjusted service lives for corresponding assets. Capacity was further analyzed using the identified design storms.

CLIMATE CHANGE CAPACITY ANALYSIS

A PCSWMM computer model of the existing drainage systems was developed to analyze hydraulic capacity under both historical and future design conditions. This model includes a hydrology module which converts rainfall and snowmelt to surface flow hydrographs, which are routed though the drainage system conduits and open channels. The following scenarios were modeled:

- **Scenario 1** – existing drainage infrastructure, existing development, and design storms based on current IDF curves generated from historical rainfall data.
- **Scenario 2** – existing drainage infrastructure, future development, and design storms based on current IDF curves generated from historical rainfall data.
- **Scenario 3** – existing drainage infrastructure, future development, and design storms based on future IDF curves generated from projected rainfall data.
- **Scenario 4** – future drainage infrastructure, future development, and design storms based on future IDF curves generated from projected rainfall data.

In all four scenarios, the following design storms were modeled:

- 1:10 year for the minor drainage system, and
- 1:200 year for the drainage system components which convey runoff from the natural drainage catchments upstream of the City.

The current IDF curves were created by Environment Canada using historical rainfall data from the Castlegar Airport. The future IDF curves were generated using the IDF-CC Tool developed by the University of Western Ontario. They were generated using the following information:

- an ensemble of 24 GCMs
- RCP 8.5
- time period 2050-2100

The 90th percentile values of all 24 GCM results were used. Note that the IDF-CC Tool generates values up to only the 1:100-year return period, so the 1:200-year values were extrapolated.

The modeling results were used to identify capacity deficiencies under both current and future conditions. Also, in both scenarios a copy of the model was created, and deficiencies were addressed by upsizing the conduits (storm sewers and culverts) responsible. This information was input to the asset management risk assessment for capital prioritization, so the costs for any recommended upgrades in the capital prioritization reflect the recommended pipe diameter from the model.

IDF curves and model results are provided in **Appendices A and B.**

2010 PIEVC ASSESSMENT

In 2010, the City of Castlegar completed a Public Infrastructure Engineering Vulnerability Committee (PIEVC) climate change vulnerability assessment for its stormwater infrastructure. This assessment assigned one of three vulnerability categories – low, medium, or high – to each of the 35 stormwater assets identified for assessment. Of these assets, 30 are included in the current Asset Management assessment.

At that time, significantly less information was available about potential climate changes, so the assessment was very much a subjective exercise based on collaborative work relying on experience and professional judgement. Participants from management, operations, maintenance, and engineering - in addition to representatives from the Columbia Basin Trust and Learning Network, Engineers Canada, and the Pacific Climate Impacts Consortium – met for a one-day workshop to complete the actual assessment once available information was collected and organized for this purpose.

Figures F and G show the location of the stormwater assets which were rated as having a high or medium vulnerability to a changing climate in the PIEVC assessment. It also shows the location of culverts and storm sewers which were rated has having a high priority risk (1 or 2) based on the asset management risk assessment. Finally, assets identified as at risk specifically because of the future climate modeling scenario and/or climate influences on pipe condition are also indicated on the maps. Note the following:

- Approximately 2/3 of the assets identified as being vulnerable to climate change by the PIEVC assessment were also identified as having a priority risk based on the Asset Management risk assessment. Approximately 1/4 of these were assessed a priority risk because of the climate change capacity analysis.
- The PIEVC assessment included reaches of natural streams and open channels, which are currently not part of the Asset Management assessment.
- The climate modelling scenario identified significantly more stormwater assets which could be upsized because of increased flows. However, the risk assessment did not result in a priority risk score because the consequences of failure were considered low.

CLIMATE CHANGE INTEGRATION METHODOLOGY

The following methodology was used to incorporate climate change into the linear asset risk assessment and the modelling was re-run:

Table 2.3: Risk Assessment Methodology for Climate Change Influence on Pipe Condition

Trigger	Modeled Parameters	Assets Impacted
Soil acidification caused by changes in soil moisture	Decrease service life by **3%**	Ferrous pressure mains
Weakening of pipes caused by increased soil moisture	Decrease service life by **3%**	Concrete pressure mains
Increased scouring of pipe due to higher sediment load	Decrease in service life: PVC/HDPE 3% Steel 5% Concrete 7% CMP 15%	Storm mains with source water of streams or creeks
High vulnerability risk assets as identified through PIEVC	Risk scores for 2037 scenario set to **5** (max)	Storm mains as identified through PIEVC as well as sanitary and water mains in immediate proximity to vulnerable storm infrastructure

ASSET MANAGEMENT RISK ASSESSMENT – CLIMATE CHANGE SCENARIO

The weighted likelihoods of the identified failure processes contributing to decreased capacity and/or service life were evaluated to develop an asset management risk assessment scenario that includes climate change. The results are shown on page nine.

2.7 Capital Prioritization

The risk analysis was applied to each pipe asset in the City storm sewer system. The result was a database of 779 assets with their own unique classification, with 248 assets with a combined risk score of 4 or 5 for either condition or capacity, or both.

In order to prioritize the inventory of risks into a strategic list of assets, in sequence of importance, a three-step merging process was completed to yield a hierarchy of upgrades based on risk scores. This hierarchy relates directly to **levels of service**. This section describes the methodology and translates level of service into tangible future asset replacement and associated value.

PRIORITIZATION METHODOLOGY

METHODOLOGY

Step 1: **Level of Service 1:** Apply triple-bottom-line analyses to determine risk scores based on considerations for social (population/land use), economic (cost implications) and environment (water resources). This step combines multiple facets of risk, including conditions *and* capacity, likelihood *and* consequence of failure, and existing *and* future scenarios. The projects triggered here are considered **Priority 1 (highest priority)** because they are classified comprehensively.

Step 2: **Level of Service 2:** Determine which assets had a combined score of 4 or greater for *either* condition or capacity (still based on both likelihood and consequence of failure). Although this step does still incorporate the triple-bottom-line analyses of the previous step, it triggers projects that demonstrate sufficient risk for either condition *or* capacity. These projects are considered **Priority 2 (moderate priority)**. It is possible that a Priority 2 project could be prioritized above a Priority 1 project if it is deemed to have sufficient impact on the system due to capacity *or* condition issues. For example, a pipe with plenty of remaining life may have capacity issues due to recent development. Alternatively, a pipe may have excess capacity, but be experiencing frequent breaks.

Step 3: **Level of Service 3:** Determine which assets scored a 4 or greater under *likelihood of failure* for *either* condition or capacity. Therefore, projects arising from Step 3 are triggered by their probability of failure, but not by the impact of that failure. These projects are considered **Priority 3 (low priority)**.

This methodology results in a three-tiered prioritization of projects, which was used to create a list of capital priorities.

2.8 Summary of the Prioritized Results

A list of capital upgrades under each category was compiled from the outputs of the risk assessment. The results of the capital prioritization process are categorized by priorities. The scope of upgrade depends on the primary trigger: for example, if a pipe was triggered for an upgrade due to capacity, the pipe will be replaced with one of greater diameter. Alternatively, if a pipe was triggered for an upgrade due to condition (with a capacity score of less than 3) the pipe will be replaced by one of equivalent diameter.

The results of the capital prioritization process are summarized in **Table 2.4**.

Table 2.4: Capital Prioritization Results of Pipe Assets

Prioritization - Asset Management Scenario									
Asset Category	**# of Pipes**	**Length of Pipe (km)**	**0-5 Year**	**0-5 Year Replacement Cost**	**5-10 Year**	**5-10 Year Replacement Cost**	**10-20 Year**	**10-20 Year Replacement Cost**	**Total Replacement Cost**
Priority 1	178	9.4	51	$ 1,819,236	10	$ 492,785	117	$ 4,704,615	**$ 7,016,636**
Priority 2									
Condition	43	2.6	6	$ 637,319	5	$ 282,862	38	$ 766,426	**$ 2,285,048**
Capacity	10	0.4	5	$ 99,167	5	$ 117,273	2	$ 210,831	**$ 216,441**
Priority 3									
Condition	20	0.6	0	$ -	0	$ -	32	$ 892,099	**$ 509,962**
Capacity	0	0.0	0	$ -	0	$ -	0	$ -	**$ -**
New Pipes	-	-	-	$ 1,000,000	-	$ 700,000	-	-	**$ 1,700,000**
Facilities									**$ -**
Total	**251**	**13.0**	**62**	**$ 3,555,723**	**20**	**$ 1,592,920**	**169**	**$ 6,579,444**	**$ 11,728,087**

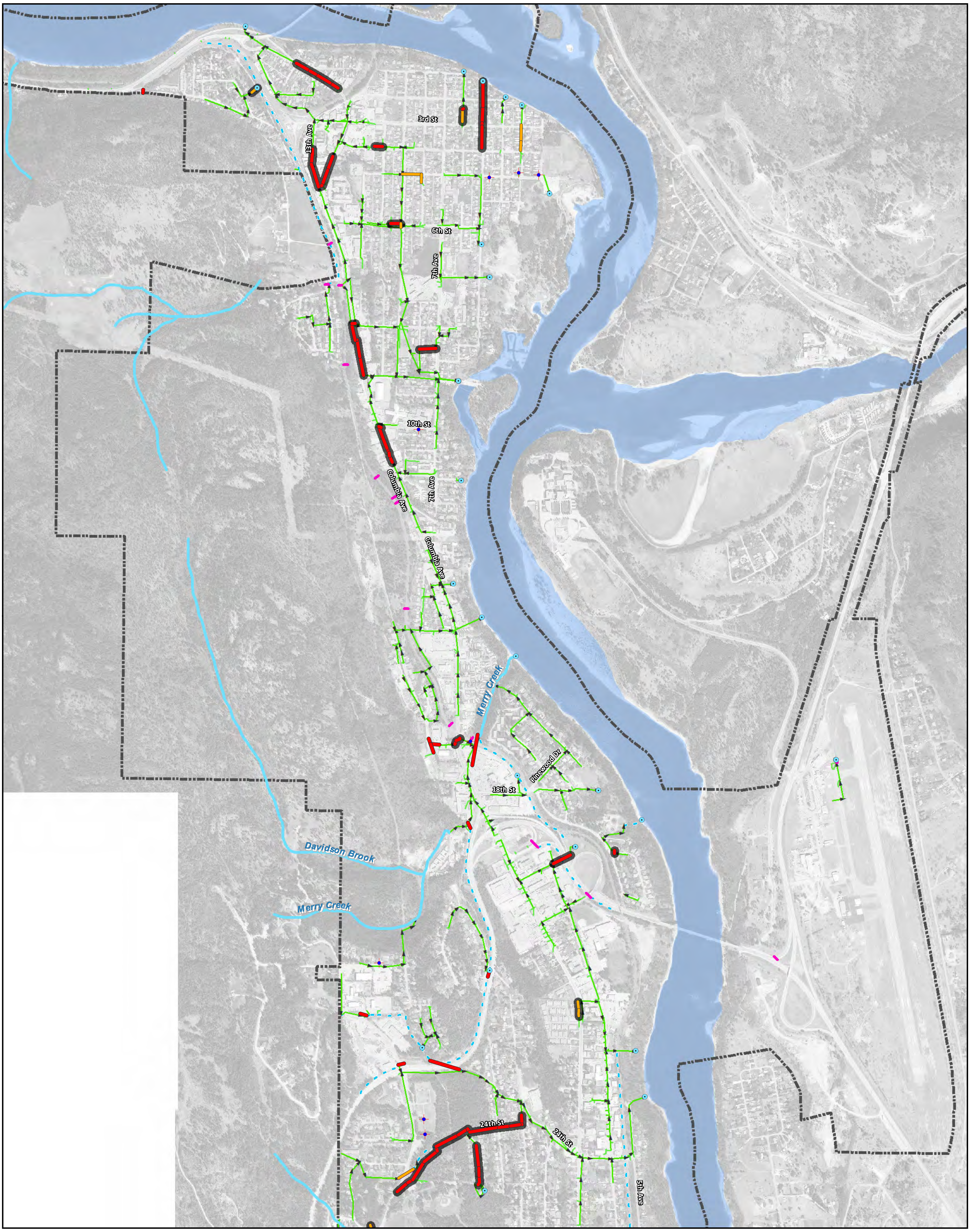
The average annual cost of for ‘critical’ linear assets is **$586,000**. This amount includes:

- Priority 1 pipes,
- Priority 2 pipes,
- Priority 3 pipes, and
- Previously planned storm expansion and development projects (2019 to 2025).

It should be noted that nearly 20% of the annual cost is related to priority 2 condition triggered pipes. There are opportunities for costs related to this category to be significantly reduced, for several reasons:

1. These pipes are potential candidates for trenchless rehabilitation. A separate investigation can be undertaken to determine trenchless candidates, and to calculate the cost savings that this rehabilitation method can realize.
2. Condition-only triggers are highly dependent on the assumed service life of the pipe, since CCTV information for the storm system was not available. It is very likely that many of these pipes will outlive their assumed service life and last well beyond the 20-year planning horizon. A CCTV program for these pipes could help refine this list.

Figures D and E illustrate the locations of the Priority 1 and 2 pipes.



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City of Castlegar

Integrated Infrastructure Capital Plan (IICP)

Storm Priority Pipes - North

Legend

- ✛ Dry Well
- ⊙ Outfall
- 🟥 Priority 1 Storm Mains (0-10 Years)
- 🟧 Priority 2 Storm Mains (0-10 Years)
- Culvert
- Watercourse
- Catch Basin Lead
- → Gravity Main
- - - Ditch / Overland Flow Path

Timing

- ▬ 0-5 Years

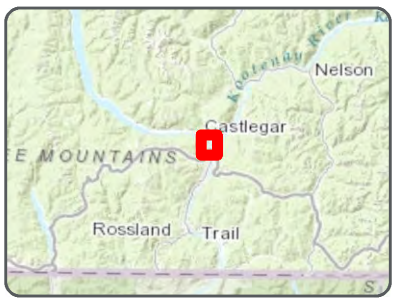

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FIGURE D

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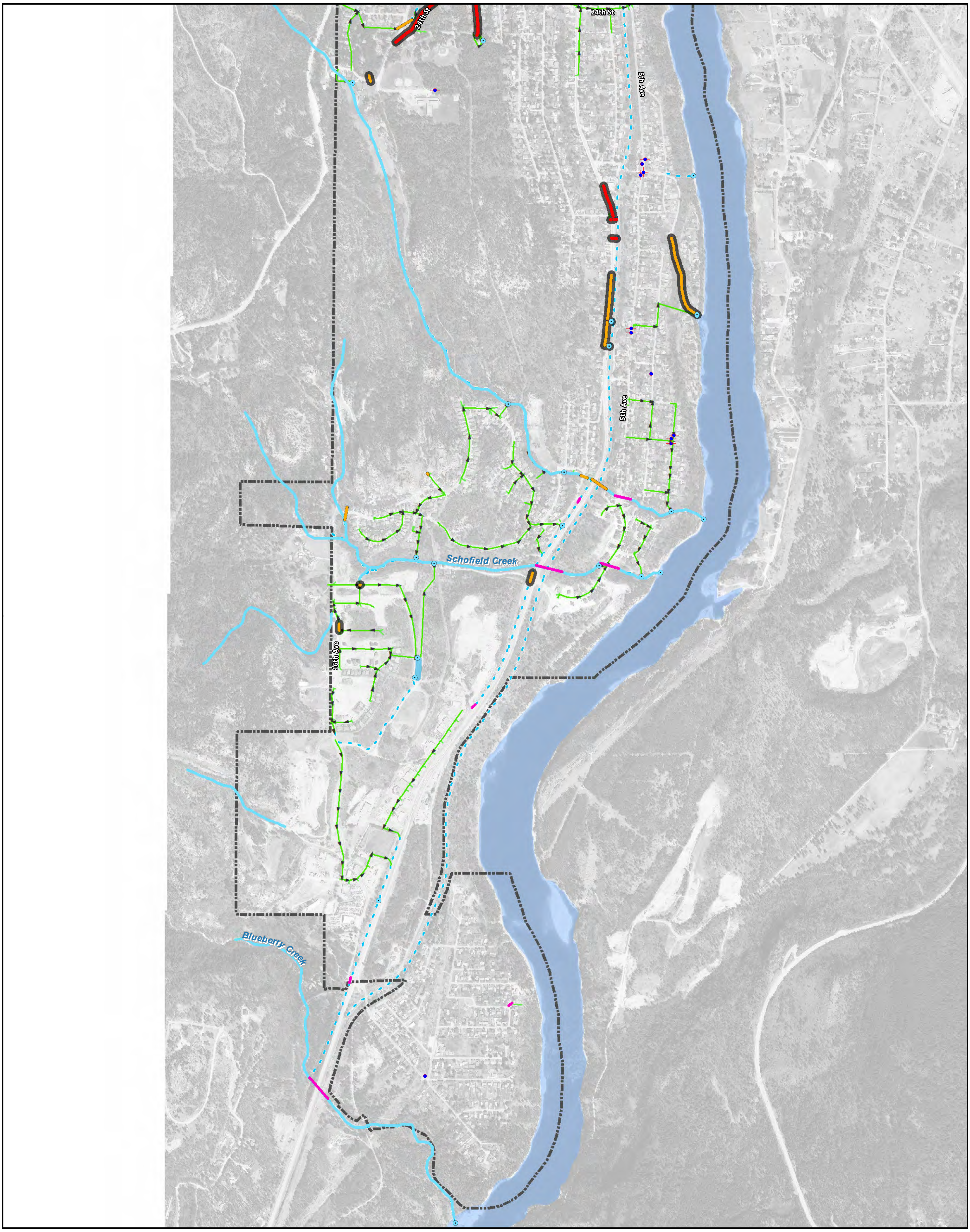

CASTLEGAR

City of Castlegar

Integrated Infrastructure Capital Plan (IICP)

Storm Priority Pipes - South

Legend

- ✦ Dry Well
- ⊙ Outfall
- 🟥 Priority 1 Storm Mains (0-10 Years)
- 🟧 Priority 2 Storm Mains (0-10 Years)
- Culvert
- Watercourse
- Catch Basin Lead
- ► Gravity Main
- ┅ Ditch / Overland Flow Path

Timing

- ▬ 0-5 Years

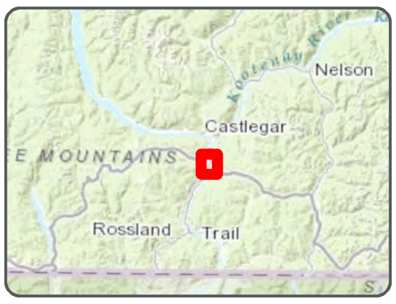

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FIGURE E

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CAPITAL PRIORITIZATION: RESULTS – EXTENDED SERVICE LIFE SCENARIOS

As discussed in Section 2.3, two scenarios were run that extended infrastructure service lives using factors of 125% and 150%. These scenarios show how annual costs can be reduced if the City is willing to accept the risk of waiting to replace infrastructure. Some pipe materials can last well past their expected service lives depending on factors such as installation technique and soil chemistry. Other pipe materials are still relatively new (i.e. PVC), so the full extent of the service life has not been adequately tested. It is possible that these pipes could maintain good condition many years past industry expectations, saving the City the cost of early replacement.

On the flip side, some pipes fail much earlier than expected. Choosing to extend service lives may lead to increased pipe breaks or failures, making staff reactive rather than proactive. Either way, it is an informed, risk-based level of service decision that the City must make. The following two tables show the replacement costs of the 125% and 150% service life scenarios.

Table 2.5: 125% Increased Service Life Prioritization Results of Pipe Assets

Prioritization – 125% Service Life Scenario									
Asset Category	**# of Pipes**	**Length of Pipe (km)**	**0-5 Year**	**0-5 Year Replacement Cost**	**5-10 Year**	**5-10 Year Replacement Cost**	**10-20 Year**	**10-20 Year Replacement Cost**	**Total Replacement Cost**
Priority 1	65	3..1	23	$ 692,086	13	$ 484,326	29	$ 927,940	**$ 2,104,352**
Priority 2									
Condition	14	1.0	0	$ -	5	$ 623,504	9	$ 332,689	**$ 956,193**
Capacity	25	1.2	20	$ 741,991	5	$ 117,273	0	$ -	**$ 859,265**
Priority 3									
Condition	15	0.3	0	$ -	0	$ -	15	$ 212,046	**$ 212,046**
Capacity	0	0.0	0	$ -	0	$ -	0	$ -	**$ -**
New Pipes	-	-	-	$ 1,000,000	-	$ 700,000	-	-	**$ 1,700,000**
Facilities									**$ -**
Total	**119**	**5.6**	**43**	**$ 3,434078**	**23**	**$ 1,925,103**	**53**	**$ 1,472,674**	**$ 5,831,855**

Table 2.6: 150% Increased Service Life Prioritization Results of Pipe Assets

Prioritization – 150% Service Life Scenario									
Asset Category	**# of Pipes**	**Length of Pipe (km)**	**0-5 Year**	**0-5 Year Replacement Cost**	**5-10 Year**	**5-10 Year Replacement Cost**	**10-20 Year**	**10-20 Year Replacement Cost**	**Total Replacement Cost**
Priority 1	46	2.3	23	$ 692,086	0	$ -	23	$ 977,111	**$ 1,669,197**
Priority 2									
Condition	13	1.0	0	$ -	0	$ -	13	$ 953,139	**$ 956,193**
Capacity	25	1.2	20	$ 741,991	5	$ 117,273	0	$ -	**$ 859,265**
Priority 3									
Condition	14	0.3	0	$ -	0	$ -	14	$ 198,798	**$ 198,798**
Capacity	0	0.0	0	$ -	0	$ -	0	$ -	**$ -**
New Pipes	-	-	-	$ 1,000,000	-	$ 700,000	-	-	**$ 1,700,000**
Facilities									**$ -**
Total	**98**	**4.8**	**43**	**$ 3,434078**	**5**	**$ 817,273**	**50**	**$ 2,129,048**	**$ 5,380,399**

Significant differences in costs can be seen between Table 2.4 (baseline scenario) and the two extended service life scenario tables (2.5 and 2.6). There is a large group of assets that were installed in the same time period, which all come up for renewal in the next 20 years under the baseline scenario. Increasing service lives has deferred those assets past the 20-year horizon and lowered immediate costs significantly.

The difference between the 125% and 150% service life scenarios is minimal. If the City is willing to accept increased risk and chooses an extended service life scenario, the 125% scenario provides the greatest cost savings with the lowest amount of increased risk compared to the 150% scenario.

Based on the 125% scenario, the average annual cost for critical linear assets is **$292,000**, or $294,000 less than the standard service life scenario.

CAPITAL PRIORITIZATION: RESULTS – CLIMATE CHANGE SCENARIO

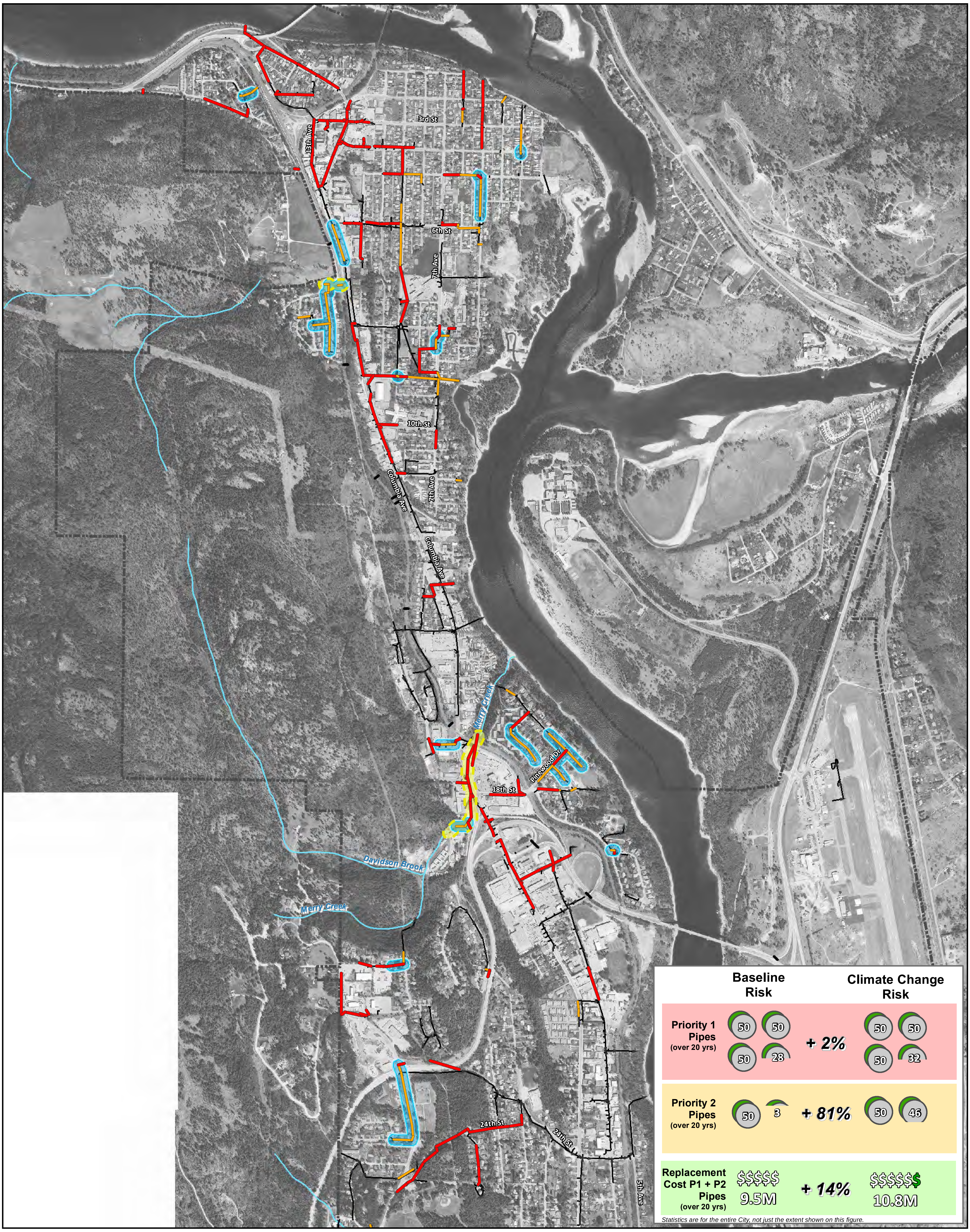
Using the methodology outlined in section 2.6 (hydraulic modeling of climate change scenario) and (where service lives of the existing pipes were reduced to incorporate climate change) climate change was integrated into the linear asset risk assessment and the model re-run. The results of the prioritization of pipe assets are summarized in **Table 2.7.** The baseline service life scenario was used as the input into the climate change scenario (no extension of service lives).

Table 2.7: Climate Change Prioritization Results of Pipe Assets

Prioritization – Climate Change Scenario									
Asset Category	**# of Pipes**	**Length of Pipe (km)**	**0-5 Year**	**0-5 Year Replacement Cost**	**5-10 Year**	**5-10 Year Replacement Cost**	**10-20 Year**	**10-20 Year Replacement Cost**	**Total Replacement Cost**
Priority 1	182	9.6	91	$ 3,667,313	84	$ 3,219,203	7	$ 201,887	**$ 7,088,403**
Priority 2									
Condition	41	2.5	15	$ 1,018,923	26	$ 1,273,242	0	$ -	**$ 2,292,165**
Capacity	55	2.9	30	$ 879,645	25	$ 556,466	0	$ -	**$ 1,436,111**
Priority 3									
Condition	30	1.0	0	$ -	0	$ -	30	$ 765,552	**$ 765,552**
Capacity	0	0.0	0	$ -	0	$ -	1	$ 7,754	**$ -**
New Pipes	-	-	-	$ 1,000,000	-	$ 700,000	-	-	**$ 1,700,000**
Facilities									**$ -**
Total	**308**	**16.0**	**136**	**$ 6,565,881**	**91**	**$ 5,748,910**	**37**	**$ 967,440**	**$ 13,282,230**

Based on the modelled adjustments for climate change, total replacement cost has increased, and the average annual cost of replacement for critical assets has increased by $65,000 to **$511,000.**

Figures F and G illustrate the locations of Priority 1 and 2 pipes that are triggered by the Climate Change Scenario.



	Baseline Risk		Climate Change Risk
Priority 1 Pipes (over 20 yrs)	50 50 50 28	+ 2%	50 50 50 32
Priority 2 Pipes (over 20 yrs)	50 3	+ 81%	50 46
Replacement Cost P1 + P2 Pipes (over 20 yrs)	$$$$$ 9.5M	+ 14%	$$$$$$ 10.8M

Statistics are for the entire City, not just the extent shown on this figure.

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Climate Change Vulnerability North

Legend

🟥	Priority 1 Storm Mains (0-20 yrs)
🟧	Priority 2 Storm Mains (0-20 yrs)
▭	Priority Triggered under Climate Change Scenario (Condition and/or Capacity)
▭	PIEVC Assessment - High or Medium Vulnerability
→	Gravity Main / Culvert
—	Watercourse

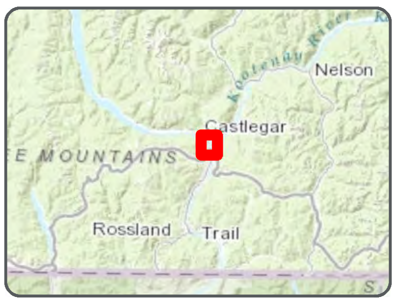

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FIGURE F

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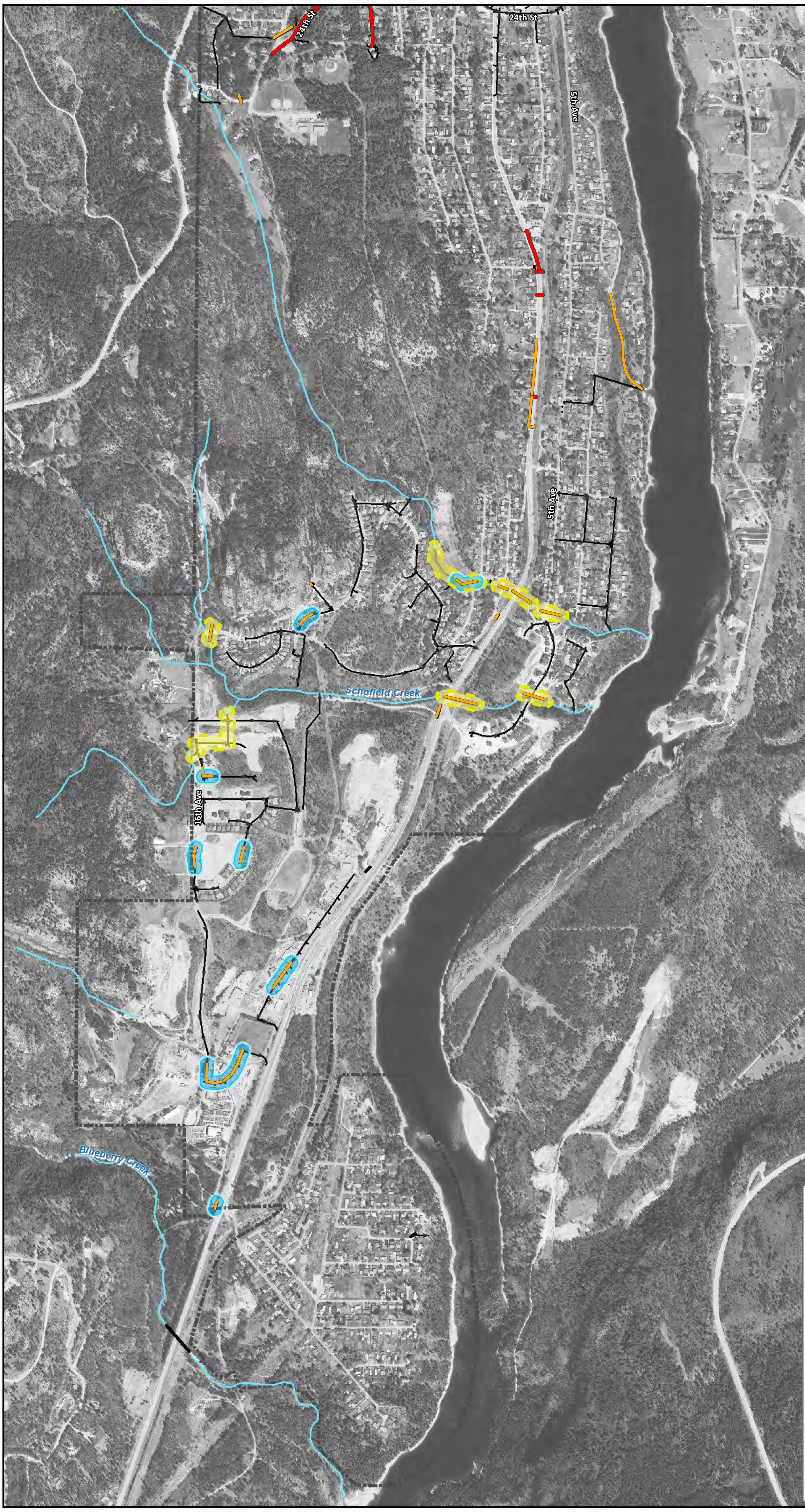

	Baseline Risk		Climate Change Risk
Priority 1 Pipes (over 20 yrs)	50 50 50 28	+ 2%	50 50 50 32
Priority 2 Pipes (over 20 yrs)	50 3	+ 81%	50 46
Replacement Cost P1 + P2 Pipes (over 20 yrs)	$$$$$ 9.5M	+ 14%	$$$$$$ 10.8M

Statistics are for the entire City, not just the extent shown on this figure.

CASTLEGAR

City of Castlegar

Integrated Infrastructure Capital Plan (IICP)

Climate Change Vulnerability South

Legend

- 🟥 Priority 1 Storm Mains (0-20 yrs)
- 🟧 Priority 2 Storm Mains (0-20 yrs)
- ☐ Priority Triggered under Climate Change Scenario (Condition and/or Capacity)
- ▭ PIEVC Assessment - High or Medium Vulnerability
- → Gravity Main / Culvert
- — Watercourse

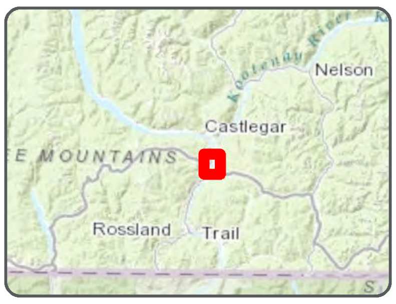

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FIGURE G

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2.9 Levels of Service, Risk and Cost: Results

The benefit of the risk assessment is the connection between levels of service, risk, and priorities. This section advances the methodology described above to define which types of projects will be funded based on the priority level and affordability limits using the asset management scenario results. The baseline service life scenario is used in this section.

PRIORITY 1 – LEVEL OF SERVICE 1

- **Risk Level:** Capital projects are selected when assets exhibit *both* condition and consequence of failure risk scores greater than or equal to 4.
- **What this means:** We will ensure that all pipes are maintained to a condition and capacity risk score of 3 or less. To do this, we will fund and construct projects that are of high risk (4 or 5) for both condition and capacity failures.
- Cost Implications: **$7,016,636** over 20 years

PRIORITY 2 – LEVEL OF SERVICE 2

- **Risk Level:** Capital projects are selected when assets exhibit risk scores greater than or equal to 4, for *either* condition or capacity.
- **What this means:** We will ensure that all pipes are maintained with a condition or capacity risk score of 3 or less. To do this, we will fund and construct asset replacements that are high risk (4 or 5) for either condition or capacity.

  Note: Selecting this risk level would also trigger the projects arising from Step 1.
- Cost Implications: Additional $2,501,489 over 20 years.

PRIORITY 3 – LEVEL OF SERVICE 3

Selecting this risk level where assets scored a 4 or greater under *likelihood of failure* for *either* condition or capacity would trigger all Priority 1, 2 and 3 pipes which has a cost implication of **$10M** over 20 years.

Selecting the preferred level of service to provide often comes down to community preferences and affordability. Willingness to pay for environmental protection or enhancement is also inherent in affordability. Based on discussions following the review of the preliminary results earlier in the study, it was determined that the following level of service and project funding would be pursued, with confirmation occurring after the long term financial analysis is completed:

- Priority 1 – to be funded and implemented as quickly as possible
- Priority 2 and 3 – to gradually increase revenues over the 20-year time frame so that this level of service is achieved by 2036

ADDITIONAL INFORMATION IN APPENDICES

This plan is submitted along with a GIS geodatabase (to be delivered with the final version of this report) which includes all the results of the modelling analysis. The geodatabase was submitted in electronic form to allow GIS personnel to manipulate and present the information in a variety of ways, depending on the needs of City staff.

Lastly, each asset ID has a risk score for existing and future conditions. These risk scores are the basis of the prioritization (ranking) of the assets and all assets in Priority 1/2/3 are listed in decreasing order of risk. This allows engineering staff to work with GIS staff to assemble projects based on risk, adjacent utility or roadworks projects (synergies), proximity and timing. Generally, however, the tables work like a check-list where each project completed results in less risk, thereby achieving the City’s stated level of drainage servicing.

3.0 IMPLEMENTATION STRATEGY

The assets identified in this study were prioritized and sequenced based on their level of risk, which was further categorized based on various rankings or risk scores and translated into levels of service. The identified Priority 1, Priority 2, and Priority 3 projects provide a high level of service for customers. The estimated costs for the critical assets is **$586,000** annually. Castlegar's storm utility currently collects **$547,000** annually from the storm sewer parcel tax. With approximately **$150,000** dedicated to annual maintenance and routine main upgrades, this equates to a shortfall of approximately **$189,000/year**. However, if planned revenues from reserves and grants are included, as shown in **Table 3.1**, the shortfall reduces to **$133,000/year.**

Table 3.1: Future Funding Strategy

Year	Storm Sewer Parcel Tax	Contribution from Reserves	Other Revenues / Grants	Total Revenues
2018*	$ 547,000	$ -	$ 320,000	$ 867,000
2019	$ 547,000	$ 149,700	$ 400,000	$ 1,096,700
2020	$ 547,000	$ 102,000	$ 400,000	$ 1,049,000
2021	$ 547,000	$ -	$ -	$ 547,000
2022-2025	$ 547,000	$ 1,280,000	$ -	$ 3,468,000

* The City's storm budget earmarked $480K in 2018 for Columbia Ave storm projects. Since the project is already underway, the risk model has considered these pipes to be installed in 2018 and they have not shown up as high risk. The earmarked $480K cost has been removed from the totals calculated in this report, however it has not been subtracted from the funding strategy shown in Table 7.

If the City were to adopt the climate change scenario, it would add $65,000/year, bringing the deficit back to $189,000.

If the City were to adopt the 125% service life extension scenario, the estimated costs for the critical assets would be $5.8M (avg. $0.292M/year). This equates to a budgetary surplus of approximately $105,000.

The aim of the funding strategy for this study is to organize the costs and expenditures over 20 years and to inform the City's current storm rates. The refinement of timing, phasing and affordability of projects will be completed as part of the City's financial planning and integrated capital planning process. The City already has a well-defined storm sewer plan for the next 5 years, so the focus of the integrated capital planning will be for the 5-20 year horizon.

3.1 Capacity Based Pipe Needs

Capacity-based pipe projects enable the storm utility to meet hydraulic levels of service now and going forward as flows increase with an increase in population, and with changes to the climate. Projects in the 0-5 and 5-10 year timeframe are typically required to address current service level deficiencies whereas 10-20 year capacity-based projects are required to deliver on growth plans and to plan for changes in climate. Capacity-based projects for growth can be eligible for development cost-sharing, which is denoted by the developer share estimate.

3.2 Condition Based Pipe Needs

Based on the utility's current capital funding level, and assuming the status quo scenario, it appears that funding is inadequate to cover asset replacement over the 20-year horizon to meet pending condition renewal and backlog investments ($133,000 deficit). If the City chooses to take on more risk and increase service lives of linear assets, then the current capital funding level becomes adequate ($105,00 surplus). While these investment levels are based on macro-funding objectives, the results of the risk analysis work from the bottom up, to develop a list of asset-specific condition upgrades. Several of these assets (condition driven) may be candidates for trenchless technology rehabilitation and the overall costs may be reduced. Further investigation would be required for each asset to determine the feasibility of a trenchless rehabilitation solution.

In summary, the proposed annual average level of renewal spending over the 20-year horizon is less than the current utility capital spending level. However, options such as extending service lives or investigating trenchless installation solutions, can balance the costs.

3.3 Capital Plan Recommendations

The prioritized capital plan for stormwater includes these following recommendations (in addition to those already planned for by the City from 2018-2021):

1. **To budget for and phase-in high priority asset replacements based on affordability.** Existing condition and capacity is the primary driver for replacement and preparing for significant projects should start immediately.
2. **To pursue trenchless rehabilitation program for Priority 2 condition-based replacement**. The scope of trenchless rehabilitation should be completed following CCTV assessment of each main identified as potential. This is a cost-containment program that must be scoped out after more detailed information on the existing infrastructure is collected.
3. To fund and construct the Priority 2 replacements by completing the highest order replacements by capacity risk score first.
4. Conduct a risk assessment of the major system (overland flow and depression storage), as described in Section 2.0. This begins with acquiring high density LiDAR data over the entire community.
5. Incorporate climate change adaptation strategies into asset maintenance and upgrades by considering the following:
   - improving inlet capacity,
   - ensure debris and sediment are regularly cleaned from culverts and pipes,
   - ensure natural assets such as creeks and streams are protected and maintained,

  - installing barrier curb and re-grading boulevards when undertaking road upgrades in the areas showing high vulnerability to climate change, and
  - Installing grizzly screens on the inlets of major culverts.

6. Continue to update the data and model as more information becomes available such as addition or deletion of infrastructure, condition assessments and field measurements of infrastructure.

7. Consider increasing investment into the storm utility in the future to account for potential impacts of climate change.

Appendix A

Technical Memoranda

This section presents a summary of the design criteria and hydraulic analyses for an existing conditions scenario and the future conditions scenarios.

Design Criteria

The model contains overland channels, which required input of its geometry and composition (material) to enable the model to run. Geometry was assigned manually using photos and visual resources, which also guided the choice of coefficient from the table below. Manning's n for Channels (Chow, 1959)

Main Channels	Manning's n
1a. Clean, straight, full stage, no rifts or deep pools	0.030
1b. Same as above, but more stones and weeds	0.035
1c. Clean, winding, some pools and shoals	0.040
1d. Same as above, but some weeds and stones	0.045
1e. Same as above, lower stages, more ineffective slopes and sections	0.048
1f. Same as 1d with more stones	0.050
1g. Sluggish reaches, weedy, deep pools	0.070
1h. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.100
Mountain streams, no vegetation in channels, banks usually steep	**Manning's n**
2a. Bottom: gravels, cobbles and few boulders	0.040
2b. Bottom: cobbles with large boulders	0.050
Excavated or Dredged Channels	**Manning's n**
4.a.1 Earth, straight and uniform – clean, recently completed	0.018
4.a.2 Earth, straight and uniform – clean, after weathering	0.022
4.a.1 Earth, straight and uniform – gravel, uniform section, clean	0.025
4.a.1 Earth, straight and uniform – with short grass, few weeds	0.027
4.e.1 Channels not maintained, weeds and brush uncut – dense weeds	0.080
4.e.1 Channels not maintained, weeds and brush uncut – clean bottom, brush on sides	0.050
4.e.1 Channels not maintained, weeds and brush uncut – same as above, highest stage of flow	0.070
4.e.1 Channels not maintained, weeds and brush uncut – dense brush, high stage	0.100

The parameters for closed pipe systems in the modeling software were directly imported from the City-supplied GIS dataset, with the exception of the pipe roughness coefficients, which are presented in the table below.

Pipe Material	Roughness Coefficient
Corrugated Metal Pipe (CMP)	0.022
Concrete	0.011
Polyvinylchloride (PVC)	0.010
Steel	0.012
Unknown pipe material	0.012

Environment Canada maintains historical data for hydrometric stations. Older data was available for only Bloomer and Merry Creeks within the stormwater model boundary. Baseline flows rates were added to the model for these two creeks per the table below.

Merry Creek	Baseline Flow (L/s)
Bloomer Creek	100
Kilough Creek	55
Schofield Creek	n/a
Unnamed Creek	n/a
	n/a

Storm subcatchments were spatially defined using the existing topography of the City (high/low points). Additional parameters were manually added to the model per the table below.

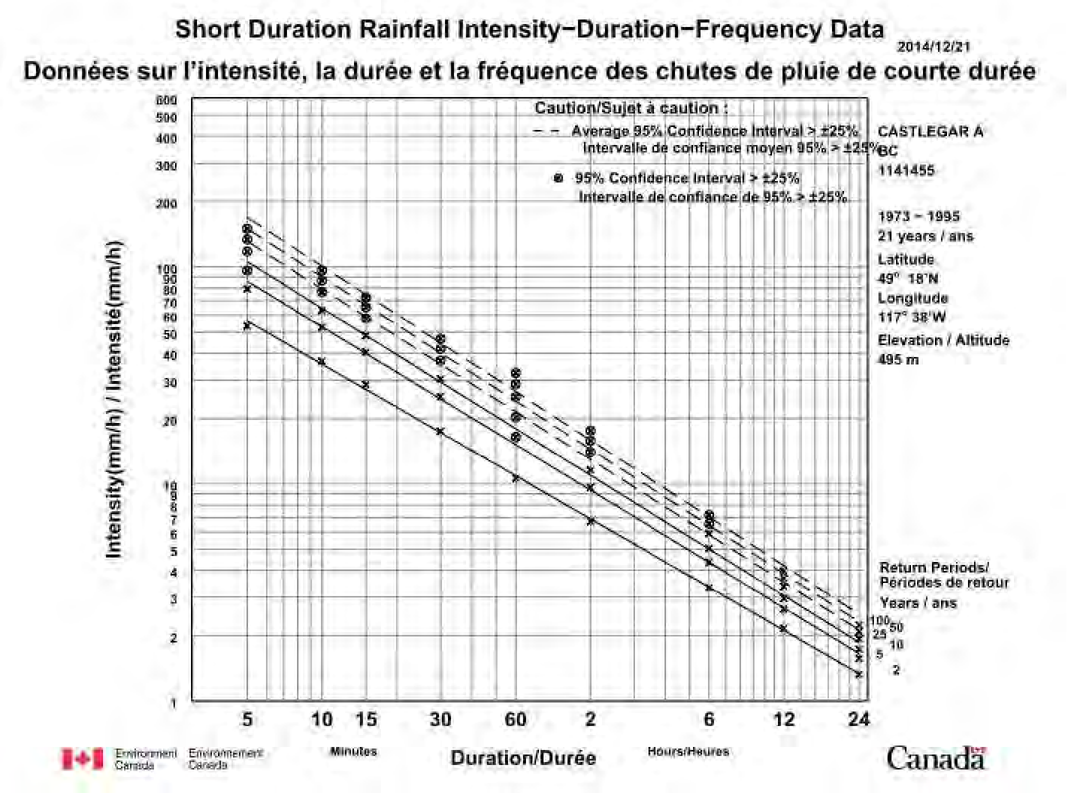
Creek	Description	Value
Rain Gage	The design storm to apply to the sub-catchment	See next section
N-Imperv	Overland roughness coefficient for impervious area	0.011
N-perv	Overland roughness coefficient for pervious area. Different values depending on whether the sub-catchment is urban (grassed) or rural (heavily treed/mountainous)	0.024 urban 0.015 rural
DStor-Imperv	Depression storage available in impervious area	1.5mm
Dstor-Perv	Depression storage available in pervious areas. Different values for urban and rural sub-catchments	5mm urban 15mm rural
Outlet	Discharge point for runoff. Set manually in the model	Varies
Slope	Average slope of catchment. Calculated in GIS using an area-weighted method for each catchment	Varies
Imperv%	Percentage of catchment that is impervious. Calculated within GIS using aerial background photographs	Varies
Percent-Routed	Percentage of the sub-catchment that is directly connected to the storm system. Calculated within GIS	Varies
Infiltration rates	Maximum and saturated infiltration rates. See next section of this memo	Varies

Infiltration rates (both maximum and saturated) were derived by inputting the soil composition of each sub-catchment into two separate calculators to estimate soil hydraulic conductivity. We chose the Irrigation BC and CDM Smith calculators and averaged the results from the two methods. Maximum infiltration rates vary between 60 and 76 mm/hour, for unsaturated soils during the summer months.

The stormwater models need to approximate the system under the worst possible conditions (highest runoff). In the highly-developed urban areas, a convective 1:10 year design storm was applied in the model. This ensured that the closed piped system (and any necessary upgrades) could adequately convey the 1:10 year design storm per the bylaw.

In the rural catchments, the amount of impervious area is dramatically lower, and a high intensity storm may not generate any runoff. Many of the major stormwater issues happened along creek corridors during the spring in a rain-on-snow event. The frozen ground allowed for very little infiltration and higher runoff volumes were experienced. The rain on snow event was replicated in the storm model by reducing the infiltration rates in the rural catchments by 90%. For example, a sub-catchment with maximum infiltration rate of 70 mm/hour based on its soil composition was set to 7 mm/hour in the rain-on-snow model. A 1:200 year design storm was applied to the rural sub-catchments.

The 1:10 year and 1:200 year design storms were taken/extrapolated from the City's IDF curve.



A summary of the design storms for the existing conditions model is shown in the table below.

Existing System	Urban Subcatchment	Rural Subcatchment

Design Storm	1:10 year	1:200 year
Storm Type	SCS Type 3 (convective, high peak)	SCS Type 1a (much lower peak)
Storm duration	24 hours	24 hours
Precipitation	41.5mm	65.1mm
Infiltration Rates	60 to 76 mm/hour	6 to 8 mm/hour
Soil status	Dry/unsaturated	Frozen/saturated
Snowmelt	n/a	15.3 mm
Total Precipitation	41.5mm	80.4mm

There are two future conditions models associated with the storm sewer system. The first future model represents growth within the City's boundaries and the second builds on the growth model and adds the effects of climate change.

To approximate growth within the City, a desktop review of the existing sub-catchments was undertaken to determine which ones could realistically become developed and how that would change the percentage of impervious and impervious areas within the sub-catchment. For sub-catchments that could potentially develop in the future, the imperviousness percentage was increased to a minimum value of 20% to account for roads, roofs and other hard surfaces.

Climate change is represented by different precipitation and intensity values for the design storms applied to the model. The IDF_CC Tool 2.0 was utilized to account for possible impacts of climate change by running up to 24 different Global Circulation Models (GMC) based on the existing IDF curve for the City. New precipitation values from the IDF_CC Tool were tabulated in a spreadsheet and the value representing the 90th percentile was chosen for the new design storms. The table below summarizes the climate change design storm parameters

Climate Change	Urban Subcatchment	Rural Subcatchment
Design Storm	1:10 year	1:200 year
Storm Type	SCS Type 3	SCS Type 1a
Precipitation	56.5mm	85.7mm
Storm duration	24 hours	24 hours
Soil status	Dry/unsaturated	Frozen/saturated
Snowmelt	n/a	15.3 mm
Total Precipitation	56.5mm	101.0mm

This memorandum presents a summary of the results from the hydraulic analyses for an existing conditions scenario and the future conditions scenario.

Existing Conditions: Gravity Main Deficiencies (d/D >= 1.0)

The table below summarize the mains that have exceeded their capacity.

ID	Diameter (mm)	Length (m)	Slope	Total Flow (L/s)	d/D	q/Q
dCV0035	300	42.67	3.59	266	1.0	1.12
dMN0012	200	84.59	3.38	79	1.0	1.11
dMN0021	200	44.94	0.36	21	1.0	0.90
dMN0026	200	35.36	0.68	26	1.0	0.81
dMN0035	300	73.86	0.60	72	1.0	0.81
dMN0090	200	35.34	0.35	31	1.0	1.34
dMN0098	200	55.69	1.20	63	1.0	1.48
dMN0099	200	3.93	4.54	63	1.0	0.76
dMN0102	200	14.27	0.94	38	1.0	1.00
dMN0103	200	92.78	0.86	39	1.0	1.08
dMN0131	200	41.39	2.47	65	1.0	1.06
dMN0132	200	74.12	1.85	65	1.0	1.23
dMN0133	200	68.95	2.40	64	1.0	1.07
dMN0204	450	65.61	0.10	227	1.0	2.13
dMN0205	450	69.88	0.10	160	1.0	1.50
dMN0207	450	16.94	0.10	227	1.0	2.12
dMN0378	750	83.50	1.58	1017	1.0	0.61
dMN0384	200	13.43	5.84	78	1.0	0.83
dMN0439	300	16.32	1.47	197	1.0	2.85
dMN0450	375	10.09	3.82	230	1.0	1.14
dMN0509	300	17.76	3.66	88	1.0	0.81
dMN0517	600	66.45	0.09	336	1.0	1.58
dMN0523	600	104.19	0.09	274	1.0	1.28
dMN0542	300	72.76	1.12	114	1.0	0.95
dMN0570	300	88.91	3.33	106	1.0	1.02
dMN0662	375	92.26	3.00	184	1.0	1.03
dMN1065	300	29.66	2.85	273	1.0	1.29
dMN1383	200	28.19	3.23	65	1.0	0.93
dMN1489	750	54.58	0.81	1017	1.0	0.86
dMN1516	300	20.88	1.75	138	1.0	1.83
dMN1556	600	13.76	0.66	215	1.0	0.73
dMN1574	450	16.59	0.42	258	1.0	2.02
dMN1605	200	30.47	0.50	55	1.0	2.02
dMN1606	300	37.53	0.40	23	1.0	0.32
dMN1756	150	5.51	1.09	56	1.0	2.70

Future Conditions: Growth-related Gravity Main Deficiencies (d/D >= 1.0)

The table below summarize the mains that have exceeded their capacity as development occurs within the City boundary over the next 20 years.

ID	Diameter (mm)	Length (m)	Slope	Total Flow (L/s)	d/D	q/Q
dCV0035	300	42.67	3.59	1120	1.0	1.12
dMN0012	200	84.59	3.38	1110	1.0	1.11
dMN0021	200	44.94	0.36	900	1.0	0.90
dMN0026	200	35.36	0.68	810	1.0	0.81
dMN0035	300	73.86	0.60	810	1.0	0.81
dMN0090	200	35.34	0.35	1340	1.0	1.34
dMN0098	200	55.69	1.20	1480	1.0	1.48
dMN0099	200	3.93	4.54	760	1.0	0.76
dMN0102	200	14.27	0.94	1000	1.0	1.00
dMN0103	200	92.78	0.86	1080	1.0	1.08
dMN0131	200	41.39	2.47	1060	1.0	1.06
dMN0132	200	74.12	1.85	1230	1.0	1.23
dMN0133	200	68.95	2.40	1070	1.0	1.07
dMN0204	450	65.61	0.10	2130	1.0	2.13
dMN0205	450	69.88	0.10	1500	1.0	1.50
dMN0207	450	16.94	0.10	2120	1.0	2.12
dMN0378	750	83.50	1.58	610	1.0	0.61
dMN0384	200	13.43	5.84	830	1.0	0.83
dMN0438	300	48.26	13.22	950	1.0	0.95
dMN0439	300	16.32	1.47	2850	1.0	2.85
dMN0450	375	10.09	3.82	1140	1.0	1.14
dMN0509	300	17.76	3.66	810	1.0	0.81
dMN0517	600	66.45	0.09	1580	1.0	1.58
dMN0523	600	104.19	0.09	1280	1.0	1.28
dMN0542	300	72.76	1.12	950	1.0	0.95
dMN0570	300	88.91	3.33	1020	1.0	1.02
dMN0662	375	92.26	3.00	1030	1.0	1.03
dMN1065	300	29.66	2.85	1290	1.0	1.29
dMN1383	200	28.19	3.23	930	1.0	0.93
dMN1489	750	54.58	0.81	860	1.0	0.86
dMN1516	300	20.88	1.75	1830	1.0	1.83
dMN1556	600	13.76	0.66	730	1.0	0.73
dMN1574	450	16.59	0.42	2020	1.0	2.02
dMN1605	200	30.47	0.50	2020	1.0	2.02
dMN1606	300	37.53	0.40	320	1.0	0.32
dMN1756	150	5.51	1.09	2700	1.0	2.70

Future Conditions: Climate Change-related Gravity Main Deficiencies (d/D >= 1.0)

The table below summarize the mains that have exceeded their capacity as development occurs within the City boundary over the next 20 years and climate change effects are realized.

ID	Diameter (mm)	Length (m)	Slope	Total Flow (L/s)	d/D	q/Q
dCV0001	600	17.61	1.26	1500	1.0	1.67
dCV0035	300	42.67	3.59	269	1.0	1.13
dMN0012	200	84.59	3.38	79	1.0	1.11
dMN0021	200	44.94	0.36	28	1.0	1.23
dMN0026	200	35.36	0.68	48	1.0	1.51
dMN0035	300	73.86	0.60	77	1.0	0.87
dMN0065	300	117.96	0.55	92	1.0	1.09
dMN0066	200	24.08	0.69	56	1.0	1.75
dMN0067	200	24.44	0.81	60	1.0	1.71
dMN0088	200	16.76	5.14	72	1.0	0.82
dMN0090	200	35.34	0.35	37	1.0	1.64
dMN0098	200	55.69	1.20	63	1.0	1.49
dMN0099	200	3.93	4.54	64	1.0	0.78
dMN0102	200	14.27	0.94	42	1.0	1.11
dMN0103	200	92.78	0.86	47	1.0	1.31
dMN0127	200	39.63	7.48	113	1.0	1.06
dMN0131	200	41.39	2.47	74	1.0	1.21
dMN0132	200	74.12	1.85	65	1.0	1.23
dMN0133	200	68.95	2.40	63	1.0	1.06
dMN0134	250	157.12	2.74	126	1.0	1.08
dMN0203	300	59.21	1.67	186	1.0	1.26
dMN0204	450	65.61	0.10	285	1.0	2.67
dMN0205	450	69.88	0.10	133	1.0	1.25
dMN0207	450	16.94	0.10	179	1.0	1.67
dMN0208	200	34.11	3.71	65	1.0	0.87
dMN0209	200	74.08	1.87	57	1.0	1.08
dMN0216	200	36.36	4.85	93	1.0	1.09
dMN0217	200	14.45	1.35	97	1.0	2.15
dMN0218	200	105.19	2.04	57	1.0	1.02
dMN0219	200	28.86	0.08	57	1.0	5.06
dMN0220	200	103.63	0.13	12	1.0	0.90
dMN0221	200	17.40	0.10	12	1.0	0.97
dMN0223	200	72.93	2.76	61	1.0	0.95
dMN0331	600	24.65	4.61	1794	1.0	1.05
dMN0332	600	51.79	2.70	1794	1.0	1.37
dMN0378	750	83.50	1.58	1427	1.0	0.86
dMN0384	200	13.43	5.84	99	1.0	1.06
dMN0385	200	14.78	1.00	99	1.0	2.55
dMN0416	200	35.41	7.78	153	1.0	1.28
dMN0418	300	285.71	2.45	213	1.0	1.08
dMN0421	250	79.62	3.77	121	1.0	0.81

Climate Change Deficiencies Cont'd (2/3)

ID	Diameter (mm)	Length (m)	Slope	Total Flow (L/s)	d/D	q/Q
dMN0437	300	109.64	12.96	209	1.0	1.01
dMN0438	300	48.26	13.22	207	1.0	1.00
dMN0439	300	16.32	1.47	197	1.0	2.85
dMN0450	375	10.09	3.82	243	1.0	1.20
dMN0509	300	17.76	3.66	120	1.0	1.10
dMN0510	300	67.91	3.26	120	1.0	1.16
dMN0516	600	130.51	0.09	336	1.0	1.58
dMN0517	600	66.45	0.09	338	1.0	1.59
dMN0523	600	104.19	0.09	278	1.0	1.29
dMN0526	250	65.85	0.88	87	1.0	1.32
dMN0527	200	97.13	0.93	37	1.0	1.00
dMN0539	900	94.72	0.13	856	1.0	1.11
dMN0542	300	72.76	1.12	152	1.0	1.26
dMN0543	300	21.92	3.65	111	1.0	0.51
dMN0570	300	88.91	3.33	106	1.0	1.02
dMN0662	375	92.26	3.00	193	1.0	1.08
dMN0680	200	26.29	2.36	47	1.0	1.59
dMN0681	200	73.06	5.90	46	1.0	0.98
dMN0682	200	78.57	6.18	45	1.0	0.94
dMN0683	300	81.39	5.85	152	1.0	1.10
dMN0702	600	30.33	0.60	371	1.0	1.32
dMN0780	900	50.12	0.94	161	1.0	0.16
dMN1027	250	56.79	4.15	173	1.0	1.10
dMN1065	300	29.66	2.85	348	1.0	1.64
dMN1078	250	29.40	1.49	39	1.0	0.41
dMN1079	250	44.30	2.33	149	1.0	1.26
dMN1120	250	56.91	0.69	115	1.0	1.80
dMN1148	200	15.03	2.93	29	1.0	0.43
dMN1155	300	112.03	0.39	95	1.0	1.21
dMN1181	250	31.91	5.21	142	1.0	0.80
dMN1182	250	31.87	5.18	142	1.0	0.80
dMN1183	250	34.42	0.81	128	1.0	1.84
dMN1184	250	96.79	1.79	117	1.0	1.13
dMN1383	200	28.19	3.23	65	1.0	0.93
dMN1392	200	96.44	0.50	21	1.0	0.78
dMN1393	300	105.66	0.95	107	1.0	0.96
dMN1401	200	107.16	5.48	102	1.0	1.12
dMN1402	200	22.67	1.94	55	1.0	1.02
dMN1403	200	99.59	1.32	58	1.0	1.31
dMN1404	200	59.09	1.83	25	1.0	0.48
dMN1411	200	91.28	3.00	89	1.0	1.32
dMN1412	200	46.99	0.49	20	1.0	0.76
dMN1413	200	35.90	0.50	19	1.0	0.71

Climate Change Deficiencies Cont'd (3/3)

ID	Diameter (mm)	Length (m)	Slope	Total Flow (L/s)	d/D	q/Q
dMN1474	300	39.67	3.85	152	1.0	0.68
dMN1483	1200	27.82	4.57	4914	1.0	1.00
dMN1484	1200	74.02	4.73	4914	1.0	0.98
dMN1487	1200	34.16	4.21	4972	1.0	1.05
dMN1489	750	54.58	0.81	1427	1.0	1.21
dMN1516	300	20.88	1.75	154	1.0	2.04
dMN1522	300	12.46	5.08	130	1.0	0.51
dMN1552	1200	39.30	3.64	5093	1.0	1.16
dMN1556	600	13.76	0.66	359	1.0	1.21
dMN1574	450	16.59	0.42	313	1.0	2.44
dMN1601	600	57.39	1.00	81	1.0	0.11
dMN1605	200	30.47	0.50	56	1.0	2.03
dMN1606	300	37.53	0.40	29	1.0	0.40
dMN1610	1200	20.18	6.45	5094	1.0	0.87
dMN1614	250	18.06	2.13	234	1.0	2.07
dMN1636	200	63.68	5.20	103	1.0	1.06
dMN1653	250	34.11	2.53	27	1.0	0.22
dMN1692	1200	43.77	2.80	4974	1.0	1.29
dMN1756	150	5.51	1.09	60	1.0	2.91
dMN1761	900	37.23	0.68	1984	1.0	1.86
dMN1762	900	6.44	9.37	1516	1.0	0.21

TECHNICAL MEMORANDUM

Date: December 04, 2017
To: Chris Barlow, City of Castlegar
cc:
From: Scott Shepherd
File: 0841.0099.01
Subject: **TECHNICAL MEMO–STORM CAPACITY RISK ASSESSMENT METHODOLOGY**

This memo outlines the proposed methodology on how capacity risks of storm pipe are identified, and how the risks will be applied in assessing pipes in the City of Castlegar. The methodology is broken down into three parts: an assessment of the likelihood of failure; an assessment of the consequence of failure; and, a risk score. These capacity risk scores will be used in conjunction with condition risk scores (methodology outlined under separate cover) to help guide the prioritized infrastructure capital replacement process.

Part 1 – Likelihood of Failure

The likelihood of failure was assessed by the hydraulic capacity, hydraulic grade line (HGL) and flow velocity of the pipe, under normal operating conditions. **Table 1** defines how the criteria listed above are correlated to the likelihood of failure.

Table 1 - Normal Operating Conditions Likelihood of Failure

LIKELIHOOD OF FAILURE	CRITERIA		
	HYDRAULIC CAPACITY	HGL	VELOCITY
5	d/D=1	Storm Level <0.3m below ground surface	
4	d/D=1	Storm Level >0.3m above the pipe crown & Storm Level >0.3m below ground surface	
3	d/D=1.0	Storm Level<0.3m above pipe crown	
2	0.7<d/D<1 d/D<0.7	<Crown	<=0.75 m/s
1	d/D<0.7	< Crown	>= 0.75 m/s

Part 2 – Consequence of Failure

The consequence of failure is a function of the land use type and their associated populations. With single family residential dwellings, the consequence is lower than with multi-story apartment complexes or commercial, industrial or institutional buildings. **Table 2** and **Table 3** correlate the consequence of failure to the population and land use respectively. The populations in **Table 2** refer to total equivalent population, irrespective of land use.

Table 2 - Consequence of Failure Definitions

CONSEQUENCE				
1 INSIGNIFICANT	2 MINOR	3 MODERATE	4 MAJOR	5 SEVERE
n/a	< 10 people impacted or property loss < $0.5MM	10-50 people impacted or property loss 0.5MM-1.0MM	50-100 people impacted or property loss 1.0MM-5.0MM	>100 people impacted or property loss >5.0MM

Table 3 - Consequence of Failure by Land Use Designation

UPSTREAM LAND USE DESIGNATION	CONSEQUENCE OF FAILURE
Open Space	1
Single Family Residential	3
Multi-Family Residential	4
Highway Commercial	4
Institutional	5
Industrial	5
Core Commercial	5

Modified Consequence Score

Due to their larger size or nearby surroundings, some storm mains present an increased level of consequence should they fail. For the analysis, pipe size, stream crossings, and pipes in special community areas are treated differently so as to elevate their priority sequencing in capital projects. Three areas of modified consequence are:

- **Gravity mains of 400mm and larger** present greater failure consequences and a modified score is added to the normal risk rating (**Table 4** below).
- **Storm mains located within environmentally sensitive areas** (as mapped in the OCP and steep slope areas) or **mains that cross or are adjacent to watercourses** present greater failure consequences and a modified score is added to the normal risk rating (**Table 4** below).

- Storm mains in **ICI areas** (Industrial, Commercial, and Institutional) demonstrate a greater consequence on community well-being. Therefore, storm assets within these areas will be assigned a modified consequence score based on **Table 4**.

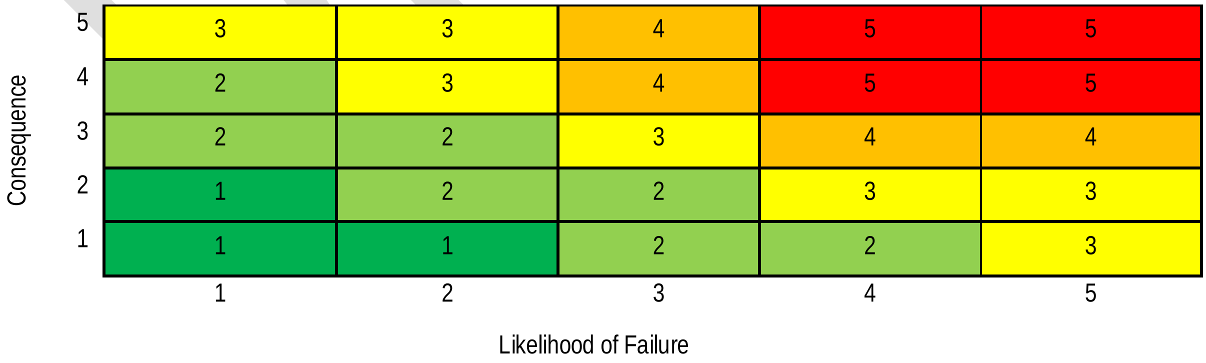
Table 4 – Modified Consequence Score

ORIGINAL SCORE		1	2	3	4	5
MODIFIED SCORE	>=250mm (gravity), or adjacent to/cross sensitive watercourses, or located within environmental, steep slopes, or ICI areas	1	3	4	5	5

PART 3 – RISK SCORE

The risk score combines the likelihood of asset failure and the consequence of asset failure into a single 1 to 5 rating. A risk score of 5 represents the highest risk and a score of 1 the least risk. **Table 5** correlates the consequence and the likelihood of failure to the risk score. In cases where a storm main is known to have failed, based on video inspection or manual investigation, the risk score is automatically set to 5, no matter what the consequence and likelihood scores may be.

Table 5 – Risk Score



Consequence					
5	3	3	4	5	5
4	2	3	4	5	5
3	2	2	3	4	4
2	1	2	2	3	3
1	1	1	2	2	3
	1	2	3	4	5

Likelihood of Failure

Likelihood of Failure

It is important to recognize that an asset that has a moderate or low risk attached to it may transition to having a higher risk over time due to changes in demand from growth or increased flows. Further, as more detailed data becomes available, the risk assessment could change. With this in mind, there must be emphasis on keeping the risk assessment a dynamic and living process.

Date: December 04, 2017
To: Chris Barlow, City of Castlegar
cc:
From: Scott Shepherd
File: 0841.0099.01
Subject: **TECHNICAL MEMO – STORM CONDITION RISK ASSESSMENT METHODOLOGY**

This memo outlines the proposed methodology on how condition risks of storm pipes are identified, and how the risks will be applied in assessing pipes in the City of Castlegar. The methodology is broken down into three parts: an assessment of the likelihood of failure; an assessment of the consequence of failure; and, a risk score. These condition risk scores will be used in conjunction with capacity risk scores (methodology outlined under separate cover) to help guide the prioritized infrastructure capital replacement process.

PART 1 – LIKELIHOOD OF FAILURE

The likelihood (probability) of asset failure for pipes is based on the Structural Condition Grade (SCGs) of the asset. The SCGs will be supplied by the City of Castlegar (where available) and will be developed with a methodology consistent with the WRc Storm Rehabilitation Manual. Where SCG's are not available or deemed unreliable, we will utilize operator knowledge from visual observations, and asset age (approximate year of installation) as a proxy for likelihood of failure, based on **Table 1**.

Table 1 - Condition Ranking (where SCG not available)

LIKELIHOOD OF FAILURE	CRITERIA
5	Asset age exceeds its SL* by 50%
4	Asset age exceeds its SL* by 25% - 50%
3	Asset age exceeds its SL* by 0% - 25%
2	75% of its SL* < Asset Age < 100% of its SL*
1	Asset age < 75% of its SL*

* **SL =** Service Life: Service life is the number of years that an asset is estimated to be able to fulfill its intended function to the community before it needs to be replaced.

Estimated Service Lives

The following table summarizes the estimated service lives used in the analysis. The table is based on discussions with staff on their experience in the Castlegar area, materials testing, and on the Province of BC's 2008 *Guide to the Amortization of Tangible Capital Assets.*

Table 2 – Estimated Service Lives

Material	Estimated Service Life
CMP	30
CONC	60
HDPE	80
PVC	80
STEEL	60

PART 2 – CONSEQUENCE OF FAILURE

The consequence of failure is based on the actual location of the infrastructure and the financial consequence that might occur, if the infrastructure failed. A simple 1 to 5 scale is used to classify the consequence of failure. **Table 3** details how each category is defined.

Table 3 - Consequence of Failure Definitions

CONSEQUENCE				
1 INSIGNIFICANT	2 MINOR	3 MODERATE	4 MAJOR	5 SEVERE
Total cost to restore service and 3rd party liability (< $500)	Total cost to restore service and 3rd party liability ($500 - $5,000)	Total cost to restore service and 3rd party liability ($5,000 - $15,000)	Total cost to restore service and 3rd party liability ($15,000 - $50,000)	Total cost to restore service and 3rd party liability (> $50,000)

For this project, we will consider the primary driver of failure consequence to be whether the pipe is located within a road, and if so what the associated road classification is. The cost to repair a storm main break is closely linked to the type of road (and associated volume) that might be damaged; for example, a failure within an arterial road presents greater traffic control and road reconstruction requirements than a failure within a local road. The City's GIS data set is used to analyze if a pipe is physically located in a road and if it is, what the road classification (and associated volume) is. **Table 4** summarizes the consequence of failure ranking by road classification and daily 2-way volume.

Table 4 - Consequence of Failure by Road Classification

ROAD CLASSIFICATION	CONSEQUENCE OF FAILURE
Arterial	5
Collector	5
Highway	5
Local	3
Strata	3
Lane	2
*SROW/Trail	1

**SROW - For pipe corridors in rights-of-way that are not overlaid by road networks.*

Modified Consequence Score

Due to their larger size or nearby surroundings, some storm mains present an increased level of consequence should they fail. For the analysis, pipe size, stream crossings, and pipes in special community areas are treated differently so as to elevate their priority sequencing in capital projects. Three areas of modified consequence are:

- **Gravity mains of 400 mm and larger** present greater failure consequences and a modified score is added to the normal risk rating (**Table 5** below).
- **Storm mains located within environmentally sensitive areas** (as mapped in the OCP and steep slope areas) or **mains that are adjacent to or cross watercourses** present greater failure consequences and a modified score is added to the normal risk rating (**Table 5** below).
- Storm mains in **ICI areas** (Industrial, Commercial, Institutional) demonstrate a greater consequence on community wellbeing. Therefore, storm assets within these areas will be assigned a modified consequence score based on **Table 4**.

Table 5 – Modified Consequence Score

ORIGINAL SCORE		1	2	3	4	5
MODIFIED SCORE	>=400mm (gravity) or adjacent to/cross a sensitive watercourse, or located within either ICI, steep slopes or environmental areas	1	3	4	5	5

Construction Cost Notes

There are scenarios in which a main will present a greater cost of construction due to any proximity to structures and railways. **Table 5** presents modifications that are to be incorporated into the estimated cost of construction for use in funding strategies.

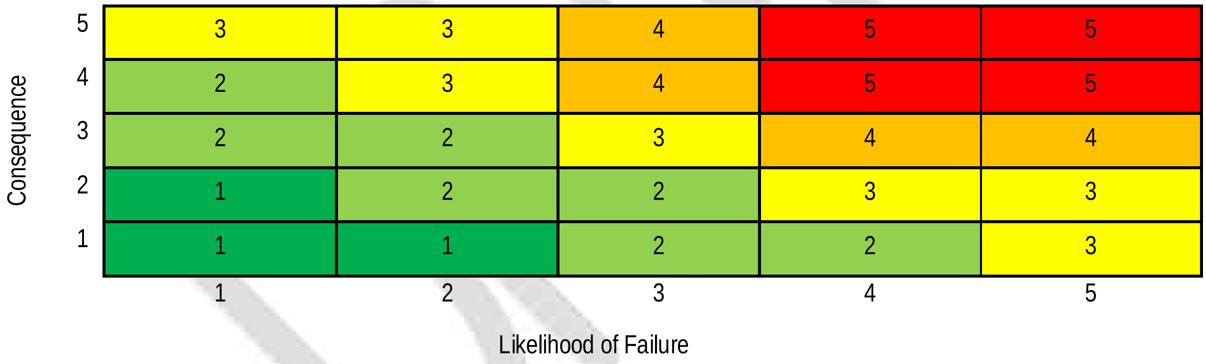
Table 5 – Modified Construction Cost

POTENTIAL OBSTRUCTION	CONSTRUCTION COST MODIFICATION
Pipe crosses railway	Increase by 25%

PART 3 – RISK SCORE

The risk score combines the likelihood of asset failure and the consequence of failure into a single 1 to 5 rating. A risk score of 5 represents the highest risk and a score of 1 the least risk. **Table 6** correlates the consequence and the likelihood of failure to the risk score. In cases where a storm main is known to have failed, based on video inspection or manual investigation, the risk score is automatically set to 5, no matter what the consequence and likelihood scores may be.

Table 6 – Risk Score



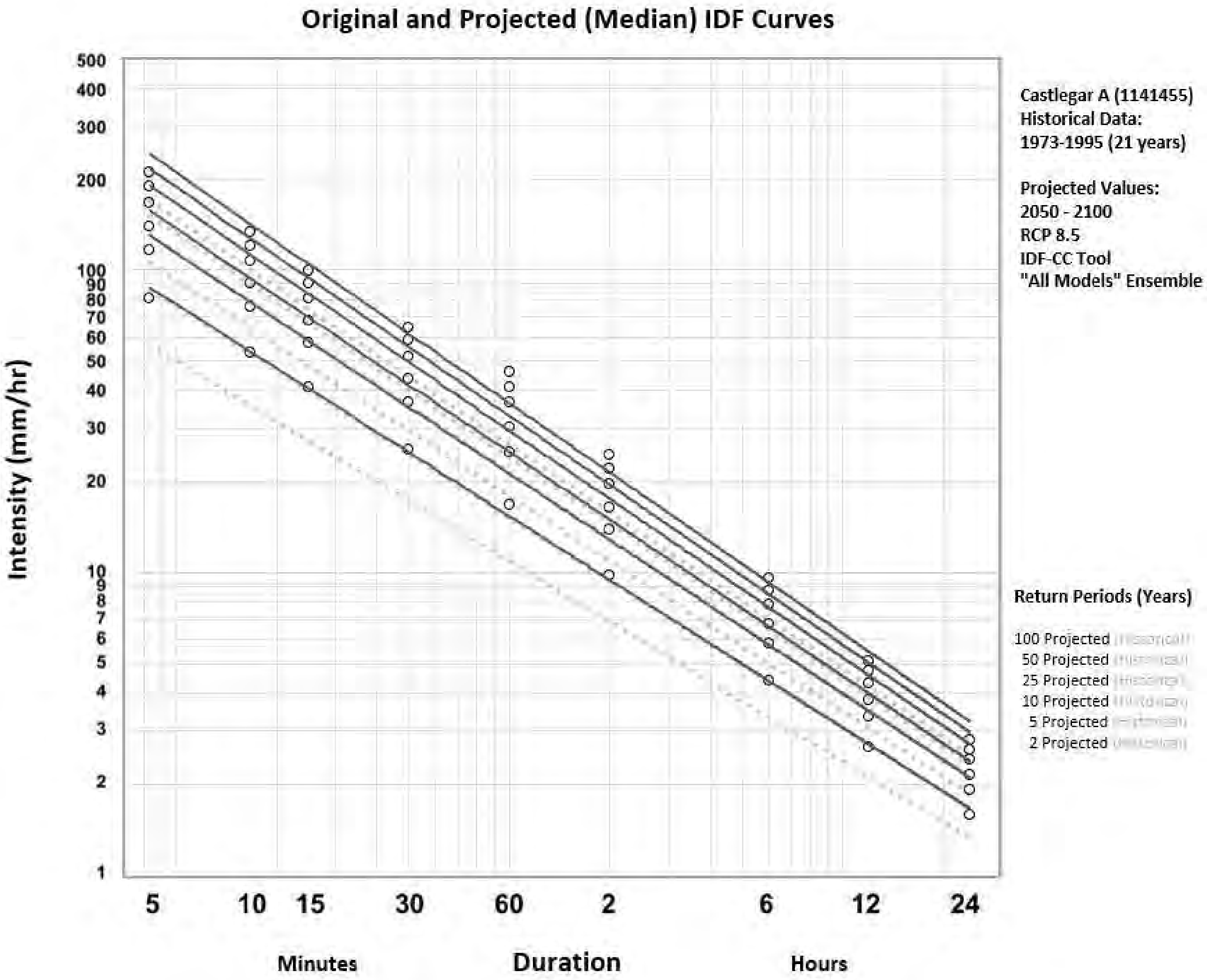
Consequence					
5	3	3	4	5	5
4	2	3	4	5	5
3	2	2	3	4	4
2	1	2	2	3	3
1	1	1	2	2	3
	1	2	3	4	5
	Likelihood of Failure				

Likelihood of Failure

It is important to recognize that an asset that has a moderate or low risk attached to it may transition to having a higher risk over time due to the simple aging of the asset. Further, as more detailed data becomes available, the risk assessment could change. For example, if new condition assessment data suggests that an asset is in better condition than its age would indicate, the risk assessment would be altered. With this in mind, there must be emphasis on keeping the risk assessment a dynamic and living process.

Appendix B

Future IDF Curves

Original and Projected (Median) IDF Curves
Intensity (mm/hr)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
5
10
15
30
60
2
6
12
24
Minutes
Duration
Hours
Castlegar A (1141455)
Historical Data:
1973-1995 (21 years)
Projected Values:
2050 - 2100
RCP 8.5
IDF-CC Tool
"All Models" Ensemble
Return Periods (Years)
100 Projected (Historical)
50 Projected (Historical)
25 Projected (Historical)
10 Projected (Historical)
5 Projected (Historical)
2 Projected (Historical)

Standard Environment Canada Tables for IDF Curves

Based on ECCC Station Castlegar A - 1141455 (1973-1995) and
IDF-CC Tool 'All Models' Ensemble (2050-2100); RCP 8.5 - Median Values

Table 2a: Return Period Rainfall Amounts (mm)

Duration	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
5 min	6.7	9.7	11.6	13.9	15.7	17.5
10 min	8.9	12.6	15.0	17.9	20.1	22.3
15 min	10.2	14.3	16.9	20.1	22.5	24.9
30 min	12.8	18.3	21.8	25.9	29.2	32.4
1 hr	16.7	24.9	30.1	36.4	41.2	46.1
2 hr	19.5	27.7	32.9	39.2	44.1	48.9
6 hr	26.5	35.2	40.7	47.3	52.6	57.7
12 hr	31.9	40.2	45.4	51.6	56.5	61.3
24 hr	37.9	46.1	51.4	57.6	62.4	67.2

Table 2b: Return Period Rainfall Rates (mm/hr)*

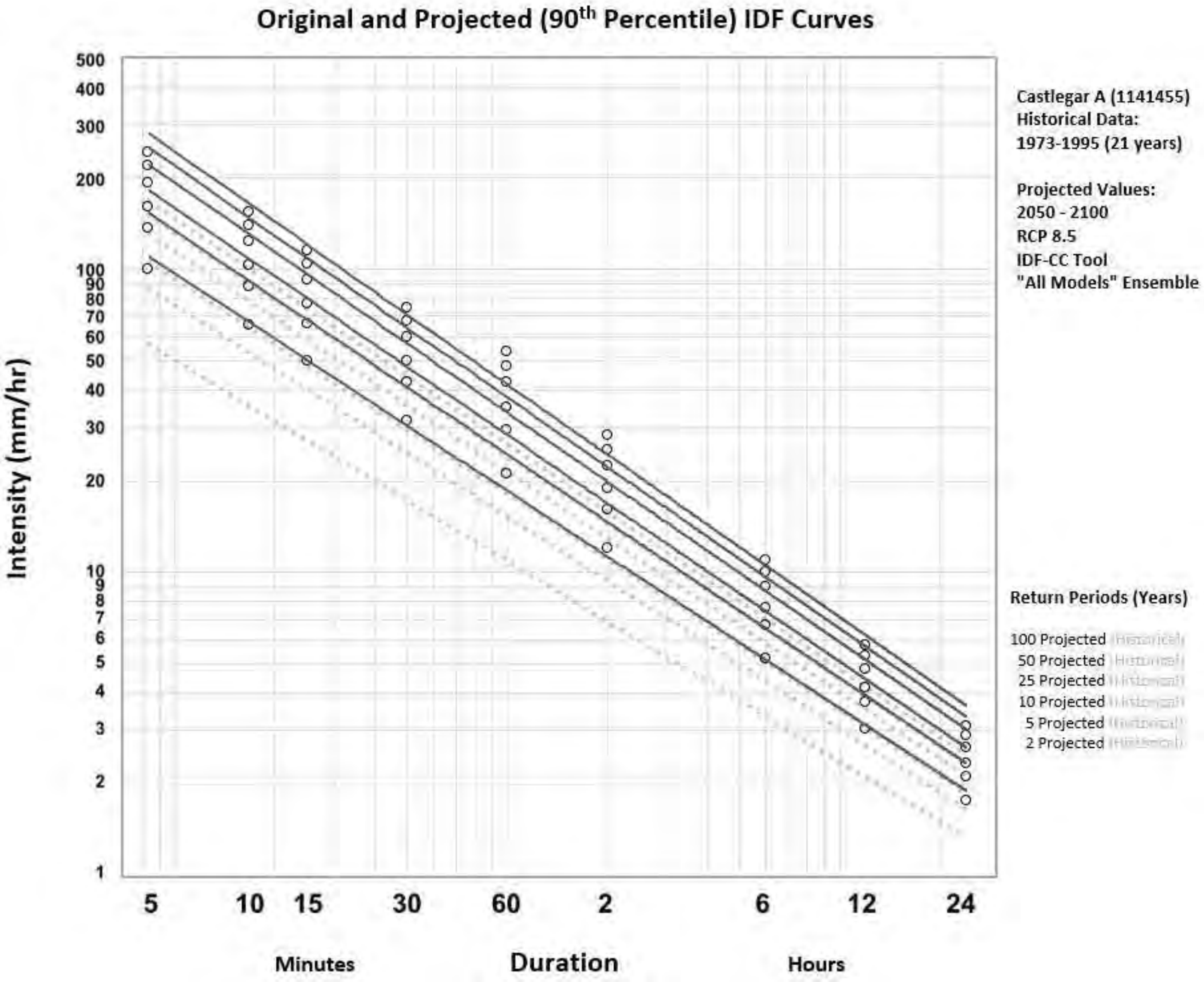
Duration	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
5 min	80.4	116.5	139.6	167.1	188.6	210.0
10 min	53.5	75.8	90.1	107.2	120.6	133.8
15 min	41.0	57.3	67.8	80.3	90.0	99.7
30 min	25.7	36.6	43.6	51.9	58.4	64.9
1 hr	16.7	24.9	30.1	36.4	41.2	46.1
2 hr	9.8	13.9	16.5	19.6	22.0	24.5
6 hr	4.4	5.9	6.8	7.9	8.8	9.6
12 hr	2.7	3.4	3.8	4.3	4.7	5.1
24 hr	1.6	1.9	2.1	2.4	2.6	2.8

* 95% Confidence Limits Not Available

Table 3: Interpolation Equation Coefficients (R = A*T^B)

	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
Mean RR	26.2	37.3	44.5	53.0	59.7	66.3
Std. Dev.	27.1	39.1	46.8	56.0	63.1	70.2
Std. Error	1.77	2.98	3.86	4.97	5.85	6.75
Coeff A	**15.38**	**21.26**	**24.99**	**29.43**	**32.90**	**36.33**
Coeff B	**-0.699**	**-0.727**	**-0.739**	**-0.750**	**-0.756**	**-0.761**
Mean % Error	3.6%	6.4%	7.8%	9.0%	9.7%	10.3%

R = Interpolated Rainfall rate (mm/h)
RR = Rainfall rate (mm/h)
T = Rainfall duration (h)


Original and Projected (90th Percentile) IDF Curves
Intensity (mm/hr)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
5
10
15
30
60
2
6
12
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Minutes
Duration
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Castlegar A (1141455)
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Return Periods (Years)
100 Projected (Historical)
50 Projected (Historical)
25 Projected (Historical)
10 Projected (Historical)
5 Projected (Historical)
2 Projected (Historical)

Standard Environment Canada Tables for IDF Curves

Based on ECCC Station Castlegar A - 1141455 (1973-1995) and
IDF-CC Tool 'All Models' Ensemble (2050-2100); RCP 8.5 - 90th Percentile Values

Table 2a: Return Period Rainfall Amounts (mm)

Duration	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	200 yr
5 min	8.3	11.4	13.4	16.1	18.3	20.3	22.4
10 min	10.9	14.7	17.2	20.6	23.3	25.7	28.4
15 min	12.5	16.6	19.3	23.1	26.0	28.7	31.7
30 min	15.8	21.3	25.0	29.9	33.8	37.5	41.4
1 hr	21.2	29.4	34.9	42.3	48.1	53.6	59.5
2 hr	24.0	32.2	37.7	45.1	51.0	56.5	62.4
6 hr	31.2	40.0	45.8	53.7	59.9	65.7	72.0
12 hr	36.4	44.7	50.2	57.6	63.4	68.9	74.8
24 hr	42.3	50.6	56.1	63.6	69.4	74.8	80.7

Table 2b: Return Period Rainfall Rates (mm/hr)*

Duration	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	200 yr
5 min	99.9	136.4	160.7	193.4	219.2	243.3	269.3
10 min	65.6	88.2	103.2	123.6	139.5	154.5	170.7
15 min	49.8	66.4	77.4	92.2	103.9	114.9	126.7
30 min	31.6	42.6	50.0	59.9	67.7	75.0	82.8
1 hr	21.2	29.4	34.9	42.3	48.1	53.6	59.5
2 hr	12.0	16.1	18.9	22.6	25.5	28.2	31.2
6 hr	5.2	6.7	7.6	9.0	10.0	11.0	12.0
12 hr	3.0	3.7	4.2	4.8	5.3	5.7	6.2
24 hr	1.8	2.1	2.3	2.6	2.9	3.1	3.4

* 95% Confidence Limits Not Available

Table 3: Interpolation Equation Coefficients (R = A*T^B)

	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	200 yr
Mean RR	32.2	43.5	51.0	61.2	69.1	76.6	84.6
Std. Dev.	33.6	45.8	53.8	64.7	73.3	81.3	90.0
Std. Error	2.39	3.74	4.70	6.05	7.13	8.15	9.26
Coeff A	**18.57**	**24.49**	**28.40**	**33.68**	**37.81**	**41.68**	**45.86**
Coeff B	**-0.716**	**-0.738**	**-0.747**	**-0.757**	**-0.763**	**-0.768**	**-0.772**
Mean % Error	5.2%	7.6%	8.7%	9.9%	10.5%	11.1%	11.5%

R = Interpolated Rainfall rate (mm/h)
RR = Rainfall rate (mm/h)
T = Rainfall duration (h)