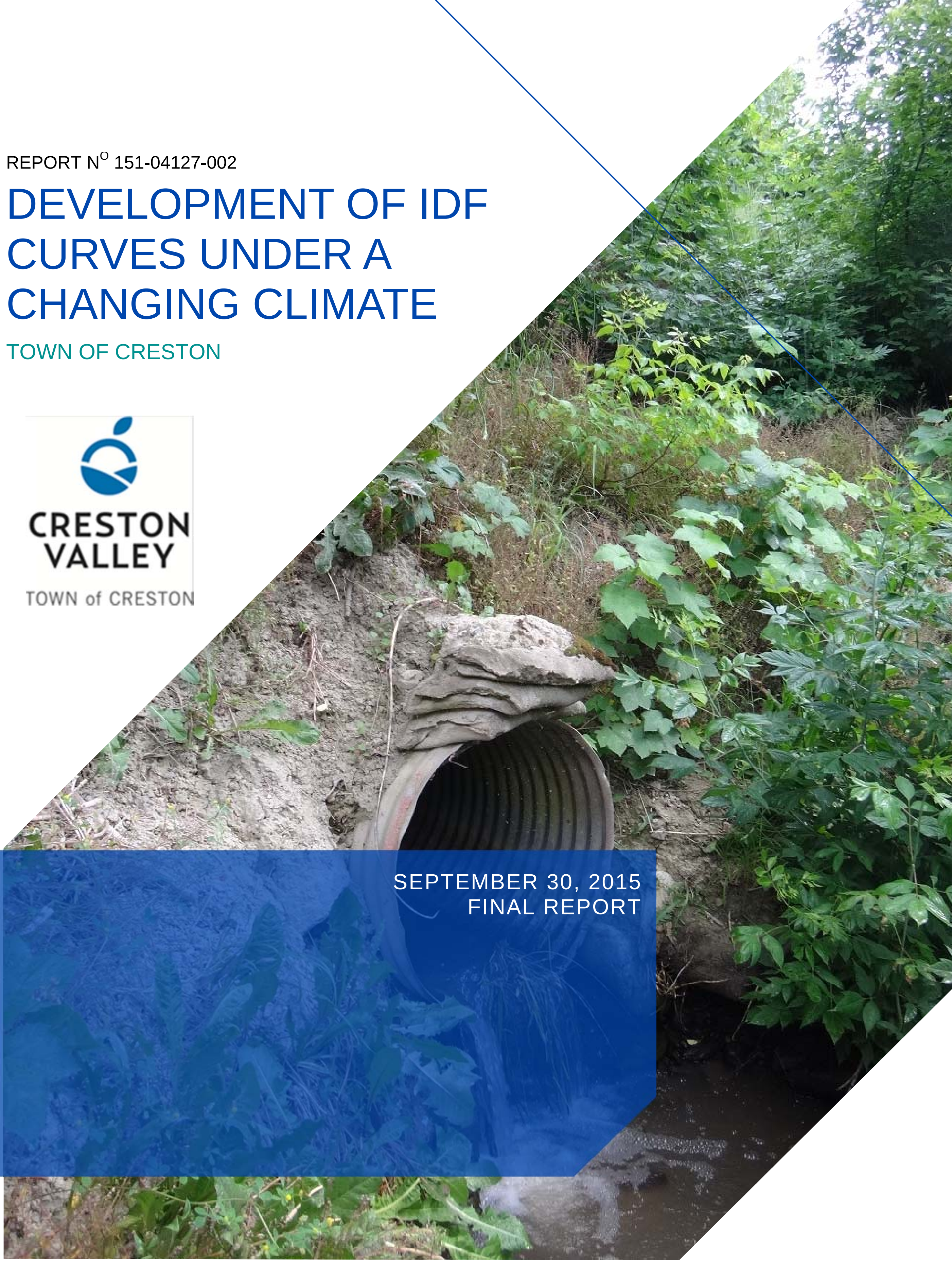
REPORT N^O 151-04127-002

DEVELOPMENT OF IDF CURVES UNDER A CHANGING CLIMATE

TOWN OF CRESTON



SEPTEMBER 30, 2015
FINAL REPORT

DEVELOPMENT OF IDF CURVES UNDER A CHANGING CLIMATE

Town of Creston

Project No: 151-04127-00
Date: September 30, 2015

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WSP Canada Inc.
PO Box 89
5-2114 Columbia Avenue
Rossland, BC V0G 1Y0

Phone: 250-362-5137
Fax: 250-362-5284
www.wspgroup.com

CRESTON VALLEY
TOWN of CRESTON

WSP

September 30, 2015 Project No. 151-04127-00

Mr. Colin Farynowski, Manager of Engineering
Town of Creston
238-10th Avenue North, P.O. Box 1339
Creston, B.C.
V0B 1G0

Subject : Development of Intensity-Duration-Frequency (IDF) Curves Under a Changing Climate

Dear Colin:

Please find attached the final report "Development of IDF Curves under a Changing Climate". Three signed and sealed hard copies will be sent under separate cover to you.

Thank you for the opportunity to work on this project together. It is our intent that this information will give the Town of Creston advanced decision making capacities with respect to stormwater infrastructure design and flood control projects such that the Town will be better positioned to adapt to a changing climate.

If we can be of assistance to you on any other matter in the future, please feel free to contact us.

Yours truly,

ORIGINAL SIGNED AND SEALED

Elise Paré, P. Eng.
Project Manager

Cc: Tim Hicks – Columbia Basin Trust; thicks@cbt.org
Jeff Zukiwsky – Columbia Basin Trust; jeff@zumundo.com
Trevor Murdock – PCIC; tmurdock@uvic.ca
Mel Reasoner; melreasoner5@gmail.com

WSP Canada Inc.
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EXECUTIVE SUMMARY

Columbia Basin Trust through its former Communities Adapting to Climate Change Initiative (CACCI) has supported the Town of Creston in this project.

This report presents the results of an update to the Intensity-Duration-Frequency (IDF) curves for the Town of Creston considering a range of climate change projections over three future time horizons. A comparative analysis of the effect on stormwater infrastructure design was then performed using the historical, current and future IDF curves for the 2020s, 2050s and 2080s.

IDF curves are an essential engineering design tool for all stormwater systems. Currently the practice of updating IDF curves is based on historical climate events and considers that extreme events will not vary significantly over time. The climate is changing. Extreme weather events such as high intensity rainfall are occurring more severely and frequently resulting in challenges for designing infrastructure that will be in place well into the future. If stormwater infrastructure continues to be designed based on historical climate events, there is an increased risk of infrastructure failure and flooding. Hence, adaptation measures for mitigation of the potential impacts of the climate change to the municipal infrastructure are extremely important for municipal governments. Consequently, the municipalities should consider development of the IDF curves under a changing climate as initial steps in minimizing municipal risk issues to the municipal stormwater infrastructure.

The projected IDF curves were generated with the web based Intensity-Duration-Frequency under a Changing Climate (IDF CC) Tool by inputting local historical climate station data for Creston. Outputs from the tool for all three Representative Concentration Pathways (RCPs), low (2.6), medium (4.5), and high (8.5) were generated, however as the current global emissions trajectory is tracking higher than the worst case scenario, all subsequent infrastructure analysis was limited to the results from the RCP 8.5 output. Without substantive socio-political action in support of emissions reduction, it is very unlikely that the current emissions pathway could be redirected to the low or even medium trajectory within the next 35 years. The risk of overdesign by choosing the RCP 8.5 over the RCP 2.6, would result in a 30% increase in intensity in the 2080s time period.

Rainfall intensity increases above historical values associated with RCP 8.5 (all return periods and all durations) were developed using the model ensemble. The average increases are 16%, 26% and 42% respectively for the 2020s, 2050s and 2080s.

The Town of Creston chose a culvert on Dodd's Creek crossing under 5th Avenue to test the effects of applying the results of the three future IDF curves in comparison to the historical and current design IDF curves. The flow at the culvert resulting from the projected 5 year storm in the 2080s is only 13% lower than flow from the 1983 100 year design storm. From the current IDF curve data to the 2020s, 2050s and 2080s, the flows generated by the 5 year return period increases range from 15% to 36% and the 100 year return period increases range from 16% to 29%.

The impact to infrastructure design will vary dependent on specific situation and the type of infrastructure being assessed. The increase in 5-year and 100-year flows due to the future climate change predictions will result in increase of frequency and magnitude of flooding.

There is an inevitable level of uncertainty to consider in using climate modeling as it relies in part on our understanding of future greenhouse gas emissions (GHG) and in part on our understanding of how the earth's climate system will respond to the changes in GHG concentrations in the atmosphere. Additional uncertainty in the results presented in this work includes assumptions related to how projections of sub-daily extreme precipitation are extrapolated from daily information and the uncertainty associated with these assumptions is not adequately defined. These assumptions can result in underestimating the sub hourly intensities and therefore flows. The revised IDF curves will provide Town of Creston staff with advanced decision making capacities with respect to stormwater infrastructure design and flood control projects.

However, discretion should be used by designers where infrastructure must quickly handle peak flow events.

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ACKNOWLEDGEMENTS AND PROJECT TEAM

The Project Team and the Town of Creston gratefully acknowledge the technical, scientific, coordination and financial support of Columbia Basin Trust (the Trust) which delivers social, economic and environmental benefits to the residents of the Columbia Basin. This project was funded under the former Trust Initiative, Communities Adapting to Climate Change Initiative (2007 to 2014). For current information related to the Trust's Climate Change Initiative visit cbt.org/Initiatives/Climate_Change.

Consulting Team

Elise Paré, P.Eng – WSP Canada, Project Manager
Bruno Jurak, P.Eng – WSP Canada, Senior Water Resources Engineer
James Michener, EIT – WSP Canada, Project Engineer
Mel Reasoner, PhD – Climate Science Advisor
Charles Cuell, PhD – Bright Sun Data Consulting Ltd, Climate Science Advisor

Project Advisory Team

Colin Farynowski, AScT, Town of Creston, Manager of Engineering
Trevor Murdock, Pacific Consortium on Climate Impact (PCIC), Regional Climate Impacts Specialist
Stephen Sobie, Pacific Consortium on Climate Impact (PCIC), Regional Climate Impacts Specialist
Tim Hicks – Manager Water and Environment, Columbia Basin Trust
Jeff Zukiwsky – Columbia Basin Trust, Communities Adapting to Climate Change (CACCI), Project Liaison

1 INTRODUCTION

1.1 BACKGROUND

The Town of Creston partnered with the Columbia Basin Trust to assist in adapting to climate change. In early October 2014, the Trust hosted a one-day climate resiliency workshop in Creston to help community members and leaders better understand climate science and future projections for this region, prioritize climate risks and develop local strategies to address those risks. As a result of participating in this one day workshop, through the Communities Adapting to Climate Change Initiative (CACCI), the Trust agreed to support the Town to complete a project that will address their climate change adaptation goals by providing access to technical advisors and match funding.

One of the resulting priorities of the workshop was to develop an Intensity-Duration-Frequency (IDF) curve that reflects the changes in precipitation that may be associated with the projected changes in climate. IDF curves are an essential design tool for all stormwater systems. IDF curves show the relationship between rainfall or precipitation intensity and duration for different levels of frequency. Each curve represents the rainfall intensity-duration which will be equaled or exceeded once in a certain number of years, indicated as the frequency of that curve. Currently the practice of updating IDF curves is based on historical climate events and considers that extreme events will not vary significantly over time. Extreme weather events such as high intensity rainfall are occurring more severely and frequently.[1] Is our current infrastructure capable of handling these changes or should the design criteria be updated to adapt to a changing climate?

Short-lived, extreme precipitation events, which are often associated with convective storms, are in many cases the most challenging for storm water management. In situations where storm water systems have been repeatedly overwhelmed in recent years (e.g. Nelson, BC) the duration of the precipitation events that resulted in flooding were sub-hourly and were not always associated with days during which higher total daily rainfall occurred. Consequently, updating IDF curves for future periods must address the difficulties associated with estimating sub-hourly rainfall intensities in a changing climate.

The range of predicted IDF curves will provide Town of Creston staff with advanced decision making capacities, and recommended design criteria with respect to stormwater infrastructure design and flood control projects.

1.2 SCOPE OF WORK

The primary objective of the project is to develop projected IDF curves for three time horizons, corresponding to typical stormwater infrastructure life:

- 2020s (2010-2039),
- 2050s (2040-2069), and
- 2080s (2070-2099).

[1] Westra et al., 2013

Further objectives include:

- Interpretation of the range of results including discussion of inherent uncertainty,
- Infrastructure design analysis comparing existing IDF curves to projected IDF curves,
- Provide recommendations on design application of the projected IDF curves.

2 METHODOLOGY AND DATA SOURCES

Researchers at the University of Western Ontario[2] have developed a methodology for updating IDF curves that captures precipitation changes caused by climate change based on the output of Global Climate Models (GCMs). The result of this research has culminated in a computerized IDF update tool consisting of a database and web-based user interface. The outputs of this tool are:

- A modified methodology for IDF update that takes into consideration different climate change scenarios
- A computerized tool to standardize the IDF update process
- Technical documentation to facilitate use of the computerized tool

Recommendations on data inputs for the online tool has been based on the consulting team's local knowledge including existing weather station data and applicable Global Climate Model results. Local climate data is based on the best available data from Environment Canada and other local weather stations. The existing IDF curve (2012) has been developed based on 20 years of climate data at the Creston WPCC station[3] and includes nine event durations ranging from five minutes to 24 hours.

The output of the projected curves, including level of uncertainty was interpreted by the team's climate scientists and reviewed with Trevor Murdock and Stephen Sobie of Pacific Climate Impacts Consortium (PCIC). PCIC is a regional climate service centre at the University of Victoria that conducts quantitative studies on the impacts of climate change and climate variability in the Pacific and Yukon region.

As there is inherent uncertainty with climate change modelling, this uncertainty will also be present in the range of possible outcomes for the IDF curve. It is crucial to assess the magnitude of this uncertainty such that users of the IDF curve will understand limitations of use.

As a test for the curves on infrastructure design, we estimated the potential impacts of future climate change conditions on selected municipal infrastructure within the Town. In agreement with the Town it was decided that this assessment will consist of a single location and test the range of projected future IDF curves on the potential impacts to this infrastructure in comparison to the current IDF curve. In addition, our joint decision was that this will be a one-time technical exercise using one

[2] Schardong et al. (2015)

[3] Creston WPCC weather station is the primary local weather station with long term climate data.

municipal structure only for the purpose of this test. The Town proposed the 5th Avenue culvert on Dodd's Creek[4] as an appropriate municipal infrastructure to be used for this project. The methodology of this test is further described in Section 4.

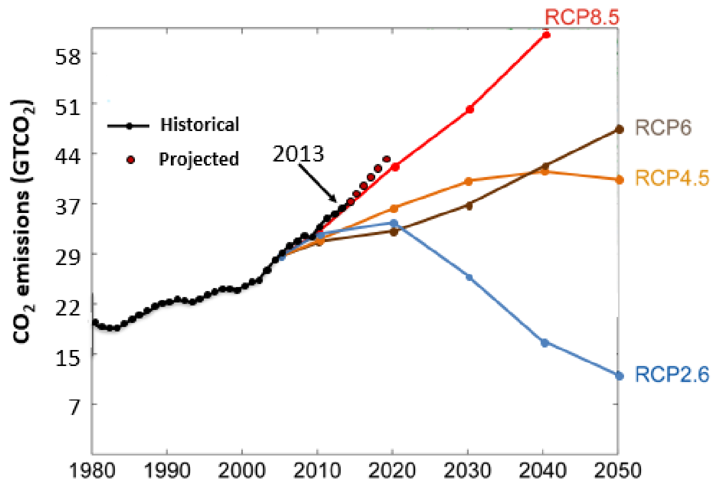
2.1 IDF CLIMATE CHANGE TOOL

The Computerized Tool for the Development of Intensity-Duration-Frequency Curves under Climate Change (IDF CC)[5] developed by Schardong et al. (2015) provides information regarding projected rainfall intensity for future time intervals based on three emissions pathways – low, medium, and high. The web based tool is linked to historic climate data from local Environment Canada weather stations.

The IDF CC Tool uses an ensemble of 22 climate models and ranks them according to their skill in simulating current or historical climate for a given region. For this report, the model ensemble was used to generate future IDF information to avoid the possibility of including spurious results that may be introduced from a single outlier model.

For each of the possible scenarios, the IDF CC Tool generated tables with rainfall intensity information and IDF curves that graphically display maximum rainfall intensity for a range of durations (5-min, 10-min, 15-min, 30-min, 1-hr, 2-hr, 6-hr, 12-hr and 24-hr) for return periods of 2, 5, 10, 25, 50 and 100 years. In addition, for each scenario the percentage change from the historical IDF data was calculated and is presented with the tables of rainfall intensity information in Appendix G.

Four representative concentration pathways (RCPs) define the range of potential future GHG concentration trajectories in the most recent Intergovernmental Panel on Climate Change (IPCC) assessment report (IPCC AR5). RCPs describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come.



[4] Dodd's Creek is also known as Dead Horse Creek in some references

[5] http://www.idf-cc-uwo.ca/

Figure 1: Observed Emissions, Projected Emissions And RCP (Representative Concentration Pathways) Emission Scenarios (Global Carbon Project, 2013).

Although output from the IDF CC Tool was generated for low (2.6), medium (4.5) and high (8.5) RCPs, our current emissions trajectory is tracking higher than the worst case RCP 8.5 (Figure 1: Observed Emissions, Projected Emissions And RCP (Representative Concentration Pathways) Emission Scenarios (Global Carbon Project, 2013).) and the emissions pathway does not have a major effect on precipitation until after mid-century. Consequently, as long as robust international agreements on rapid and substantive emissions reductions strategies remain elusive, a prudent approach would be to consider RCP 8.5 as a distinct likelihood for the 2050s and probably beyond.

2.2 HISTORICAL CLIMATE RECORDS

The existing and future IDF curve have been developed based on 20 years of climate data at the Creston WPCC station and includes nine event durations ranging from five minutes to 24 hours. The current IDF curve for the Creston WPCC station is shown below in Figure 2: 2012 Creston WPCC IDF Curve and data used to produce it can be found in Appendix B.

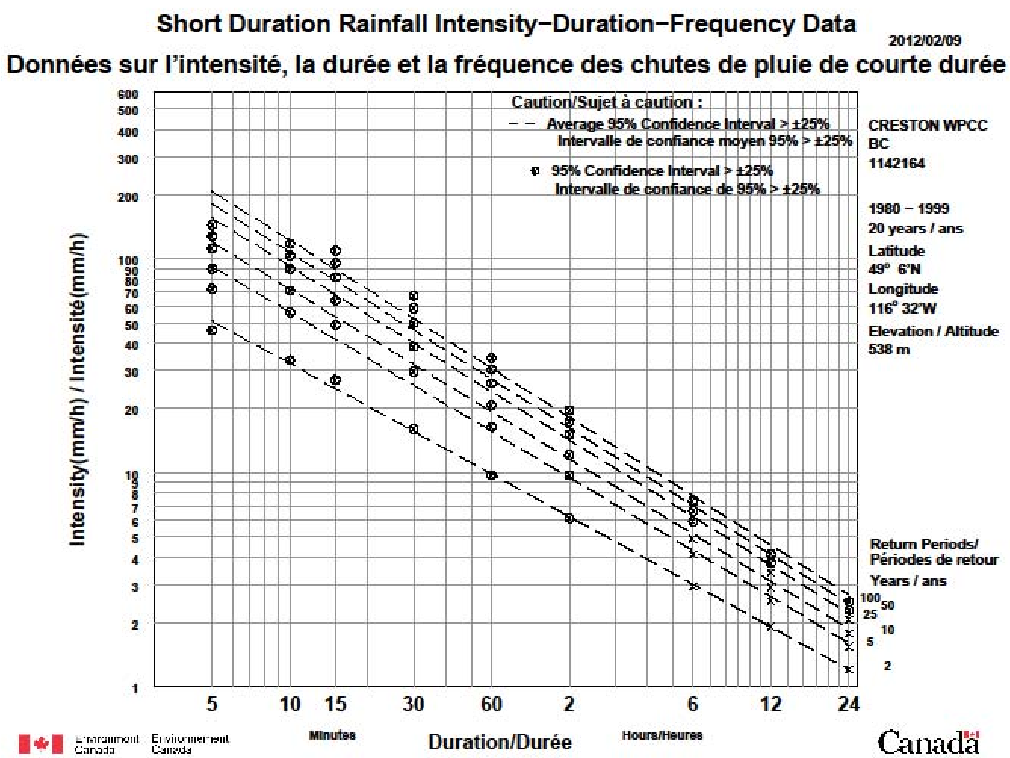


Figure 2: 2012 Creston WPCC IDF Curve

Unfortunately, very few meteorological stations in southern BC record sub-hourly rainfall data, and those that do, only have data spanning the last few years. Consequently, time series of sub-hourly precipitation are too short for statistically significant trends in extreme precipitation. It is therefore necessary to use statistical techniques in conjunction with down-scaled model projections to develop reasonable estimates for increases in daily to sub-hourly rainfall intensities that are likely to occur in the coming decades. These projections are the basis for updating IDF curves to include anticipated changes in regional climate which are fundamental for assessing storm water management strategies, guidelines and design practices.

2.3 OTHER DATA SOURCES

In consultation with the Town and based on the site investigations all relevant background information for the purpose of this report was obtained including:

- Master Drainage Plan report prepared by Dayton & Knight Ltd. in 1983;
- The 5th Avenue culvert as-built drawings;
- Site images;
- Google air images

3 DISCUSSION AND UNCERTAINTY

The earth's climate system is extremely complicated and many of its interconnected sub-systems are not understood well enough to predict with certainty how they will respond to increasing GHGs in the coming decades. Consequently, although all climate models indicate the planet will continue to warm, model projections have a wide range of outcomes.

In addition, the various possible emissions pathways that humanity could follow over the coming decades (RCPs), which are entirely dependent upon geopolitical factors, result in a range of climate forcing which significantly influence model results. For example, if humanity follows RCP 8.5, by the end of the 2040s period, mean annual temperature in BC will be about 1.3°C warmer than if emissions were to track RCP 2.6. The difference in BC mean annual temperature between the two emissions pathways will be about 3.4°C by the 2080s[6]. Similarly, by the 2080s, projected rainfall intensity for the Creston area based on the RCP 8.5 model ensemble are 30% higher than projections based on RCP 2.6.

There is an inevitable level of uncertainty to consider in using climate modeling as it relies in part on our understanding of future greenhouse gas emissions and in part on our understanding of how the earth's climate system will respond to the changes in GHG concentrations in the atmosphere. Downscaling regional or global climate models to generate local climate projections can be helpful, though users must bear in mind that the projections resulting from the downscaling process will generally have additional uncertainty introduced by this process. However, adaptation decisions still need to be made now with imperfect information.

[6] Pacific Climate Impacts Consortium – Climate Insights 101
https://www.pacificclimate.org/resources/climate-insights-101

The average percentage increases in rainfall intensity above historical values associated with RCP 8.5 (all return periods and all durations) for the model ensemble range from 16% to 42% as shown in Figure 3: Average Percent Change In Precipitation Intensity Above Historical (All Durations, All Return Periods) For RCP 8.5.. Additional comparison charts and data for individual durations and return periods are located in Appendix G.

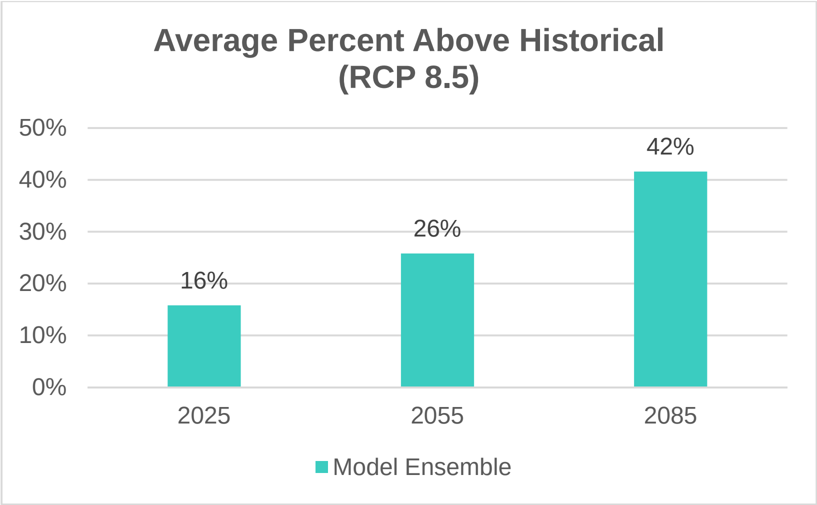


Figure 3: Average Percent Change In Precipitation Intensity Above Historical (All Durations, All Return Periods) For RCP 8.5.

4 EFFECTS OF UPDATED IDF CURVES ON SELECTED MUNICIPAL INFRASTRUCTURE

4.1 COLLECTION AND REVIEW OF BACKGROUND INFORMATION

At the beginning of the project, WSP carried out consultation with the Town of Creston representatives. The purpose of the meeting was to obtain all relevant background information (stormwater management criteria, reports, maps, models, etc.) and to agree upon the specific municipal infrastructure that would be used in our impact assessment.

The most important document collected was the Master Drainage Plan report prepared by Dayton & Knight Ltd. in 1983. The information from the report regarding Dodd's Creek at the 5th Avenue crossing confirmed with the Town is as follows:

- One culvert: 1 x 900mm CMP, L= 24m, S=5.6%
- Inlet Conduits: 1
- Design Flow: 5yr = 4.9 m^3/s; 100 yr = 9.5 m^3/s
- Drainage Area = D20 (5 acres/2ha)
- Runoff coefficient = 0.49

In addition to collection of information a site investigation was carried out with Mr. Colin Farynowski, Manager of Engineering of the Town of Creston. At the 5th Avenue crossing site, all necessary information was obtained and images of the watercourse crossing, i.e. culvert at 5th Avenue were taken as seen in Appendix A.

All received information was carefully reviewed and based on collected information and site investigations the existing conditions were established.

Figure 4: 5th Avenue Culvert

4.2 EXISTING CONDITIONS

In order to establish the existing conditions, new hydrologic analysis and new hydraulic computation were carried out. The as-built drawing including elevation contours was provided by the Town. Relevant data such as size and type of the culvert, upstream and downstream invert elevations of the culvert, elevations of the top of the road, ground elevations, etc. were taken from this design drawing.

The first step in our hydrologic assessment was to confirm the 1983 conditions in order to calibrate the model. Once calibrated, these baseline conditions were used later for comparison purposes with selected climate change scenarios to estimate potential climate change impacts on the 5th Avenue culvert crossing.

4.3 FUTURE CLIMATE CHANGE CONDITIONS

Based on the IDF curve analysis described in Section 2.1, three (3) future most likely climate change scenarios were used to estimate the potential future conditions. The selected scenarios are:

- Model Ensemble RCP 8.5 2020s,
- Model Ensemble RCP 8.5 2050s, and
- Model Ensemble RCP 8.5 2080s.

The rationale for using these climate change scenarios is provided in Section 3 of this report.

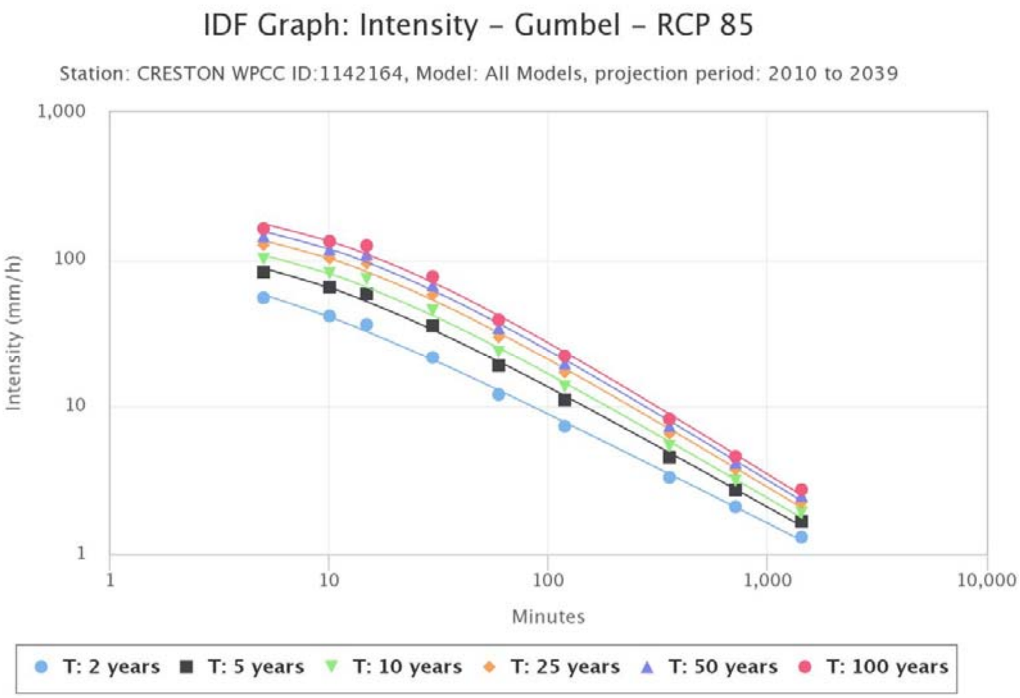


Figure 5: 2020s Creston WCPP IDF Tool – Future Precipitation Intensity (mm/hr) for 5 min – 24 hr Duration

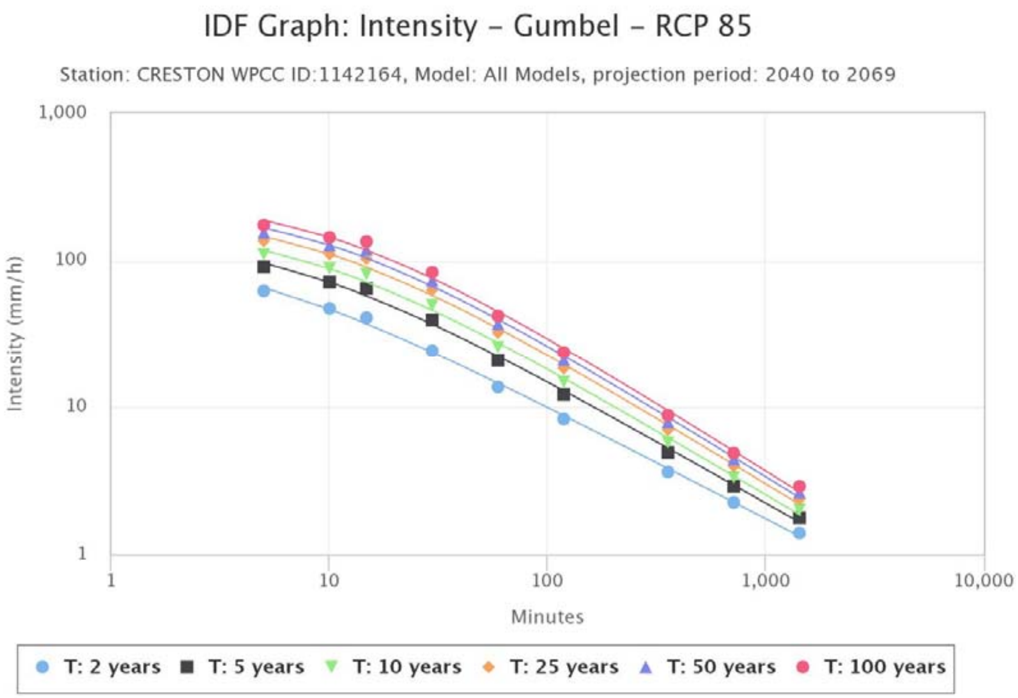


Figure 6: 2050s Creston WCPP IDF Tool – Future Precipitation Intensity (mm/hr) for 5 min – 24 hr Duration.

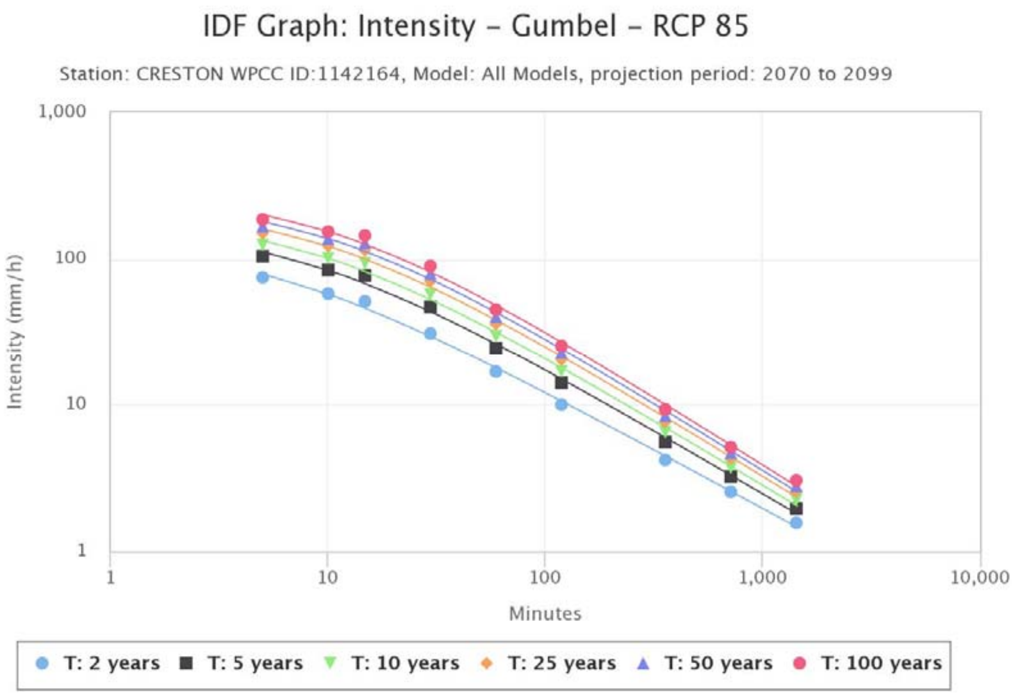


Figure 7: 2080s Creston WCPP IDF Tool – Future Precipitation Intensity (mm/hr) for 5 min – 24 hr Duration.

4.4 HYDROLOGIC ANALYSIS

The Master Drainage Plan as prepared by Dayton & Knight Ltd. was the primary source of catchment parameters used for the existing and future hydrologic modelling. The hydrologic analysis consisted of hydrologic modeling and discussion of the results. In order to compare the results for existing and future climate conditions the same models were used in hydrologic modeling. More detailed explanation of the hydrologic modeling is provided in the following sections of this report.

4.4.1 HYDROLOGIC MODELLING

The only hydrologic modelling of Dodd's Creek in the Creston area comes from the Dayton & Knight Ltd. Master Drainage Plan report. This modelling used published information and parameters judged to be best suited for Creston conditions to simulate Dodd's Creek. As no storm drain or meaningful creek flow data were available for the Creston area at the time of the Master Drainage Plan report, the 1983 model could not be calibrated to match the results of past return period events.

Two computer models were used to predict resulting return period flows: ILLUDAS, and TR-20. A combination of the results from these two models was used to create the Master Drainage Plan. Both models use runoff curve numbers (soil cover data), antecedent moisture data, and channel data in order to predict runoff flow.

Catchment areas used in these models include one large area upstream of the developed Creston area, as well as a number of smaller developed catchments within Creston. Each of these catchments was assigned a composite curve number, as well as a weighted runoff coefficient.

In order to calibrate our hydrologic model, the peak flow results from the Master Drainage Plan (Dayton & Knight Ltd.) were used as a bench mark. In order to match the results of the 1983 hydrologic modeling for Dodd's Creek at the 5th Avenue culvert, parameters from the 1983 report were used. These parameters include the catchment parameters as well as the 1983 IDF curve data. The 1983 IDF curves as shown in Appendix B were entered into SWMHYMO computer software to produce a usable input for Visual OTTHYMO 2.4 (V02) hydrologic modeling software. SWMHYMO results are included in Appendix C. V02 was chosen as widely accepted hydrologic modeling software and was used to match the 1983 predicted flows (using a 6hr AES rainfall distribution). V02 results can be seen in Appendix D. Because the 1983 analysis utilized software no longer in use (ILLUDAS), the results from the V02 model vary slightly. The 5 year flows for ILLUDAS and V02 are 4.98 and 4.55m^3/s respectively, while the 100 year flows are 9.54 and 10.81m^3/s respectively.

Due to the scope of this project, the hydrologic modeling was greatly simplified. In reality, there are many different catchments contributing runoff flow to Dodd's Creek, however, in the model only two catchments were used: developed and undeveloped. It is important to note that between 1983 and current conditions, a subdivision has been developed just upstream of the 5th Avenue culvert. The simplified V02 model is not sensitive enough to account for minor effect this would have on creek flows as the subdivision area is much smaller than the overall developed area.

Once the V02 results closely resembled the 1983 results, the physical parameters of the V02 model were held constant and rainfall data was entered for each of the following scenarios – current IDF, 2020s IDF, 2050s IDF, and 2080s IDF. These IDF curves were entered in SWMHYMO to produce the total rainfall volume for each scenario in order to fit them each to a six hour AES storm in the V02 model. The detailed results of the V02 model can be seen in Appendix D, and a flow rate summary can be seen in Table 1. For visual simplicity, flow rates for the IDF scenarios are shown as a chart in Figure 8: IDF Scenarios Predicted Flows Chart.

Table 1: IDF Scenarios Summary of Flow Rates at 5th Avenue Culvert

*HEC-RAS PLAN	Q_5	DIFFERENCE	***DIFFERENCE	Q_{100}	DIFFERENCE	DIFFERENCE
TIME SPAN	(m^3/s)	(m^3/s)	(%)	(m^3/s)	(m^3/s)	(%)
1983	4.6	-	-	10.8	-	-
Current IDF	6.1	1.5	25%	13.5	2.7	20%
2020s	7.1	1.0	15%	16.1	2.6	16%
2050s	7.9	1.9	24%	17.6	4.1	23%
2080s	9.4	3.3	36%	19.0	5.5	29%

*HEC-RAS Plan is the name of the simulation runs within the model.
**Q is the flow rate (Q_5 and Q_{100} are the 5 and 100 year return period flows respectively)
***Note: the percent difference for the current scenario is relative to the 1983 scenario. The percent difference for the future scenarios is relative to the current scenario.

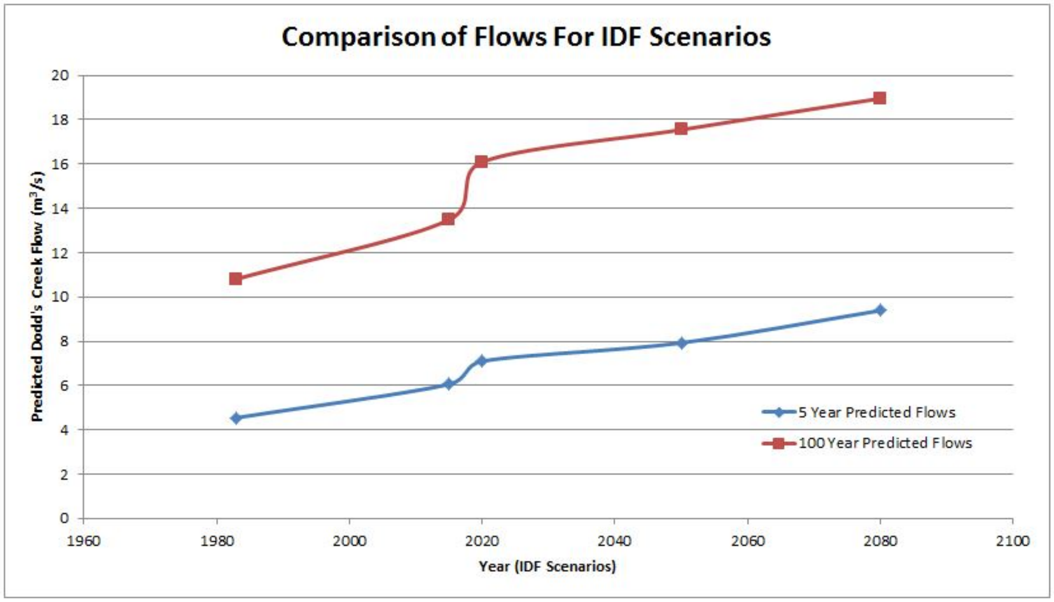


Figure 8: IDF Scenarios Predicted Flows Chart

4.5 HYDRAULIC ANALYSIS

Hydraulic modelling for municipal culverts is typically performed with either Culvert Master, or HEC-RAS software. For this exercise HEC-RAS was chosen to model the 5th Avenue culvert as it uses more detailed input data to simulate design flows and water surface elevations. This software, developed by the Hydrologic Engineering Center of the US Army Corps of Engineers, is widely used for watercourse hydraulic computations. HEC-RAS is also capable of modeling up and downstream creek conditions and backwater storage while Culvert Master is not. As the effects of upstream and downstream conditions impact the model results, the HEC-RAS will have a greater benefit to the Town. The only downside to using HEC-RAS in this project is the amount of detailed data required to build an accurate model. Hence, more detailed topographic surveying and mapping of the creek, floodplain and the road crossing would be required to meet the requirements for detailed design of a proposed culvert replacement.

4.5.1 HYDRAULIC MODELLING FOR EXISTING CONDITIONS

The HEC-RAS backwater model was set up to determine the water surface profile along the Dodd's Creek and at the 5th Avenue culvert location. The most up to date HEC-RAS model V. 4.1 was utilized for the purpose of this exercise. This model allows for computation of one-dimensional steady flow water surface profiles, appropriate for the objective of this assessment.

Standard steps in development of the hydraulic model are:

- Entering geometric data (physical parameters i.e. culvert and creek shape data);
- Entering flow data (5 year and 100 year flows as shown in Table 1);
- Entering boundary conditions (Dodd's Creek channel slopes beyond the confines of the model);
- Performing hydraulic computation; and
- Computation and verification of the results.

The geometric/physical component of the model was based on 11 cross sections taken from the as-built drawing with 5ft (1.52m) contour line intervals. The HEC-RAS cross sections are spaced to capture changes in the floodplain, model the slope of the channel, and where the most detailed data is available. The geometric layout of the HEC-RAS model, cross section plots, and reach (creek) profile can be seen in Appendix E. Inlet and outlet of the existing culvert constructed under the 5th Avenue road were taken from the SWM report.

Based on the site conditions, the Manning's roughness coefficient for the channel was estimated as n = 0.03 and the overbank roughness as n = 0.055. Other inputs into the model included the calculated 5 year and 100-year flow and upstream and downstream channel slopes as boundary conditions.

Once all inputs were completed and entered into the model, hydraulic computation was carried out. The results of the hydraulic computation for existing conditions show that the current culverts do not have sufficient capacity to convey 5-year and regulatory 100-year flow concurring with recommendations in the 1983 Dayton and Knight report.

4.5.2 HYDRAULIC MODELLING FOR FUTURE CLIMATE CHANGE CONDITIONS

The same HEC-RAS model was also used to model the future climate change conditions. Return period flows (5 & 100 Year) were predicted from the hydrologic analysis and used to run the HEC-RAS model for future conditions as per the flows generated by the 2020s, 2050s and 2080s IDF curves. As the purpose of this exercise is to predict the effects of updated IDF curves on existing and future infrastructure, no changes were made to the hydraulic model geometry between scenarios. The site in interest is the 5th Avenue culvert just south of Cook Street, and it is for this culvert that the five scenarios were compared.

4.6 DISCUSSION OF THE RESULTS

The results of this exercise are subject to limitations of the available data, IDF CC Tool, and are based on the best background information provided by the Town.

4.6.1 HYDROLOGIC MODELLING RESULTS

From Table 1 it can be seen that the projected IDF curve data based on projected climate change has a significant impact on return period storm flow rates. The 5 year flow rate from the 2080s scenario is 9.4 m^3/s, only 1.4 m^3/s less than the 100 year flow rate from the 1983 scenario (10.8 m^3/s). As the historical 100 year storm results in a similar peak flow to the projected future 5 year storm, the impact of the climate change IDF curve data results in a substantial increase in peak flow rates.

Comparisons with the predicted climate change IDF flows and current IDF flows reveal an increase in projected flow rates as well. The increase from the current scenario to the 2020s scenario is approximately 15%. This is a substantial increase as it is within the current time period and end of design life of the culvert, and not a long term projected future increase. It can be seen that the long term future climate change IDF curves continue to show an increase in return period flows. From 1983 to the 2080s scenario, the predicted 5 year flows have doubled, and the 100 year flows have nearly doubled. From the current IDF curve data to the 2050s and 2080s scenarios, increases of 24% and 36% can be seen respectively. The impact to infrastructure design will vary dependent on specific situation and the type of infrastructure being assessed.

4.6.2 HYDRAULIC MODELLING RESULTS

In the 1983 scenario, the capacity of the existing 5th Avenue culvert is not sufficient to convey the 5-year flow without overtopping the road. Because of the overtopping of the road by 5 year and 100 year flows the flood water spills into the wider floodplain upstream and downstream of the crossing. Flows under current and the 3 future conditions also overtop the road, but with an increase in the overtopping depth and flow velocity. Under the 5 year return period flow, comparing results from 1983 to the 2080s conditions, the depth of flow over 5th Avenue increases from 0.25m to 0.47m, an increase of 0.22m. Under the 100 year return period flow, comparing results from 1983 to the 2080s conditions, the depth of flow over 5th Avenue increases from 0.53m to 0.68m, an increase of 0.15m. Comparing the 1983 to 2080s scenarios under 5 and 100 year return period flows show an increase in flow velocity of 0.09 m/s and 0.15 m/s respectively. Most relevant hydraulic parameters such as flow velocities and headwater elevations are shown in Table 2.

It should be noted the 5th Avenue culvert crossing is creating a backwater effect and consequently very low creek flow velocities. Velocities upstream and downstream of this backwater are in excess of 3.5m/s.

Table 2: 5th Avenue Headwater Comparison under IDF Scenarios

HEC-RAS PLAN	Q_5	CHANNEL VELOCITY	HEAD WATER ELEVATION*	Q_{100}	CHANNEL VELOCITY*	HEAD WATER ELEVATION
TIME SPAN	(m^3/s)	(M/S)	(M)	(m^3/s)	(M/S)	(M)
1983	4.6	0.11	560.25	10.8	0.22	560.53
2012	6.1	0.14	560.34	13.5	0.27	560.58
2020s	7.1	0.16	560.39	16.1	0.32	560.64
2050s	7.9	0.17	560.42	17.6	0.34	560.67
2080s	9.4	0.20	560.47	19.0	0.37	560.68

*Note the top of road is at elevation 560m.

5 DISCUSSION AND RECOMMENDATIONS

5.1 INFRASTRUCTURE DESIGN ANALYSIS

The purpose of this technical exercise was to quantify the potential change and impacts to stormwater infrastructure in the Town of Creston under predicted climate change conditions.

The increase in 5-year and 100-year flows due to the future climate change predictions will result in increase of frequency and magnitude of flooding. This will be due to insufficient capacity of select municipal infrastructure to convey the increased flows.

With the projected climate change IDF curves, increase in return period flows can be seen with hydrologic modelling. With higher rain fall intensity, it can be expected that peak flow rates in tributaries, creeks, and rivers will increase in any catchment.

The increase in headwater depth and flow velocity at the 5th Avenue culvert is much less evident than the peak flow increase. Effects of increased flow on culverts and bridges are situational and depend largely on the geometry at each unique location. The 5th Avenue culvert is part of a creek with a steep average channel slope (3-7%), and steep natural valley embankments. The steep channel slope results in high flow velocities and the steep valley embankments result in higher flood levels staying contained within the natural valley. It is possible that the climate change IDF curve projections may have a much more profound impact on other culvert/bridge locations.

Although the impacts on the 5th Avenue culvert are not as significant as they might be on culverts with shallower channel bed slopes, the impacts can still be seen. Under the 5 year return period, the road overtopping depth from historical IDF curves (1983) shows the depth at 0.25m, which is under 0.30m. The 5 year overtopping depths for climate change conditions are over 0.3m in depth. A flow depth of 0.30m or lower is considered safe for emergency vehicles to drive through. Any flow depth higher than 0.30m is considered unsafe for emergency vehicles to drive through. It can be seen that for this culvert, it was possible to be overtopped and still allow emergency vehicle passage under historical conditions; however this will no longer be possible under the climate change conditions.

It is understood that historically this culvert has never overtopped the road. This discrepancy between the modeled and observed results could be caused by undersized culverts upstream that reduce the peak flow at the 5th Avenue culvert, or it could be that the 1983 Master Drainage Plan has overestimated the flows at this culvert.

5.2 LIMITATIONS

Information provided by the IDF CC tool is useful for planners who are designing infrastructure to accommodate the anticipated increases in rainfall intensity. However, the Tool's methodology includes assumptions related to how projections of sub-daily extreme precipitation are extrapolated from daily information and the uncertainty associated with these assumptions is not adequately defined. It is estimated that the effects of these assumptions may significantly widen the range of projected sub-daily rainfall intensities (Murdock pers. comm., 2015). Further, other assumptions and sources of variability included: method of spatial interpolation, estimated parameters for Gumbel distribution[7] (both the technique of estimation, and the statistical variability - 95% confidence interval), and the choice of GCM/RCM. These assumptions can result in underestimating the sub hourly intensities and therefore flows. Discretion should be used by designers where infrastructure must quickly handle peak flow events.

However, the IDF CC tool is currently the best tool available for municipalities to improve their design criteria and provides municipalities with improved design information than the current IDF curves do. Understanding how the climate system will respond at its extremes under future GHG scenarios is an emerging area of scientific research that carries important ramifications for those involved in adaptation planning. Consequently, there is significant interest within the research community to continue refinement of the tools available for engineers to design climate change adaptable municipal infrastructure that will accommodate extreme climate events in the coming decades.

As part of this study, we provided hydraulic analysis for the 5th Avenue crossing over Dodd's Creek using HEC-RAS software/model. Due to number of assumptions made in development of the 5-year and 100-year flows, the results of HEC-RAS modeling provide rather a range of potential impacts to the water surface elevations than exact water surface elevations at this section of Dodd's Creek. A detailed design based on topographic surveying of the culvert, floodplain and the top of the road will be required for detailed design and replacement of the 5th Avenue crossing culvert.

The results of the design analysis are subject to limitations of the available data, IDF CC Tool, and are based on the best background information available, provided by the Town.

5.3 RECOMMENDATIONS

When making infrastructure design decisions, municipalities should consider that our knowledge of climate change science has thus far improved with time. When considering which IDF curve to choose in design, the projected lifetime of the infrastructure should play a significant role in determining how conservative the design should be. Considering our current carbon emission outputs are not trending towards a more optimistic level, the future IDF curve should be chosen to match the future time period within the lifespan of the selected infrastructure. For example a culvert designed in 2015, which expected to be used until 2040, should be designed using the 2050s IDF curve (RCP 8.5). As ongoing climate change projection information becomes more refined, it is recommended that the Creston IDF curves be re-assessed periodically.

The Master Drainage Plan report was completed in 1983. Since then parts of the Dodd's Creek sub-watershed have been developed and the results from the report don't reflect current site conditions anymore. Hence, an update of the Master Drainage Plan is highly recommended.

It is recommended that for future storm infrastructure installations and rehabilitation, the predicted climate change IDF curve information be taken into account during the planning and design process. One approach is to design and construct infrastructure with sufficient capacity to handle future flows. Choosing which time period and related IDF curve is a matter of policy decision based on the design life of the infrastructure and the risk of property damage due to flooding. In this case, major

[7] The Gumbel distribution is a probability distribution of extreme values. In probability theory and statistics, the Gumbel distribution is used to model the distribution of the maximum (or the minimum) of a number of samples of various distributions.

infrastructure should be designed for the IDF curve at the end of its design life. The IDF curve chosen can have a significant impact as Table 1 shows a 35% and 29% increase in flow at the 5th Ave culvert respectively for the 5 year and 100 year return period from the current IDF curve to the 2080s scenario.

The typical range of design life for both minor and major drainage infrastructure components are shown in Table 3. The design life of individual drainage features varies based on location and materials chosen as the serviceable life is affected by pH, corrosive environments, oxidation of thermoplastics, and abrasion, etc. This range of design life is provided as a reference only. The replacement of stormwater infrastructure should be designed according to recommended design specifications of an updated Master Drainage Plan.

Table 3: Typical Design Life of Stormwater Infrastructure

Stormwater Infrastructure Component	Design Life Range (Years)	Proposed IDF Curve Range
Culverts	10-25	2050s
Pipes and Manholes	50-100	2080s
Bridges	75-100	2080s

The results of the limited design analysis show significant increases in flows at the 5th Avenue culvert by applying the future IDF curves. It is recommended that a similar analysis be repeated for other stormwater infrastructure which is not already subject to flooding to analyze the impact.

As the overdesign of pipe and structures can be costly, alternative stormwater management processes should be explored to accommodate the predicted effects of climate change. Municipalities can address the predicted increase in stormwater flows by focusing on runoff detention, temporary storage and infiltration of runoff water which also improves stormwater quality and therefore the quality of the receiving environment. This can be accomplished by re-designing roads and parking lots so that the runoff water is directed into swales, sand filters, detention ponds and wetlands.

6 REFERENCES

Pacific Climate Impacts Consortium – Climate Insights 101.
https://pacificclimate.org/resources/climate-insights-101

Schardong A., Srivastav R., and Simonovic P.. (2015). Computerized tool for the Development of Intensity-Duration-Frequency Curves under a Changing Climate. User's Manual v.1.1. Water Resources Research Report no. 088, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 62 pages. ISBN: (print) 978-0-7714-3085-5; (online) 978-0-7714-3086-2.

Seth Westra, Lisa V. Alexander, and Francis W. Zwiers, 2013: Global Increasing Trends in Annual Maximum Daily Precipitation. *J. Climate*, **26**, 3904–3918.

Trenberth, K.E. (2011). Changes in precipitation with climate change. *Clim Res* 47 123-138.

Wolff, E., et al. "Climate change evidence and causes." *The Royal Society and US National Academy of Sciences* (2014).