PROJECT NO.: 131-23258-00

DRAINAGE MASTER PLAN

BEAR RIVER BASIN, MACKENZIE COUNTY

JUNE 2015

WSP

DRAINAGE MASTER PLAN

BEAR RIVER BASIN

Mackenzie County

FINAL VERSION

Project No: 131-23258-00
Date: March 2015

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June 3, 2015

Mr. Grant Smith
Mackenzie County
4511-46 Avenue
Fort Vermillion, AB T0H 1N0

Subject: Drainage Master Plan – Bear River Basin (Final Version)

Dear Mr. Smith,

Please see attached the final report titled "Master Drainage Plan – Bear River Basin". This report has now been finalized after presenting the material and receiving comments from the County.

As requested, we will send an electronic copy and twelve paper copies of this report.

The WSP team would like to thank the Agricultural Services Board, including Julia Whittleton, Grant Smith, and Mackenzie County for the opportunity to work on this project.

Please contact the undersigned if you have any questions.

Yours truly,

Kevin Henshaw, P. Eng.
Senior Bridge Engineer, Bridges

Encl.

c: Joulia Whittleton, Mackenzie County, Fort Vermillion
Mark Onaba, WSP, La Crete
Michael Bird, WSP, Sherwood Park

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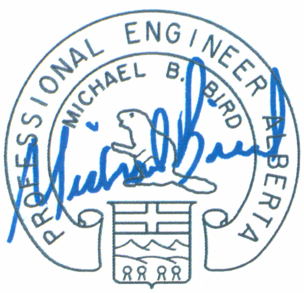
SIGNATURES

IMPORTANT NOTICE

This report was prepared exclusively for Mackenzie County by WSP Canada Inc. (WSP). The quality of information, conclusions and estimates contained herein is consistent with the level of effort provided by WSP and are based on: i) information available at the time of preparation, ii) data supplied by outside sources, and iii) the assumptions, conditions and qualifications set forth in this report. This report is intended to be used by Mackenzie County only, subject to the terms and conditions of its contract with WSP. Any other use of, or reliance on, this report by any third party is at that party's sole risk.



June 3, 2015

Michael Bird, P. Eng.
Senior Bridge Engineer

June 3/2015

Kevin Henshaw, P. Eng.
Senior Bridge Engineer

PERMIT TO PRACTICE
WSP Canada Inc.
PERMIT NUMBER: P07641
The Association of Professional Engineers and Geoscientists of Alberta

EXECUTIVE SUMMARY

Mackenzie County commissioned WSP Canada Inc. (WSP) to carry out a study of the drainage issues within an area of the County east of La Crete, and south of Fort Vermillion, specifically within the Bear River Basin.

The Bear River Basin contains a productive agricultural area situated between the Peace River and Buffalo Head Hills. Continuous development has put strain on the existing drainage system in the area resulting in flooding in multiple locations every spring. Subsequently, there have also been many drainage improvement projects constructed to mitigate ongoing flooding concerns. Projects range from small ad-hoc ditches created by landowners, to large scale drainage systems completed by AESRD and the County.

There now is concern that a surge of further clearing and drainage manipulation will overwhelm the existing drainage system, which already may be undersized in some locations.

An overall drainage plan has never been completed for the area and this report is the first step in instituting a more proactive approach to drainage issues. It can be used as a reasonable and practical tool for the County and for landowners to manage drainage issues and mitigate flooding. It can also be used as a basis for further more detailed studies of specific areas within the basin.

The plan includes a general review of drainage information and relevant documents, identification of areas with existing flooding concerns, analysis of the existing drainage system and the problem areas, and recommendations on flood mitigation solutions and drainage improvements.

A broad scope was defined for the subject of this study including high level recommendations, general concepts for drainage, and some specific design investigations. The study area is also very large at over 2,500 km^2.

Originally physical survey data was proposed for the analysis and modeling, however, LiDAR became available and was used instead. Although the LiDAR was a considerable expense, it provided a wealth of valuable and detailed information used for this report and will provide information for any project completed in the future within the captured area. Although the overall project scope was reduced to add the LiDAR, it allowed for a level of detail in the analysis that would otherwise have been impossible.

WSP has reviewed all available existing documents and files, cataloged the existing drainage system, and analysed existing hydrology data. The results are summarised in the report which can be used as a reference for future related work.

A conceptual model of the drainage system was then created. The model represents a reasonable simulation of the network and the hydraulic routing through each channel. The model was simplified to be able to handle the vast area being covered and to eliminate the unpredictable effects of icing and snowmelt. The final model is a reasonable representation of the conditions within the study area and it generates results that are calibrated to local gauge data and are within a reasonable range established in the hydrology review. For specific design purposes the hydrology should be reviewed.

Using collected data, GIS information, and the model results, a comprehensive study of drainage throughout the study area was completed. The study area was split into six zones and each was assessed in terms of the identified problem areas and future development areas with conceptual solutions being provided for each. Conceptual cost information is also provided for each solution.

Recommendations include:

- An alternative alignment for the Steep Hill Creek Drainage Ditch.
- Conceptual design information for drainage improvements in development areas.
- Identified sensitive areas that should be protected from development.
- Drainage infrastructure maintenance guidelines.
- Applicable environmental regulations.

General information regarding drainage issues is which includes details on some common mechanism behind flooding related to snow and ice, which is common in this area. General flood mitigation measures are also included which provides a helpful overview of information for the County and Landowners that can assist with land development.

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SYMBOLS, ACRONYMS, AND ABBREVIATIONS USED

AESRD .... Alberta Environment and Sustainable Resources Development
AT .... Alberta Transportation
BMPs .... Best Management Practices
County .... Mackenzie County
IDF .... Intensity Duration Frequency
LiDAR .... Light Detection and Ranging (DEM Data with 1 m Resolution)
NTS.................. National Topographic System
RG .... Range
RR.................... Range Road
ROW .... Right Of Way
TWP................. Township
TR .... Township Road
WSC .... Water Survey of Canada
XP – SWMM .... Expert System Stormwater Management Modelling
ha .... Hectares
km^2................... Square Kilometres
$m^3/s/km^2$........... Cubic Meters per Second per Square Kilometre
mm/hour........... Millimetres per Hour
cm/s .... Centimetres per Second

1 INTRODUCTION

1.1 GENERAL

Mackenzie County (the County) commissioned WSP Canada Inc. (WSP) to prepare a Drainage Master Plan (the Plan) to evaluate surface drainage and to address drainage related issues within the watershed of the Bear River.

The Bear River drainage basin covers a large area including the Buffalo Head Hills to the south, extending north and west to the Peace River, and east past Highway 88. The majority of the basin consists of relatively flat agricultural land and muskeg.

Farming and development over the past century have, by necessity, altered the land by clearing and changing drainage patterns. Once the land has been developed additional impervious surfaces, reduced water retention, and increased snowmelt rates all contribute to increased runoff rates. Associated roads and ditches required to access land further manipulate flows and, as clearing and development of land are expanding; the need for adequate drainage grows thus creating an ongoing water management challenge.

Flood control based on flow quantity is the primary focus of the study. Runoff quality is not directly addressed; however, in mitigating flood and erosion issues, water quality will also be improved.

1.2 PROBLEM

The Alberta Government has recently sold roughly 136,000 acres (~550 km^2) of public land in Mackenzie County to private owners and many of the new land parcels are located within the area of the Bear River basin. The new parcels of land are rapidly being cleared and ad-hoc drainage works are being constructed. Figure 1-1 displays new land parcels as shown in black. Roughly half of the parcels are located in the Bear River basin study area.

There is concern that once these new land parcels have been cleared, increased runoff will overwhelm an already taxed drainage system. Road and drainage infrastructure constructed in the past were focused primarily on local drainage and did not take the general area or future development into account. The challenge now is to effectively and efficiently drain newly developed land parcels through rehabilitation and upgrading of the existing infrastructure with the ultimate goal of meeting the needs of farmers and other rate payers by preventing damage to property and infrastructure due to flooding. Flows need to be discharged to the receiving watercourses and rivers in such a way that the downstream capacity of the entire system is not exceeded.

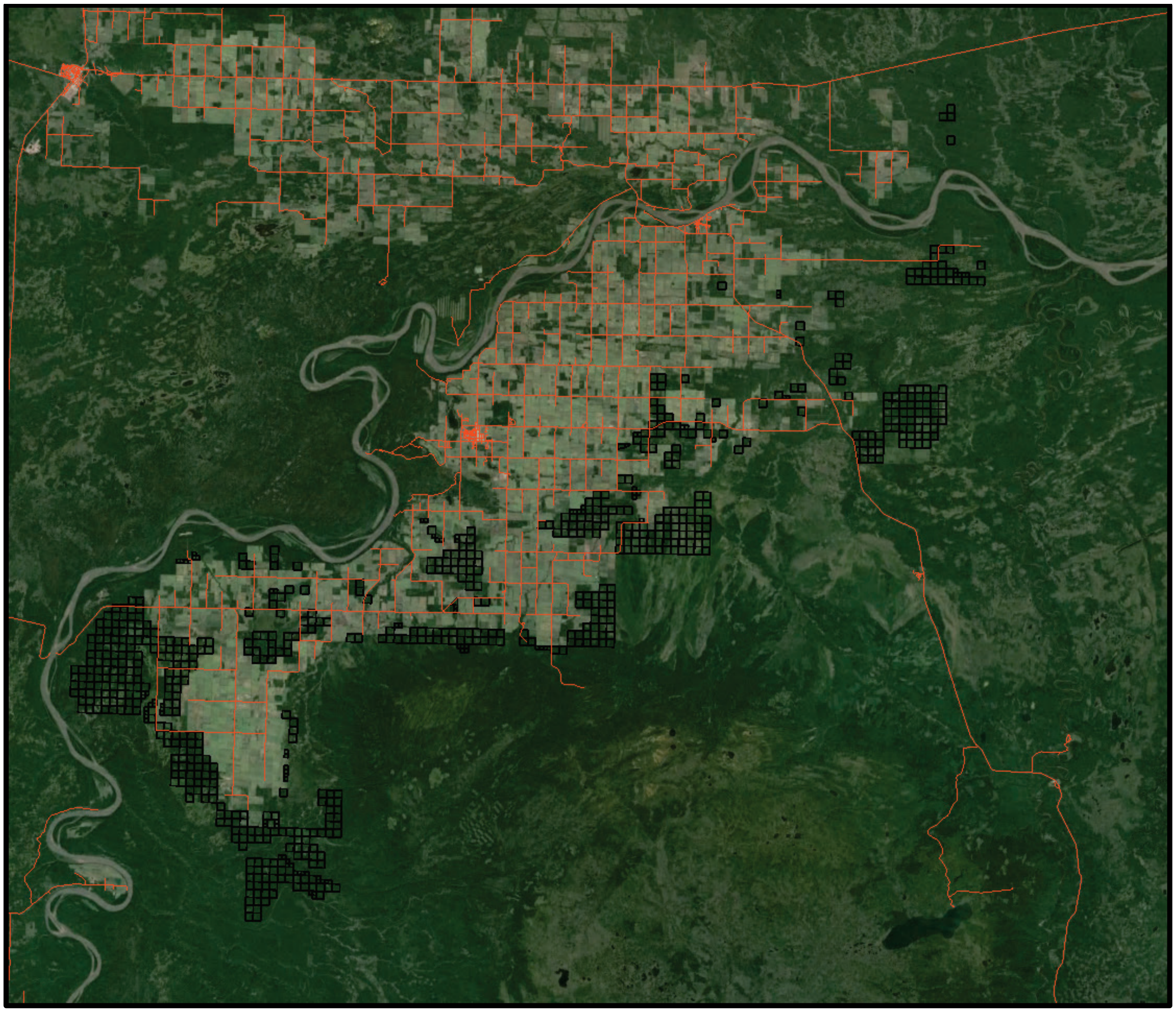


Figure 1-1 New land parcels are shown in black. The majority of the parcels are located in the Bear River basin study area. Roads are shown in orange.

1.3 PLAN

Due to the vast size of the area of concern, the long complex history of flooding issues and piecemeal drainage improvements within the Bear River basin, the County has decided to take a systematic approach to the recent concern.

The first step in this approach is to prepare an overall review and plan of drainage in the area (the Drainage Master Plan) which is a high level review of the study area which will be used as a basis for further, more specific studies to address the issues.

This Plan will assist the County with direction for addressing problem drainage areas with current and future development. The study will focus on impact of drainage from the new land within the Bear River Basin and will propose some conceptual solutions for addressing both present and future drainage concerns within the study area.

In general, this project will assess the capacity of the existing system, predict possible future development and associated drainage issues, investigate possible solutions, and make recommendations that can be used to assist the County with future growth.

This study is based on the guidelines of AESRD and analysis of the Bear River basin has been carried out by computer modeling using XP-SWMM.

1.4 STUDY OBJECTIVES

Develop a Drainage Plan to assess the capacity of the existing system, predict possible future development and associated drainage issues, investigate possible solutions, and make recommendations that can be used to assist the County with drainage management.

Specific objectives of this study include the following:

- Gain an understanding of the drainage history and existing drainage patterns.
- Identify problem areas that are currently prone to flooding.
- Analyse the impacts of historical, current, and future developments in the area (including the impacts due to the clearing of the recently sold lands to private owners).
- Identify drainage system areas that may be inadequate for existing and future drainage requirements.
- Assess possible solutions to the deficiencies identified.
- Make recommendations for implementation of the solutions.
- Establish guidelines related to future watershed management.

1.5 METHODOLOGY

The following tasks and methodology will be used to achieve the objectives of the study:

- **Data Collection**
  - Field investigation and tour with County staff.
  - Review and summarise existing history, previous studies, existing reports, local knowledge, and other information relevant to the drainages in the study area.
  - Collect relevant geomatic data for the study (LiDAR, DEM, Maps, and existing GIS information).
  - Collect historical flood, rainfall information, and other climate data.
  - Document sites with a history of flooding within the study area.
- **Hydrology / Modelling**
  - Define the watershed and sub basins areas contributing to the study area.
  - Conduct a general hydrology study of the area.
  - Collect historical flood and rainfall information.
  - Establish a representative drainage network.
  - Create drainage model (pre and post development).
  - Calibrate the model based on known parameters.
  - Establish model limitations.
- **Assess Issues**
  - Use hydrology and model to analyse possible causes of identified flooding problems.
  - Assess major infrastructure for existing and future hydraulic adequacy.
  - Identify possible future problem areas based on predicted development.
- **Investigate Drainage Management Solutions**
  - Identify general solutions for watershed management issues.
  - Assess possible solutions for problem areas identified within the study area.
  - Assess possible solutions to mitigate the impacts of increased run-off in identified areas.
  - Apply conceptual costs to each solution.

1.6 PROJECT EVOLUTION

The study area was originally defined as the watersheds of the Bear River, Steep Hill Creek, and Blues Creek. Through discussion with the County regarding their expectations for this project, and the data needed for a large area such as the Bear River Basin, a significant amount of work was done to investigate the possibility of ordering a large area of LiDAR. The LiDAR provides a level of detail that would not be possible with traditional survey. It can also be used for any future projects with in the area.

In order to limit the area needed, LiDAR was purchased for a grid of quarter sections lines covering a swath of land through the study area. This made it possible to purchase the data within the budget set aside for the study, however, the scope of the study area also needed to be reduced. This included the elimination of Steep Hill Creek and Blues Creek basin from the scope of the study, as well as a reduction of some modeling and reporting in the original scope.

It was agreed that the end result will still provide the best value overall to the County in keeping with the original intent of the study. The LiDAR data was used for the plan and can also be used for future projects (drainage or otherwise). In addition, the study results are based on more accurate and widespread elevation data.

2 STUDY AREA

The study area is focused in the general Bear River area, which was loosely defined at the initial stages of the project. Discussion with the County and some initial investigation provided information to refine the general area to be studied such that problem areas and related land is captured. Figure 2-1 below shows the final study area. The Bear River drainage basin is highlighted in black. The main natural channels are shown in dark blue and the drainage ditches in light blue. The sub-basins for the overall drainage are shown in green.

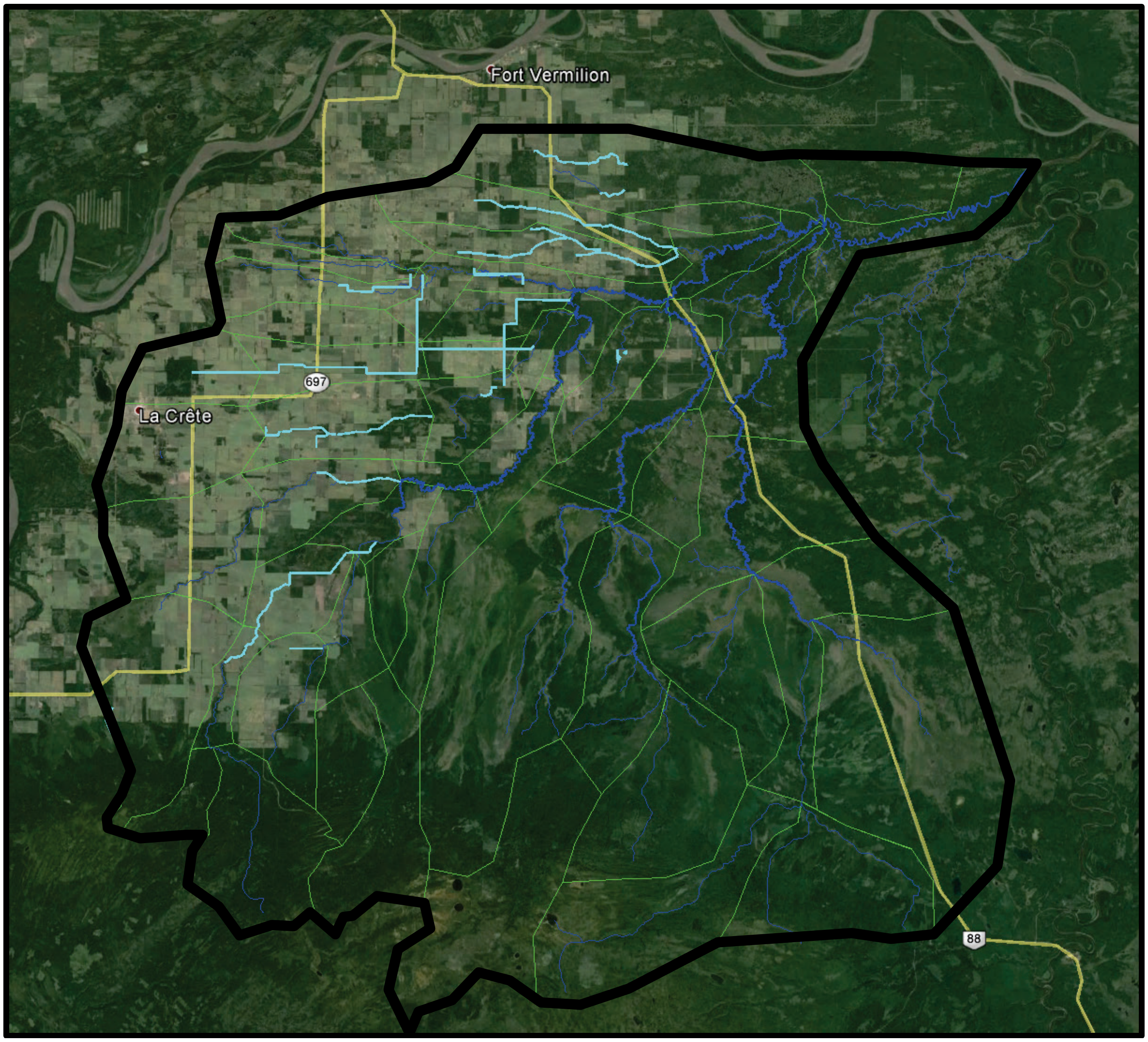


Figure 2-1 The study area where the Bear River drainage basin is highlighted in black. The main channels are dark blue and the drainage ditches are light blue

The basin is large, with a total area of roughly 2,600 km^2. Approximately half of the basin is currently developed, making up the northwest section of the study area. The southeast section of the basin (roughly divided by the main trunk of the Bear River) consists of the Buffalo Head Hills to the south, and a large area of undeveloped land covering two large tributaries. Water flows into the Wabasca River to the northeast.

From observations and past records, the Peace River and Wabasca River do not directly contribute to flooding in the study area and were not included in the analysis.

The following features outline the approximate area of interest:

- North Boundary – Peace River and Fort Vermilion.
- South Boundary – Buffalo Head Hills
- East Boundary – Wabasca River
- West Boundary – Peace River and La Crete

3 RELEVANT BYLAWS AND GUIDELINES

3.1 STORMWATER MANAGEMENT GUIDELINES FOR THE PROVINCE OF ALBERTA

Alberta Environment and Sustainable Resource Development (AESRD) published guidelines in January 1999 to assist municipalities in the planning, design, implementation, and operation of stormwater management facilities in Alberta. General stormwater management information is provided as well as more specific methodologies that are amiable for use.

Planning levels of stormwater management are discussed, which include the following as they pertain to rural drainage:

- River Basin Plan - High level, large scale planning typically at the provincial level.

- Watershed Drainage Plan - General planning for large areas at the municipality level including analysis of the drainage system, identification of environmental concerns, predicting future drainage requirements, and assessing general options for meeting those requirements.

- Master Drainage Plan - Drainage planning at a local level to develop alternatives that will satisfy acceptable levels of service, the Watershed Drainage plan, and specific local considerations. The scope is to identify major drainage facilities, and land requirements for drainage purposes. Conceptual designs of major facilities may be developed. General design standards for site implementation plans are also recommended.

- Site Implementation Plans - Detailed design of drainage facilities.

The scope of this report includes a study area consistent with a River Basin Plan or Watershed Drainage Plan; however the scope includes aspects of a Master Drainage Plan.

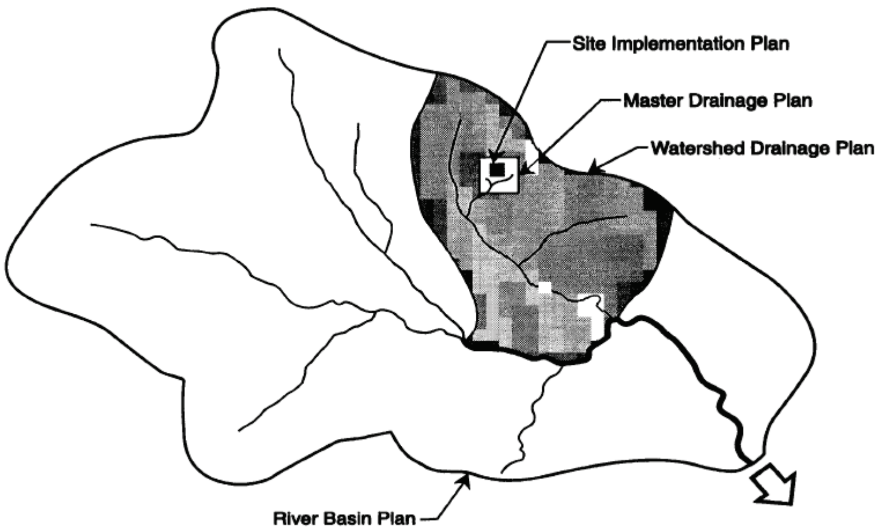


Figure 3-1 Stormwater Management Planning Levels (from the AESRD Guidelines)

The stormwater management guidelines document is primarily focused on urban drainage; however, rural drainage is also discussed. The following relevant points are quoted from the document;

- "Many rural drainage channels routinely overflow their banks and cause flooding of adjacent land during spring runoff. Usually this is not a problem, provided that the excess water drains away quickly. In many cases, particularly in the upper reaches of a watershed, the primary drainage routes are not incised channels but broad overland flow routes active only during spring runoff. During the summer months these floodplains may be productive farmland where flooding would cause extensive economic damage."

- "The most significant impacts of agriculture on rural drainage systems results from either the drainage of wetland areas or the conversion of woodlands or pasture to cropland."

- "A lack of maintenance is the primary cause of failure for drainage works."

Contrary to urban stormwater management practices, flow regulation policies based on pre-development and post-development flow should be avoided.

Best Management Practices (BMP's) and maintenance procedures are detailed which applies mostly to urban settings, however, some pertain to rural development and are included in this report.

3.2 MUNICIPAL DEVELOPMENT PLAN, BYLAW NO.735/09

The purpose of the Mackenzie County Municipal Development Plan (MDP) is to provide direction to the County to guide development and is intended to be used in conjunction with the Land Use By-Law. The MDP was completed by ISL Engineering and Land Services on November 10, 2009.

Agriculture is a significant part of the area's economy and it is identified as the most important land use in the rural areas. There are over 700 farms within the County covering over 200,000 hectares of land. As of 2009 the total area of improved agricultural land has tripled since 1971. The plan recognizes that agricultural land should be protected and that development should contribute to fiscal, social, and economic well-being.

Roughly half of the study area is Crown Land (Green Zone). This land is managed by the Alberta Government. One agricultural policy is to pursue the re-designation of Green Zone land to White Zone land for further agricultural use.

In general landowners must follow by-laws, and regulations set by the County and the Provincial Government. The development plan includes policies regarding agriculture, environmental stewardship, and addresses the protection of natural areas, however, the there are no current policies directly dealing with drainage and associated land development practices.

Review of the Municipal Development Plan is recommended to be competed every 5 years. The recommendations made in this Master Drainage Plan could be considered as part of that review.

3.3 ALBERTA PUBLIC LAND USE ZONES

According to data from AltaLIS, the Green Area (forested portion) comprises most of northern Alberta as well as the mountain and foothills areas along the province's western boundary. In the Green Area, public land is managed for timber production, watershed, wildlife and fisheries, recreation and other uses. Agricultural use is limited to grazing where it is compatible with other uses. The White Area (settled portion) consists of the populated central, southern and Peace River areas of the province. In the White Area, public land is part of the agricultural landscape. It is managed for various uses including agriculture, recreation, soil and water conservation, and fish and wildlife habitat. Some parts of the province have large tracts of public land whereas other parts have very few scattered parcels. Most of the public land in the White Area is under disposition or is otherwise committed.

A Green and White land use map for the Mackenzie County area is shown in Figure 3-2. Additional development since 2009 has increased the areas of Freehold Land and agricultural lands.

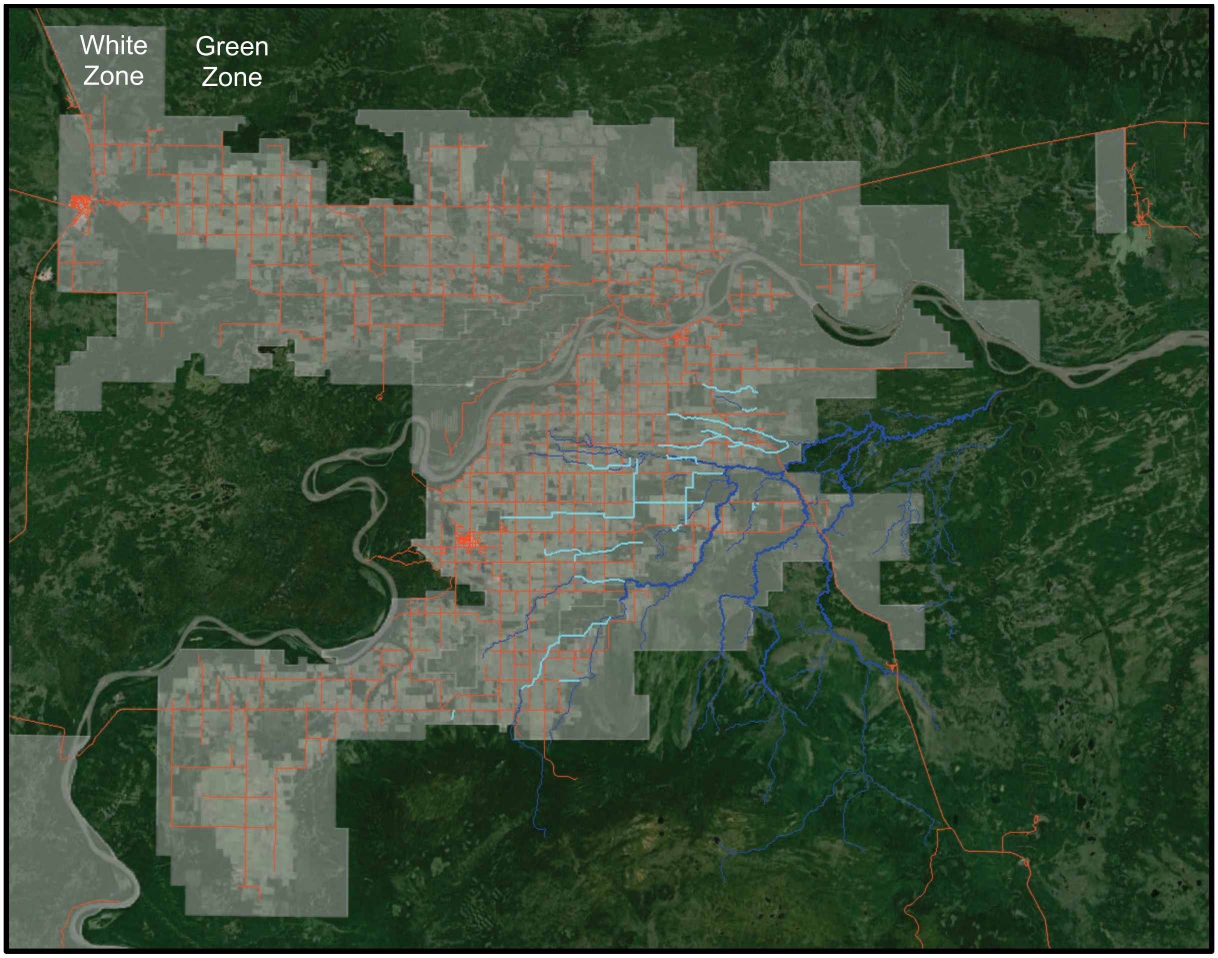


Figure 3-2 Green and White Land Use Map (data from AltaLIS dated 2010)

3.4 LAND USE BYLAW, BYLAW NO. 927-13

The Mackenzie County Land Use Bylaw, Bylaw No. 927-13, was adopted on September 23, 2011 and revised with a consolidated version on October 29, 2014.

The purpose of this bylaw is to regulate use and development of land and buildings within the boundaries of the County to achieve orderly and economic development.

The vast majority of land within the Bear River basin is considered to be Agricultural “A” land. The south east half of the basin is Crown Land.

Drainage is addressed in general in section 7.1 of the Bylaw, stating that the “total site area (lot) of any development shall have a positive surface drainage that does not adversely affect the neighbouring properties”.

Restrictions to any construction activity in a flood prone area is also addressed. Development on land which may be subject to flooding is not permitted on lands that are within the 1:100 year flood plain, unless otherwise permitted in this bylaw. Flood zones are established by the Alberta Government and are based on the Peace River only in this area. Flooding of small drainage channels and watercourses are not considered.

4 REVIEW OF EXISTING DRAINAGE

4.1 GENERAL

A review of available existing information was done to gain an understanding of the history of drainage projects in the study area as well as a better understanding of current drainage channels and related documents. Starting in the 1970's, drainage channels were built in the Bear River basin. The drainage construction and rehabilitation works are continuing. Figure 4-1 displays drainage ditches in light blue and the dark blue lines display natural watercourses.

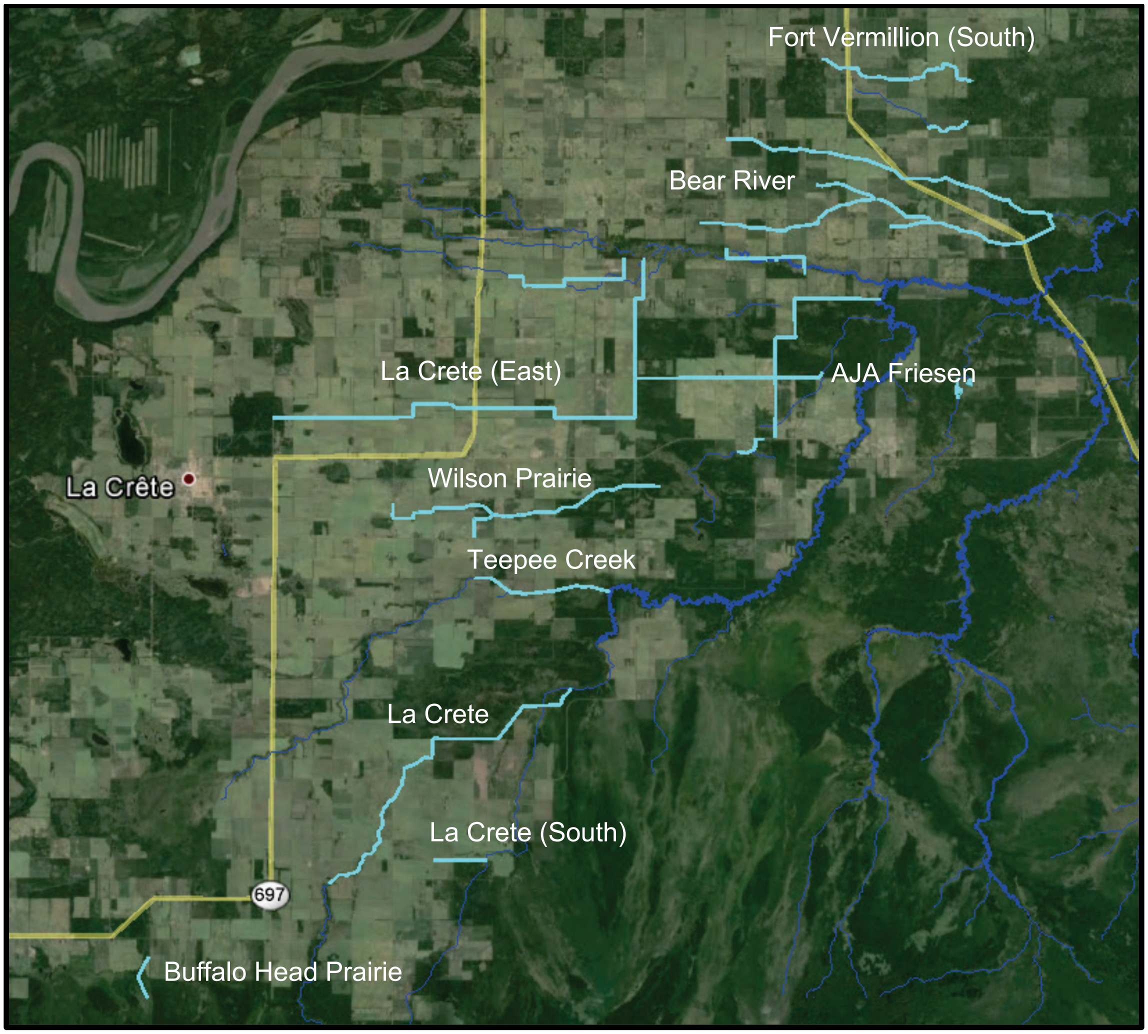


Figure 4-1 Drainage ditches where the light blue show the drainage ditches and the dark blue displays the natural watercourse

WSP was directed to the AESRD office in Peace River as the best place to find historical documentation. Other sources include files from previous projects completed by WSP, Mackenzie County, and the County internet site.

This is not meant to be an exhaustive review of all existing information. It is noted that some projects are more represented than others; however, the information included does provide a good general history and summary of relevant information.

Development and drainage issues in the study area have been ongoing for the past several decades. Over that period there have been multiple drainage studies, reports, and projects completed that can provide relevant history and general information to this study. A review of available pertinent information was completed and noteworthy information is summarised herein. The following reports and documents were provided by the County and AESRD.

- Feasibility Study for La Crete (East) Flood Control Project in Improvement District No. 23, Townships 106 and 107, Range 12, 13, 14, 15, W5, April 1993 (Torchinsky Engineering Ltd.)
- La Crete Area Flood Control Proposals (AESRD's Memorandum)
- La Crete (South) Flood Control, March 1976 (AESRD)
- La Crete (South) Flood Control, Level I, Design Report, September 1975 (AESRD)
- Tee Pee Creek Flood Control - Level I, June 1983 (Liland Engineering Ltd.)
- Tee Pee Creek Flood Control, As Constructed Report, March 1985 (AESRD)
- Buffalo Head Prairie Flood Control Project, As Constructed Report December 1992 (Bekevich Engineering Ltd.)
- Bear River North Flood Control Line 4, As Constructed Report, April 1985 (AESRD)
- Bear River North Flood Control Line 4, As Constructed Report, 1986 (Keneema Engineering Ltd.)
- Wilson Prairie Flood Control, August 1985 (Liland Engineering Ltd.)
- Wilson Prairie Flood Control Project (AESRD)
- Wilson Prairie Drainage Extension Assessment, June 2003, (WSP, formerly EXH Engineering Services Ltd.)
- AJA Friesen Drainage (Township Road 106-4), 18 Km East of La Crete, Conceptual Drainage Design Report, December 2009

4.2 LA CRETE (EAST) FLOOD CONTROL

A map of this drainage ditch location is displayed in Figure 4-2.

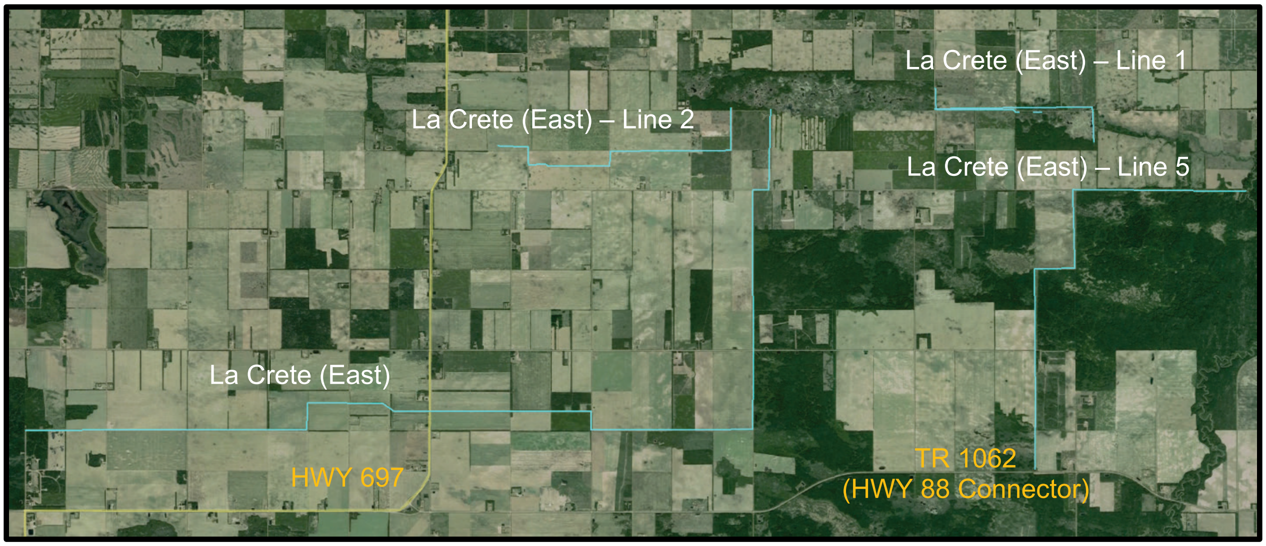


Figure 4-2 Map of the La Crete (East) drainage Project

4.2.1.1 FLOOD FREQUENCY ANALYSIS - LA CRETE (EAST) FLOOD CONTROL PROJECT (1980, AESRD)

A report titled, “Flood Frequency Analysis - La Crete (East) Flood Control Project” was submitted by the Hydrology branch of Alberta Environment in July 1980. This report identified historical drainage problems include the lack of a defined watercourse, expansion of the agriculture land, road and ditch construction.

As well, when the land was cleared during winter months, the farmers experienced a large quantity of water that translated to a loss of roughly 10 acres per quarter. Private ditching also contributed to downstream flooding. Since the land was released for agricultural development, the farmers recognized a high loss of productivity due to flooding high and were not in an economic position to solve the flooding issues.

The flood frequencies were derived by estimating the snowmelt runoff volumes during the normal spring runoff period using WSC Gauge 07HF002 at Keg River near Highway 35. The estimated flood frequencies are listed in Table 4-1.

Table 4-1 Flood Frequencies Were Derived By Estimating The Snowmelt Runoff Volumes During The Normal Spring Runoff Period Using WSC Gauge 07HF002 At Keg River Near Highway 35

Return Period (Years)	Maximum Annual ($q = ft^3/s$ / $mile^2$)	Instantaneous Discharge ($q = m^3/s$ / km^2)
1:100	19	0.196
1:50	16	0.165
1:25	14	0.144
1:10	11	0.113
1:5	8	0.082
1:2	6	0.062

The drainage area at the downstream end of this project is 44 km^2 as derived from 1:50,000 scale maps.

4.2.1.2 FEASIBILITY STUDY FOR LA CRETE (EAST) FLOOD CONTROL PROJECT, FEASIBILITY STUDY (1993, TORCHINSKY ENGINEERING LTD.)

A Feasibility Study for La Crete (East) Flood Control Project was by Torchinsky Engineering Ltd. on April 15, 1993.

The La Crete (East) Flood Control Project covers an area of Townships 106 and 107, Range 12, 13, 14, 15 of west of fifth meridian. The total study area is 260 km^2 which experiences flooding during spring runoff. The project area for this study is shown in Figure 4-3.

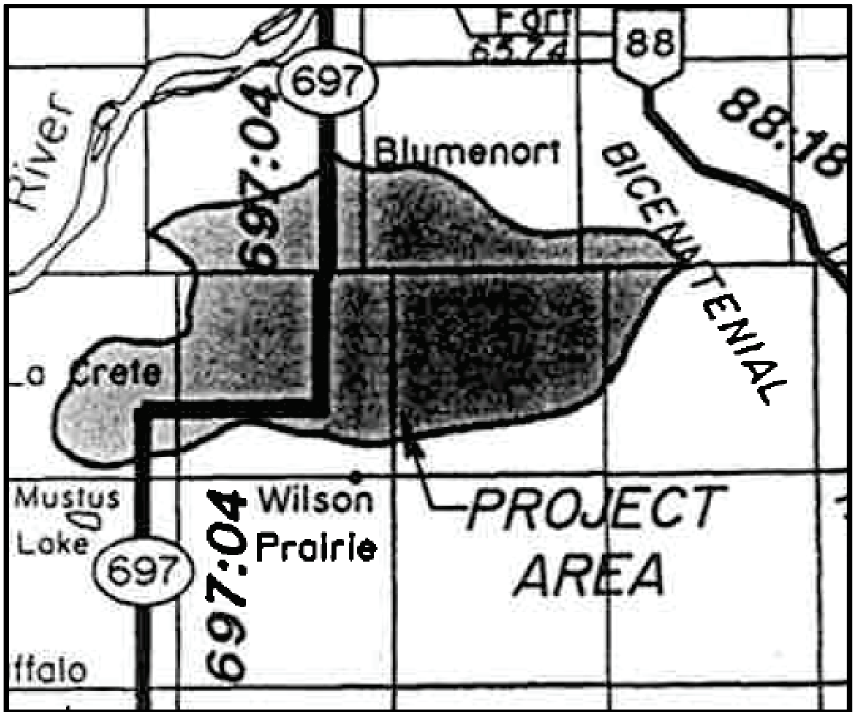


Figure 4-3 Project Area Study (by Torchinsky Engineering Ltd.)

The area consists of mainly agricultural lands that are flooded due to lack of well-defined water courses.

The study area was experiencing flooding due to the spring runoff in the form of sheet flow and the situation was aggravated due from additional flooding from La Crete. Water management issues in this area have existed since the lands were developed for agriculture purposes. Individual owners have tried to control the flooding by construction of channels and dikes but they have been ineffective.

Correspondence with the Alberta Environment regarding flooding in this area is dated as early as 1968. Due to funding and other issues, the La Crete (East) Flood Control Project did not get approval until December 1990 when Torchinsky Engineering Ltd. was assigned to carry out this feasibility study for the project area.

The study addressed general water management issues east of La Crete. The area was divided in to four sub basins and several possible alternative solutions were proposed for each.

The report also noted that major summer rains can create a back flooding effect from the flood waters of Bear River. There is also mention of beaver activity in both Bear River and Hay Creek that cause flooding nearly every spring event and summer storm event.

Based on the “Northwest Alberta Regional Hydraulic Study” it is estimated that the instantaneous peak flows increase roughly 15% as a result of on-farm improvements. Recommendations for improving flooding in each sub basin were made. A conclusion of the study mentioned that roughly 3650 acres of agricultural lands would benefit directly by reducing flooding and erosion.

Flood frequency analysis was conducted using various gauges in the area. After preliminary review from Alberta Environment, the Teepee Creek Gauge was selected. Some photos are in the report that display road being flooded. These images were taken during spring runoff in April 1991 and are displayed as Figure 4-4.

Figure 4-4 Photos of spring runoff in April 1991 (by Torchinsky Engineering Ltd.)

Additional report images were taken during spring runoff in May 1988 and are displayed as Figure 4-5.

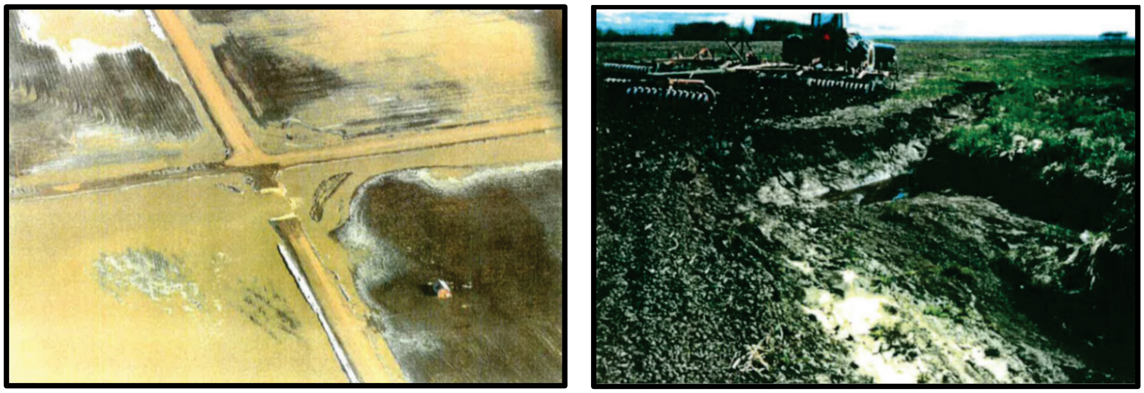


Figure 4-5 Photos of spring runoff in May 1998 (by Torchinsky Engineering Ltd.)

4.2.1.3 LA CRETE (EAST) FLOOD CONTROL PROJECT, CONSTRUCTION DRAWINGS

During the WSP File Review process, drawings for the La Crete (East) Flood Control Project, were found. The drawings refer to Line 1 through Line 5. Some of the details in the drawings are noted below:

Some of the drawing details included:

- Profiles,
- Spillway Wier Structure,
- Culvert Crossing Details for 3 x 1.4 m diameter CSP culverts,
- Culvert Crossing Details for 2 x 1.2 m diameter CSP culverts,
- 0.5 m Gabion Mini Drop Structure (5.0, 4.0, 3.0 m bed width),
- 1.0 m Gabion Drop Structure (5.0 m bed width),
- 3.0 m Gabion Chute Drop Structure.

4.3 TEEPEE CREEK FLOOD CONTROL

A map of this drainage ditch location is displayed in Figure 4-6.

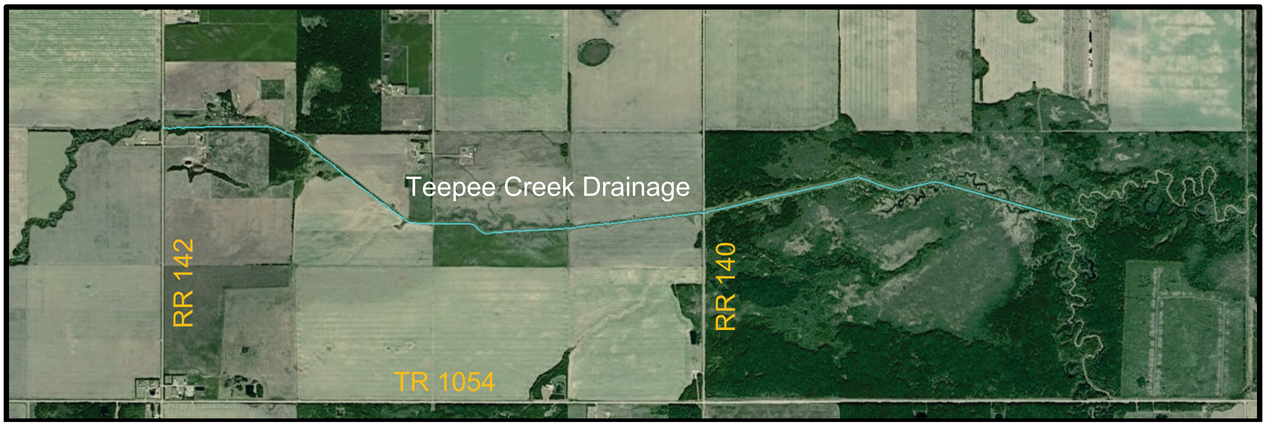


Figure 4-6 A map of the Teepee Creek drainage project in Mackenzie County.

4.3.1.1 TEEPEE CREEK FLOOD CONTROL PROJECT (1979, AESRD)

The Teepee Creek Flood Control Project was noted in a memorandum written by the Hydrology branch of Alberta Environment in 1979.

It was suggested that originally proposed route would not be favourable as the flooding problem will still remain and there should be some improvements in the Teepee Creek as overtopping of the proposed channel would result in flooding of the land.

In addition, there are a number of watercourses from the south that discharge into to the creek and will cause flooding problems, especially if the beaver activity remains high. It was also noted that the flooding problem in this area are results of agricultural expansion, beaver activity and the flat gradient upstream where the Teepee Creek enters Bear River.

4.3.1.2 TEEPEE CREEK FLOOD CONTROL - LEVEL I (1983, LILAND ENGINEERING)

Teepee Creek Flood Control - Level 1 was a report submitted by Liland Engineering Limited in June 1983. It was submitted to Alberta Environment, Water Resources Management Services and Water Resources Administration Division in the Peace River Region.

Teepee Creek is very meandering and choked with willows and beaver dams which caused continual overtopping of the creek banks during runoff periods and causes damage to the seeded crops.

The project is located roughly 13 km southeast of La Crete. The report recommended that 6.47 km of flood control channel is constructed to improve productivity on agricultural land, earlier spring seeding, decreased spreading of weeds, better access to the channel, and improved environmental conditions.

As per this report, to date the only flood control project implemented in the area is the La Crete Drainage Project which was constructed in 1970.

The proposed work was to clean out and straighten around 6.47 km of flood control channel. The channel was to be designed to accommodate a 1:10 year flood event with a depth of 2.5 m, a bed width of 3 m and a slope of 0.00074 m/m. Other than the installation of low level crossings, all bridge and bridge sized culvert crossings were designed for a 1:25 year flood event. It was noted that some culverts were designed for negative freeboard, which could cause localized flooding upstream of the culvert.

Alberta Environment provided comments to the report in January, 1984. The following design parameters were updated:

- Bed width = 5.0 m (minimum)
- Slope = 0.00074 m/m
- Manning roughness coefficient = 0.030
- Channel velocity = 0.91 m/s (max.)

Three 0.5 m drop structures were required. The designs of low level crossings were not accepted since the gabion baskets would not be able to withstand the loading subject by vehicular traffic or farm machinery.

Alberta Environment provided additional flood control comments in October 1989. The WSC gauge located on Teepee Creek was analysed using frequency analysis. The maximum instantaneous discharges for the 1988 and 1989 flood years were 8.22 m^3/s and 5.48 m^3/s respectively. These maximum instantaneous discharges represent flood events with return periods between 2 and 5 years.

4.3.1.3 TEEPEE CREEK FLOOD CONTROL - AS CONSTRUCTED REPORTS (1984-1986)

The report included construction details for;

- Teepee Creek Flood Control – Phase 1 (1984 – 1985)
- Teepee Creek Flood Control – Phase 2 (1984 – 1986)

The Teepee Creek Flood Control project runs east southeast, starting at SW 35-105-14-W5. It then flows southeast through NE 26-105-14-W5. From this point it flows east through the 25-105-14-W5 and 30-105-13-W5. It then meets the Bear River at NW 29-105-13-W5.

The project was built mainly to straighten a severely winding Teepee Creek, containing dense growth and the beaver activity. The project consisted of the flat bottom channel with a 5 m bed width and 3:1 sideslopes.

Phase 1 included common excavation and rock processing. Phase 2 included reshaping and regarding of roughly 4,000 lineal meters of creek bed and sidelsopes. The work also included construction of ten grade control rock chute drop structures, two low level crossings and one ditch liner.

Pre and post-construction photos are shown in Figure 4-7. The left picture was taken pre-construction with the right image taken after construction.

Figure 4-7 Pre-construction (left) and Post-construction (right) photos for the Teepee Creek Flood Control drainage project.

4.3.1.4 TEEPEE CREEK DESIGN INFORMATION (VARIOUS YEARS, WSP)

WSP has worked on various projects within Tepee Creek. This worked included obtaining file review information, BIM Inspections, engineering assessments, preliminary engineering reports, detailed design reports and construction. A summary of this information is given in the Hydrology section of this report.

4.4 BUFFALO HEAD PRAIRIE FLOOD CONTROL PROJECT

A map of this drainage ditch location is displayed in Figure 4-8.

Figure 4-8 Map of the Buffalo Head Prairie Drainage Project

4.4.1.1 BUFFALO HEAD PRAIRIE FLOOD CONTROL PROJECT – LINE A1 (1992, BEKEVICH ENGINEERING LTD.)

The 'As Constructed Report' for Buffalo Head Prairie Flood Control Project – Line A1 was submitted by Bekevich Engineering Ltd. in December, 1992.

The project is located approximately 18 km south of La Crete. The project was initialed in an effort to control flooding and erosion of the agricultural area.

The total length of the project was 2000 m with a total vertical displacement of 25 m. The project extended from the south boundary of 8-104-15-W5 and extended roughly 100 m into 17-104-15-W5. There were three road crossing installations, 1 farm crossing, and 17 mini drop structures installed to reduce the potential for erosion.

The construction started in October 1991 and was completed in December 1992. A photo showing the completed works shown in Figure 4-9.

Figure 4-9 Photo of the completed Buffalo Head Prairie Flood Control Project – Line A1 (photo by Bekevich Engineering Ltd.).

4.5 BEAR RIVER NORTH

A map of the Bear River North drainage ditch location is displayed in Figure 4-10. The map refers to Lines 1 through 4. A single report for Line 4 was obtained during the file review.

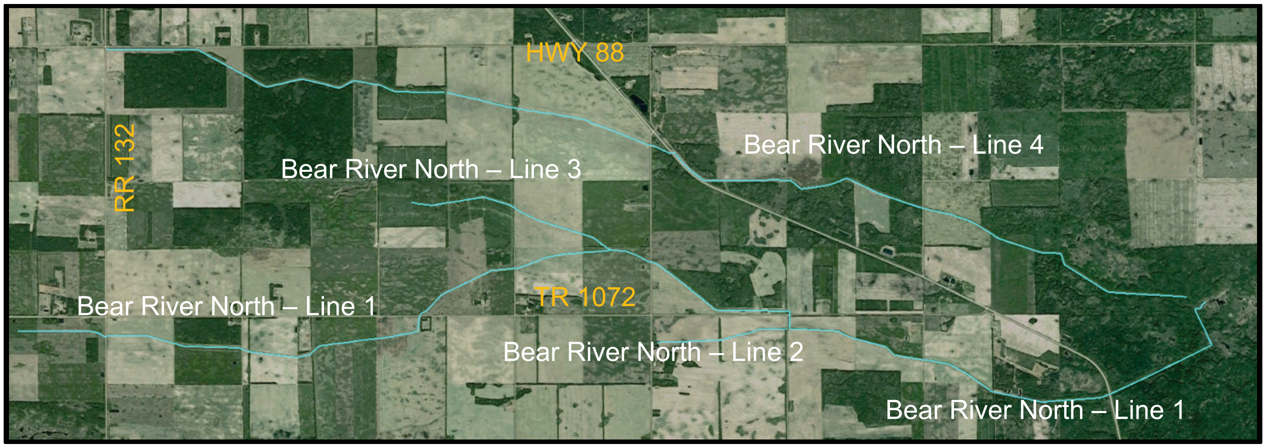


Figure 4-10 A map of the Bear River North Drainage Project

4.5.1.1 BEAR RIVER NORTH FLOOD CONTROL - LINE 4 (1985-1986, AESRD AND KENEEMA ENGINEERING LTD.)

The 'As Constructed' Summary Report for Bear River North Flood Control - Line 4 was competed by AESRD in April, 1985. Information given below was also combined with the 'As Constructed' Report for Bear River North Flood Control - Line 4 as competed by Keneema Engineering Ltd. in 1986.

The project is located approximately 11 km southeast of Fort Vermilion. The upstream portion of the work is 24-107-13-W5M and the downstream reach of the work is 18-107-11-W5M. The overall length of the project is 14.3 km.

The work included installation of three road crossings completed with culverts and ten crossings of 3-1000 mm diameter culverts per crossing. Rock riprap was installed at the crossing locations to minimize erosion potential.

Construction started on December 12, 1984 and was completed on February 25, 1985.

4.6 WILSON PRAIRIE

Three reports were completed on the Wilson Prairie Drainage project. The locations of this ditch are between the regions 106-14-W5M and 106-13-W5M. A map of this drainage ditch is shown in Figure 4-11.

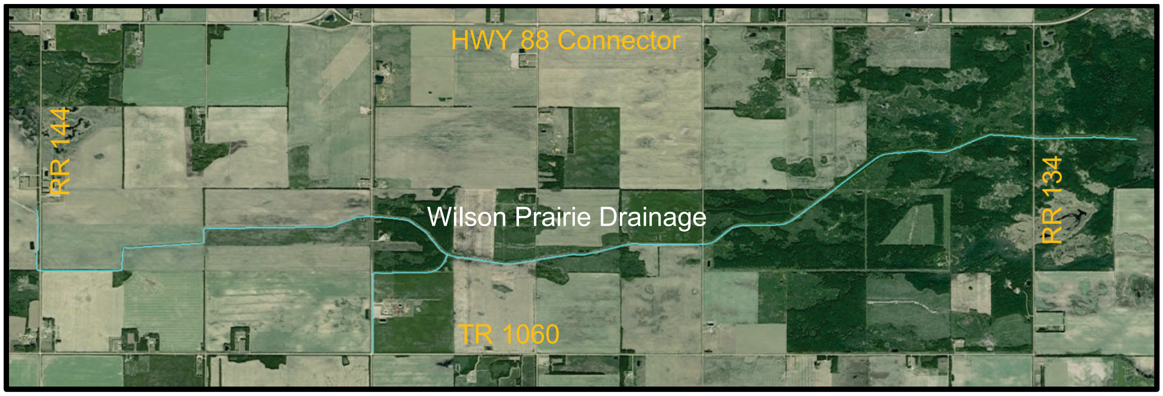


Figure 4-11 Map of the Wilson Prairie Drainage Project

4.6.1.1 WILSON PRAIRIE FLOOD CONTROL (AUG 1985, LILAND ENGINEERING LTD.)

The feasibility study was carried in order to assess alternatives and make decision to control flooding in an agriculture area of the County. The proposed project is located 8 km east of La Crete. The project area is located area in the project is developing for the agriculture, the drainage routes are poorly defined and the topography of the land is very flat. With increased runoff from cleared land and the flat nature of the existing drainage, flooding is increasing and affecting farming.

The project was anticipated to provide agricultural benefit to 1800 acres of farmland. It was proposed that 12.2 km of flood control channel be constructed. Two low level crossings were to be provided for farmer to access on the road allowance. One low level crossing was to be installed between 3-106-14-W5M and 4-106-14-W5M and one low level crossing between 1-106-14-W5M and 2-106-14-W5M. There was also to be removal of a large beaver dam in 10-106-13-W5.

The channels were designed to accommodate flow from a 1 in 10 year flood event and the culverts designed for a 1:25 year flood event. The channels will have a bed width of 3.5 m with a side slope of 3:1 (H:V). The channel design velocities ranged from 0.79 m/s to 0.91 m/s. Two drop structures of 0.8 m height were proposed.

The maximum annual daily flood frequency estimates were determined from the WSC gauge station at Keg River near Highway 35 as shown in Table 4-2.

Table 4-2 Maximum annual daily flood frequency estimates as determined from the WSC gauge station at Keg River near highway

Return Period (Years)	Discharge ($q = ft^3/s$ / $mile^2$)	Discharge* ($q = m^3/s$ / km^2)
1:100	23.1	0.25
1:25	16.4	0.18
1:10	12.1	0.13
1:5	8.9	0.10
1:2	4.6	0.05

Note: *Conversion was completed by WSP in 2015

Channel construction timing was recommended in late fall as wet areas were expected to be at the driest state and the construction would cause the least interference with farming activities. It was also anticipated that clearing would take place in the winter prior to the channel construction.

4.6.1.2 WILSON PRAIRIE FLOOD CONTROL PROJECT (FEB 1998, AESRD)

Design flows were requested by the Water Administration Resources Division in Peace River to be used for sizing of a ditch at the location 10-106-13-W5M. At the time of this report, the area was approximately 60% wooded with the remained of the lands cleared.

Alberta Environment has carried out flood frequency analysis to be used for sizing of the drainage ditch for the Wilson Prairie Flood Control Project. The drainage area considered was 57.2 square kilometers and instantaneous peak and the maximum daily discharges were computed as given in Table 4-3.

Table 4-3 Flood Frequency Analysis for Wilson Prairie Drainage

Return Period (Years)	Maximum Daily Discharge (m^3/s)	Maximum Instantaneous Discharge (m^3/s)	Discharge* ($q = m^3/s$ / km^2)
1:100	13.0	16.5	0.11
1:50	11.0	14.0	0.09
1:25	9.0	11.5	0.08
1:10	6.6	8.8	0.06
1:5	4.8	6.3	0.04
1:2	2.4	3.2	0.02

* Conversion was completed by WSP using a drainage area of 57.2 $mile^2$ (148.1 km^2)

4.6.1.3 WILSON PRAIRIE DRAINAGE EXTENSION ASSESSMENT (JUNE 2003, WSP)

EXH Engineering Services (now called WSP) was retained by Mackenzie County to assess an extension to the Wilson Drainage project in June 2003. This extension was to improve the drainage to the NW corner of NE 5-106-14-W5 and provide an option to extend the drainage further to the west in the future.

The proposed extension will start at the inlet of the existing 3 x 1200 mm diameter and 1 x 800 mm diameter CSP culverts crossing the Range Road 144 at the SE corner of the NE 5–106-14-5 and terminate at the NW corner of the same section.

The proposed upgraded ditch cross-sections had a 3 meter wide bottom, 3:1 side slopes, depth of 0.8 m and a channel slope of 0.0018 m/m. The designed discharge in the channel corresponded to a 1:10 year discharge of 4 m^3/s with a design velocity of 0.9 m/s. The report also recommended installing 2 x 1400 mm diameter CSP culverts. There report also recommended that any work completed should be incorporated into the now licensed Wilson Prairie Drainage Ditch System.

4.7 AJA FRIESEN DRAINAGE

A map of the AJA Friesen drainage ditch drainage ditch is shown in Figure 4-12.

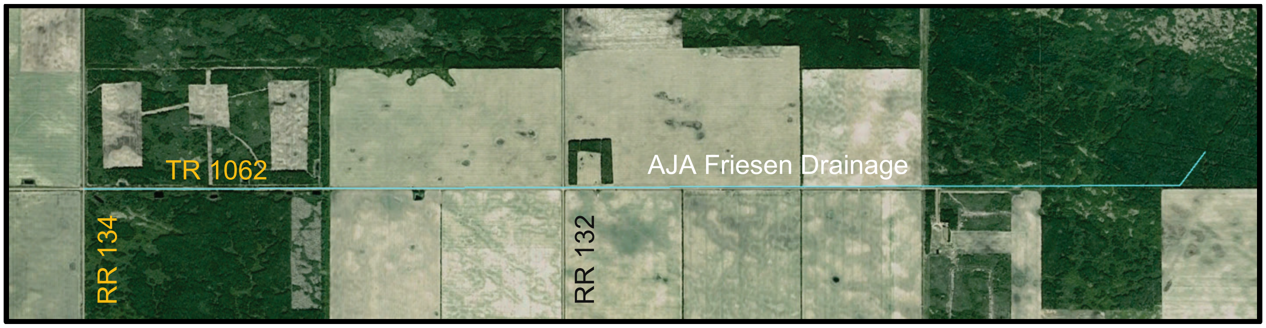


Figure 4-12 Map of the AJA Prairie Friesen Drainage Ditch Project.

4.7.1.1 CONCEPTUAL DRAINAGE DESIGN REPORT (2009, WSP)

GENIVAR (now called WSP) completed a Conceptual Drainage Design Report in December 2009. The project is located roughly 18 km east of La Crete. The project is nearly 10 km long, in which the drainage ditch starts at Range Road 13-4 of SW 28 - 106 - 13 - W5 and goes up to near the Bear River, Section 32 -106 - 12 - W5. The Line 3 of the La Crete East Flood Control and drainage ditch of this project intersect at Township Road 106-4. The area included in this study is also part of the current Drainage and Conservation Master Plan.

The report discusses some history of the flooding issues in the study area. Intersection between Wolfe Lake Road (Township Road 107-0) and Range Road 13-4 has posed a serious drainage problem over the last couple of years as the intersection creates a bottleneck in the drainage course and is witnessed every year during the spring runoff. The flood is mainly due to the spring runoff, continued agriculture land development such as clearing, on-farm drainage improvements and road infrastructure improvements.

As per the report, La Crete (East) Flood Control Lines 5 and 3 were constructed in 1995 by Alberta Environment to alleviate some of the drainage issues there.

The basin is mainly agricultural and grazing land. However, lower parts of the basin contain some forested and marshy areas. Development activities in area and growth of bushes / grasses on the drainage ditch all contributed in flooding issues in the area. A conceptual plan of the ditch alignment is shown in Figure 4-13.

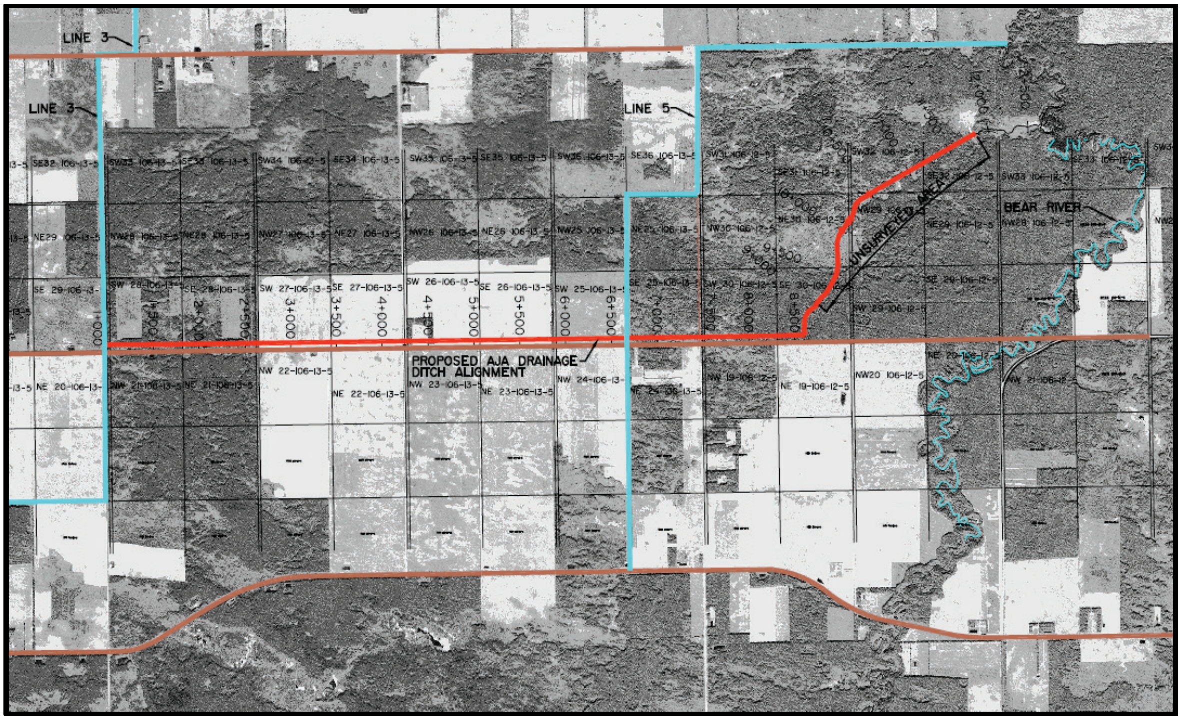


Figure 4-13 Conceptual plan for the AJA Friesen drainage ditch project

4.7.1.2 CONSTRUCTION SUMMARY REPORT AND FINAL DETAILS (WSP, 2012)

GENIVAR (now called WSP) completed a Construction Summary Report and Final Details in February 2012. The construction of the project started in late 2010 with the project deficiencies completed in 2012.

The work was completed from SW 27-106-13-W5 to NE 30-106-142-W5 and included clearing, installing culverts and ditching. Lateral shoot structures were constructed around landowner's fields with rock riprap placed on each shoot. An example of an as constructed drawing is shown below in Figure 4-14.

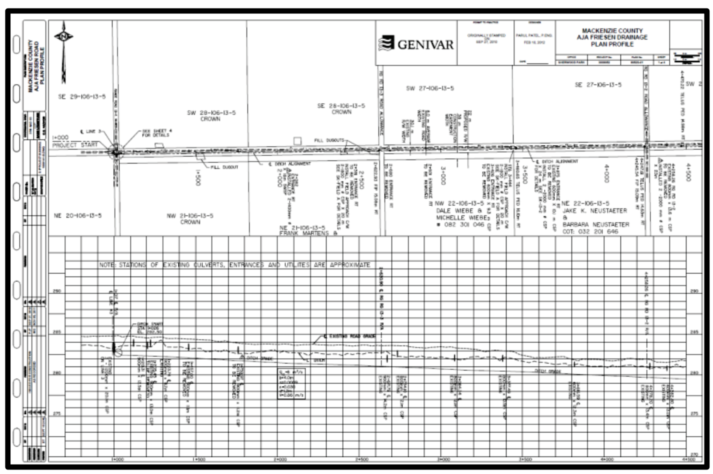


Figure 4-14 As constructed drawing for the AJA Friesen drainage ditch project

4.8 LA CRETE (SOUTH) FLOOD CONTROL

A map of this drainage ditch location is displayed in Figure 4-15.

Figure 4-15 A map of the La Crete (South) drainage project in Mackenzie County.

4.8.1.1 LA CRETE (SOUTH) FLOOD CONTROL, MARCH 1976 (AESRD)

Flooding dates back to 1973 at this location. The site is located in the Bear Creek drainage system.

The legal location of the site is near SE 1- 105-14-W5M. The concern was flooding due to incorrect installation of a culvert (outlet end was higher than the inlet end). Because of this, the land upstream of the culvert was flooded and as per the request from the landowner, Alberta Environment proposed to carry out a new project. It was proposed to install a new culvert with a 2.7 m (9 ft) drop and a drainage ditch.

The design was anticipated to affect roughly 1,300 acres of land. The proposed drainage alignment is displayed in Figure 4-16.

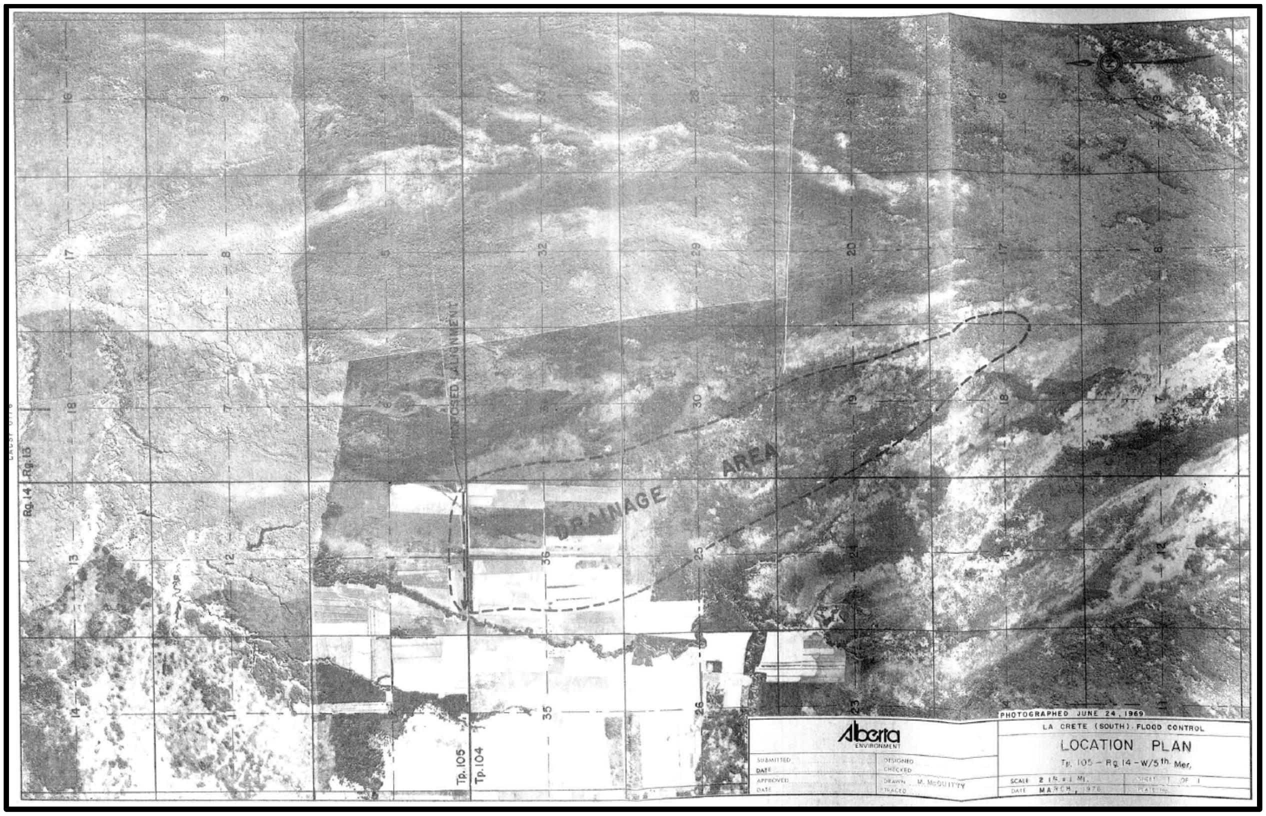


Figure 4-16 Drainage alignment proposed for the La Crete (South) drainage ditch (by Alberta Environment)

4.8.1.2 LA CRETE (SOUTH) FLOOD CONTROL - LEVEL 1, DESIGN REPORT (1975, AESRD)

A Level 1 Design Report was completed for the La Crete (South) Flood Control by AESRD in September 1975.

A design criteria listed in this report is:

- Drainage Area: 7.12 km^2 (2.75 $mile^2$)
- Design Discharge = 2.33 m^3/s (82.5 ft^3/s)
- Channel Bed Width = 3 m (10 ft)
- Channel Side Slope = 2:1
- Channel Bed Depth = 0.8 m (2.7 ft)
- Minimum Velocity = 0.6 m/s (2.0 ft/s)
- Manning's 'n' = 0.025
- Channel Gradient = 0.0005 m/m
- Culvert Drop = 2.7 m (8.7 ft)

The design was based on a runoff coefficient of 30 ft^3 / $mile^2$, which is roughly equal to a 1:10 year flood frequency according to the report.

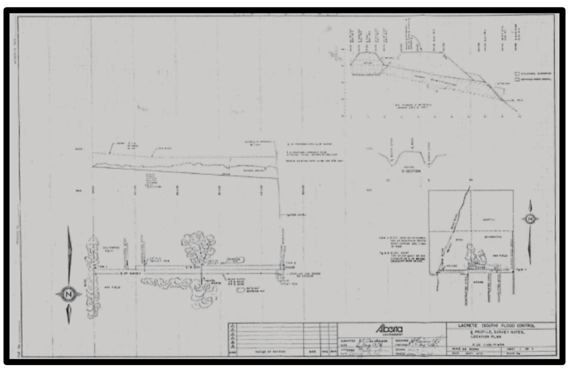
Comments to the design report were provided by the Alberta Environment Technical Services Division on February 28, 1976. The drainage area was given as 88.5 km^2 (72.8 mile^2) and the annual maximum daily mean flow values were estimated as shown in Table 4-4.

Table 4-4 Annual Maximum Daily Mean Flow Values (By Alberta Environment)

Return Period (Years)	Specific Flows ($q = ft^3/s / mile^2$)	Mean Daily Flows (ft^3/s)	Specific Flows* ($q = m^3/s / km^2$)
1:100	11.0	800	0.12
1:50	8.5	620	0.09
1:25	5.7	410	0.06
1:10	4.0	290	0.04
1:5	2.6	190	0.03
1:2	1.4	100	0.02

Note: *Conversion was completed by WSP in 2015 using a drainage area of 72.8 mile^2

Three drawings were given in the report as displayed in Figure 4-17.



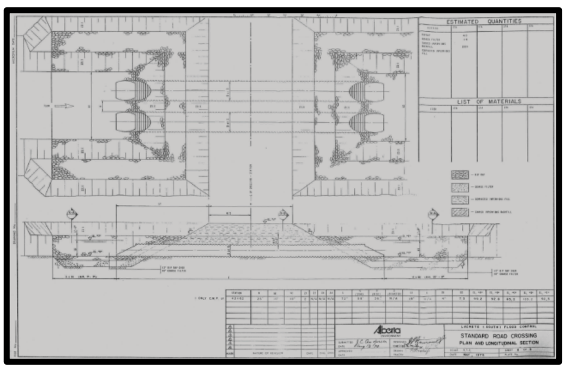
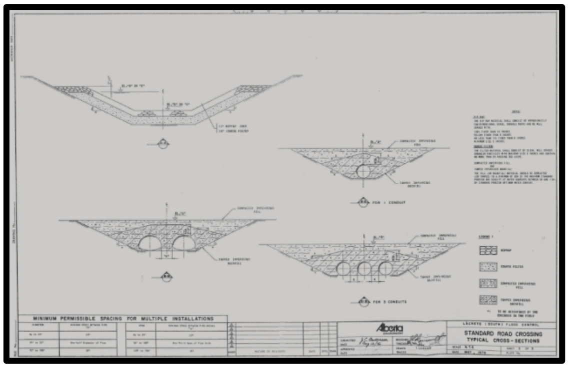


Figure 4-17 Construction drawings from the La Crete (South) report (by Alberta Environment)



4.9 LA CRETE DRAINAGE

A map of the La Crete drainage ditch is shown in Figure 4-18. File review information for this project was not avaialble.

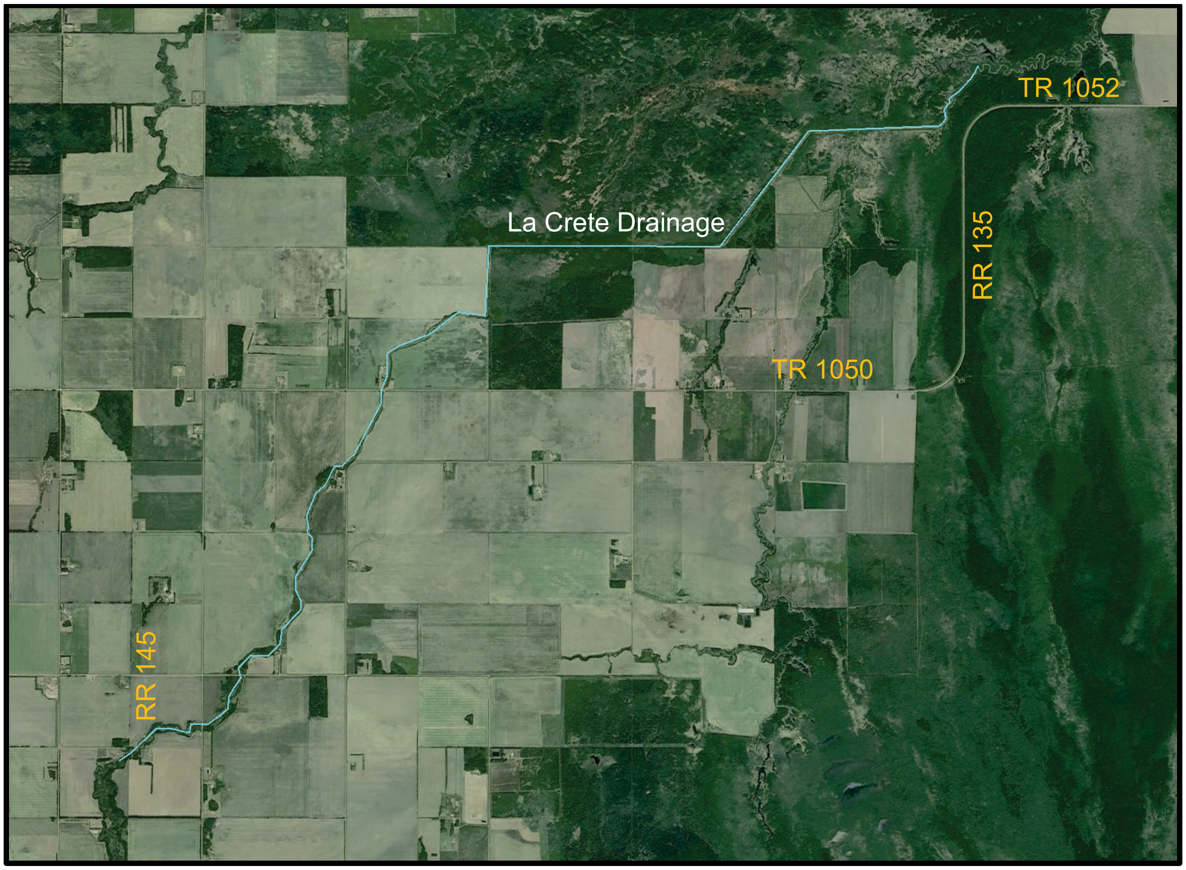


Figure 4-18 Map of the La Crete Drainage Ditch Project

4.10 FORT VERMILLION SOUTH DRAINAGE

A map of the Fort Vermillion South drainage ditch is shown in Figure 4-19. File review information for this project was not avaialble. In addition, there is an unamed drainage south located to the south of the Fort Vermillion South drainage ditch.

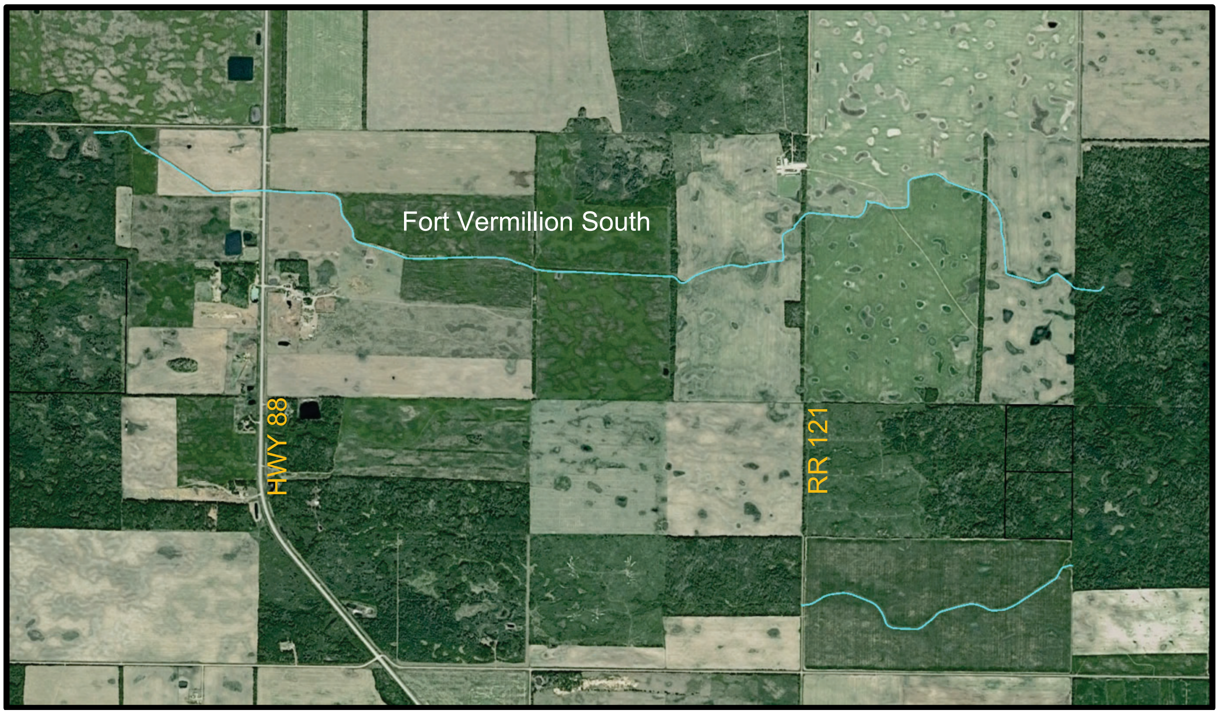


Figure 4-19 Map of the Fort Vermillion South Drainage Ditch Project

5 EXISTING CONDITIONS

5.1 SUMMARY OF FIELD INVESTIGATION

WSP staff conducted a site visit in November 2013 and again in April 2014. The primary investigation was completed during the first visit. The second visit was timed to coincide with the spring melt, which had passed the peak flows, but where spring melts were still occurring.

WSP toured the study area with County representatives Grant Smith and Joe Peters. Development and drainage history, current problem areas and issues, and drainage pattern details were discussed. This information provided the basis for flood issues addressed in the study.

Both investigations included photo documentation and recording of observations related to drainage ditches, channels and structures. All inspections were done from local road access.

In general, observations in the field included a wide range of conditions from small well-manicured ditches, to large overgrown ditches. Ditch icing was a common occurrence in the spring with overland and ditch flooding in some cases. Erosion was also noted in some areas. Icing and excess snow in culverts and ditches was apparent as a contributor to flooding issues at the time of the inspection.

As per WSP's discussions with County officials and local residents, the problems of flooding during the spring melt are an annual issue. Non-melt related flooding occurs, but is much less prevalent.

5.2 PHOTOS

Photos of the study area from both site inspections are included in Appendix B.

A photo of flooding over RR 141 at TR 1070 in 2008 is shown in Figure 5-1.

A key map of the photos taken are shown in Figure 5-2. Some additional flood photos from 2008 in the vicinity of Highway 697 and TR 1064 and 1070 are also provided in Appendix B.

Figure 5-1 Flooding over RR 141 at TR 1070 (2008)

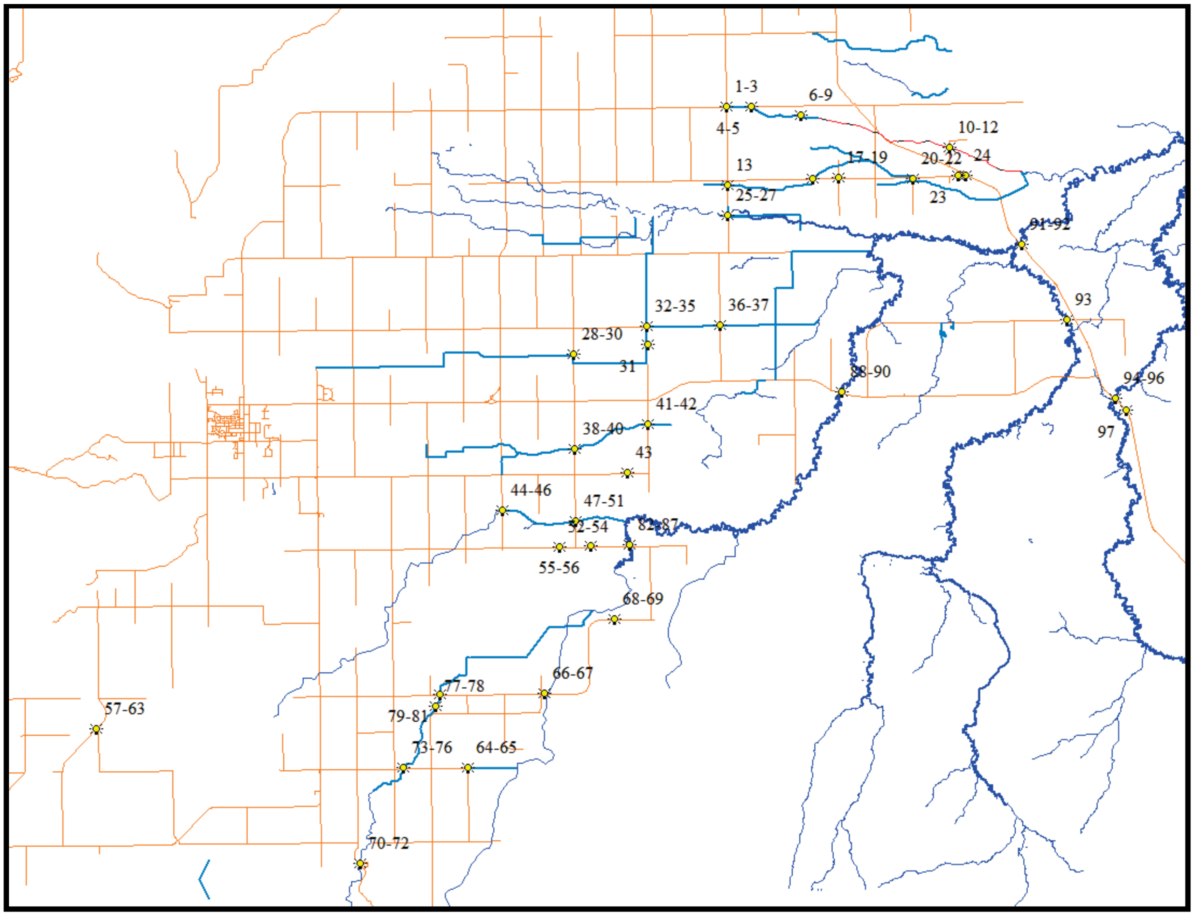


Figure 5-2 Key Map of Photos

6 GENERAL DRAINAGE ISSUES

6.1 GENERAL DRAINAGE ISSUES

The simple purpose of a drainage system is to effectively increase the conveyance of water from a location where an excess of water is a problem. There are two aspects to drainage issues in general, those related to the mechanisms conveying excess water to a location, and those related to the lack of conveyance away from a location.

6.1.1 DEVELOPMENT / CLEARING

Clearing of forested areas for agricultural use has a dramatic effect on its runoff characteristics. The following factors assist in increasing runoff rates, which in turn, increase the risk of flooding downstream of the newly developed area:

- Reduced Depression Storage - When land is prepared for farming, most dips and bumps in the topography are removed. The dips retain water during a storm event which reduces the amount of runoff during the peak flow.

- Reduced Retention – In some cases land development includes the removal of larger water storage areas such as small ponds, muskeg areas, or wet lands type areas. Not only does this remove storage, but the effect is compounded by adding conveyance.

- Removed Woody Vegetation - Vegetation in the form of trees, shrubs, and ground cover all aid in reducing runoff.

- Reduced Infiltration – In some cases working of the land for agriculture can reduce infiltration rates of the soil. This only effects the initial stage of a storm, and its effect is minimal.

Figure 6-1 Clearing east of Hwy. 88.

- Additional Local Drainage – Rural development includes the addition of small ditches and swales which are effective at removing excess water from the land and also increase runoff rates downstream.

6.1.2 SYSTEM CAPACITY

One obvious reason for flooding of a drainage system is that it may be inadequate to convey water from an area in a timely manner. Ditches, culverts, and other drainage infrastructure may be inadequate for the following reasons:

- Inappropriate design size, slope, or geometry.
- Poor condition (maintenance required).

6.1.3 EROSION

The issue of erosion is not directly related to flooding, but it could be indirectly related. Erosion is typically a result of flow velocities that are too high. Improper land development or inadequate drainage infrastructure can contribute to erosion.

6.2 SNOW AND ICE RELATED DRAINAGE ISSUES

In addition to the issues described above, there are many additional factors involved when considering drainage systems in climates affected by snow and ice. These mechanisms are all related, but they each have separate causes and effects on drainage during the spring melt. The following are issues that contribute to flooding during the spring melt in Mackenzie County.

6.2.1 ICING (AUFEIS)

Icing can occur for different reasons. In some areas it can occur due to natural springs, in other areas is can occur due to subsurface flow. In the case of Mackenzie County it is likely due to uneven temporal and spatial melting / freezing. More specifically, the following three scenarios can produce icing conditions:

- Uneven snow melt (ditch): Water flowing in a ditch encounters a localized frozen area which impedes the flow and freezes. The uneven melt could occur due to shade from the sun, or from excess snow and ice in an area.
- Uneven snowmelt (basin): Water from an upstream area of a basin may melt faster than lower areas where the water backs up and freezes.
- Daily freeze/thaw: Snowmelt during the day does not drain and freezes overnight. This cycle, in combination with the other factors can produce widespread icing problems.

Figure 6-2 Culverts half full with ice (RR 122)

- In general icing occurs when flowing water is blocked by snow or ice, and then freezes in thin sheets. The effect is that the drainage ditches and culverts become blocked, causing further icing conditions, which can then lead to flooding when temperatures rise further.

6.2.2 EXCESS SNOW

Ditches tend to fill with snow over the winter months. This happens naturally to all ditches through drifting, and can also occur in road ditches where snow is plowed. In both cases the snow reduces the capacity of the ditch and adjacent culverts, and can also promote icing. Snow plowed from roads tends to be dense, can include ice, can be piled into a windrow, and typically melts slower than drifted snow.

7 HYDROLOGY

7.1 GEOMATIC DATA

A variety of data was collected for use in this study. This information includes the following:

- National Topographic System (NTS) Maps;
- LiDAR (Light Detection And Ranging) Data;
- Digital Elevation Model (DEM) Data;
- Base mapping.

The data was used for delineating the drainage boundaries and identifying the drainage channels and other existing structures. It was also instrumental for analysing problem areas and recommending possible solutions. The NTS maps used have a scale of 1:250,000 and 1:50,000. The LiDAR Data has a resolution of 1 m while the DEM Data has a resolution of 100 m. The base maps used were a combination of satellite images from Google Earth, Flash Earth (NASA aqua, NASA daily, ArcGIS, Mapquest), ESRI maps (streets, imagery, topographic, grey canvas), Bing maps (road, aerial) and Valtus imagery.

Figure 7-1 displays the DEM data. The data has a resolution of 100 m. The colors represent the elevation with red being the highest elevation and blue being the lowest elevation. The main watercourses are shown with blue lines and the main roads are shown with black lines. The thick black lines are near the center of Figure 7-1 was used to show the location where the high resolution LiDAR data was purchased.

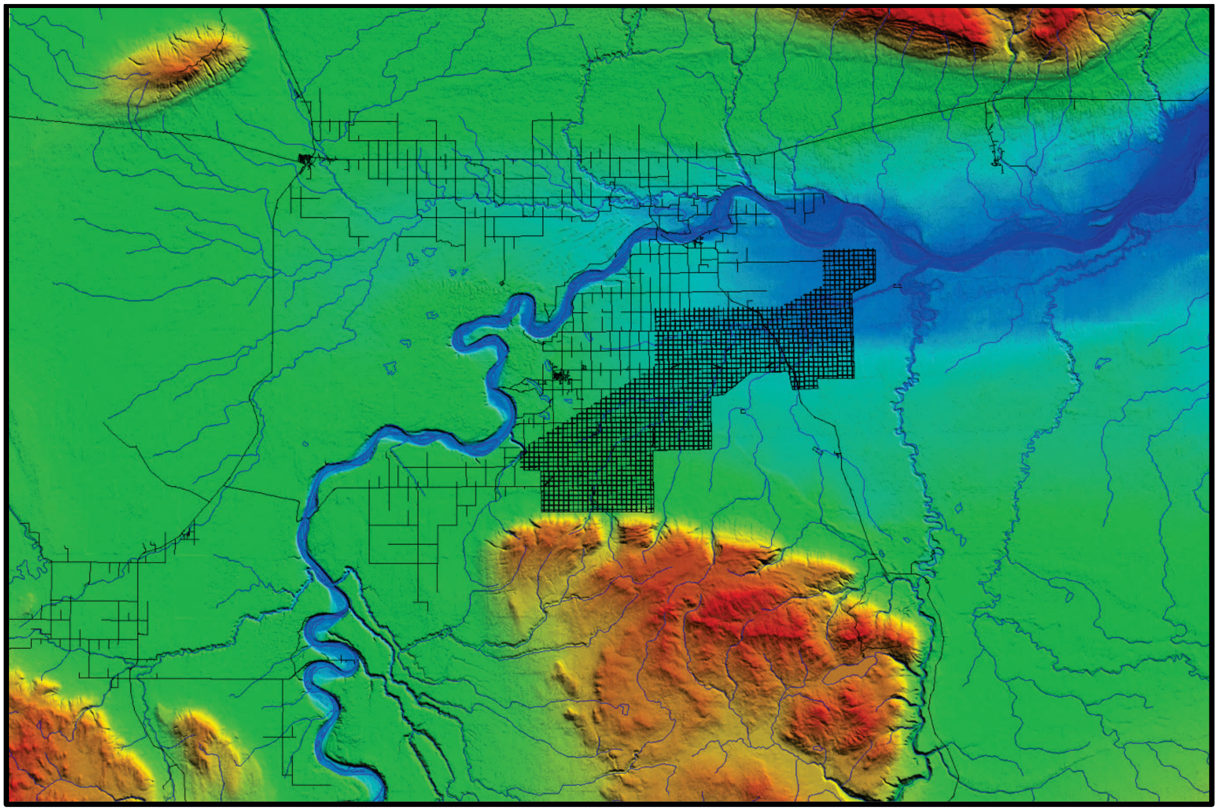


Figure 7-1 DEM Data with a resolution of 100 m. The main watercourse is colored in blue and the main roads are in black. The thicker black lines show where LiDAR was purchased. The LiDAR data has a resolution of 1 m.

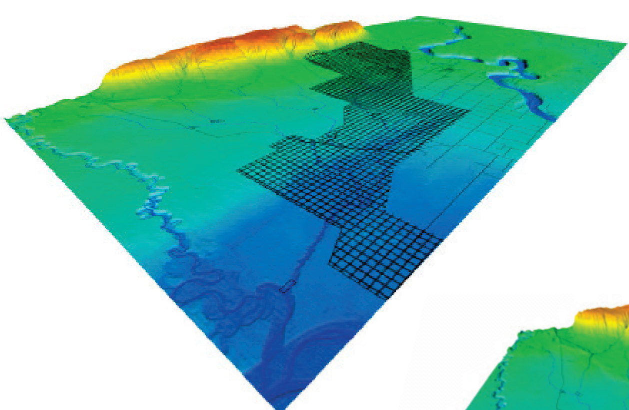
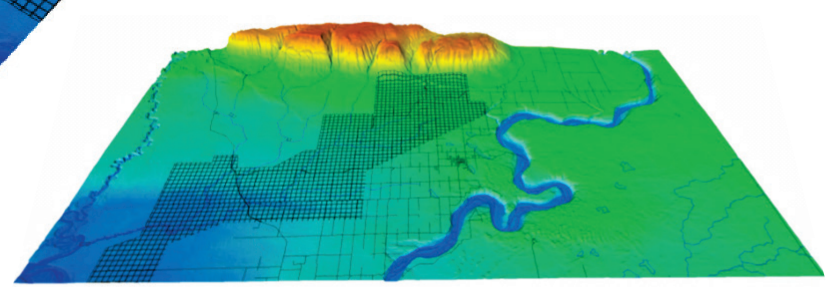


Figure 7-2 The DEM Data, as shown in Figure 7-1, is displayed as a 3D image to the left and below. The data was rotated to help with visualizing the general surface topography of the Bear River basin. The 3D data is shown with a 15:1 vertical exaggeration to emphasize the Bear River basin topography.



A close up of the high resolution 1 m LiDAR data is displayed in Figure 7-3.

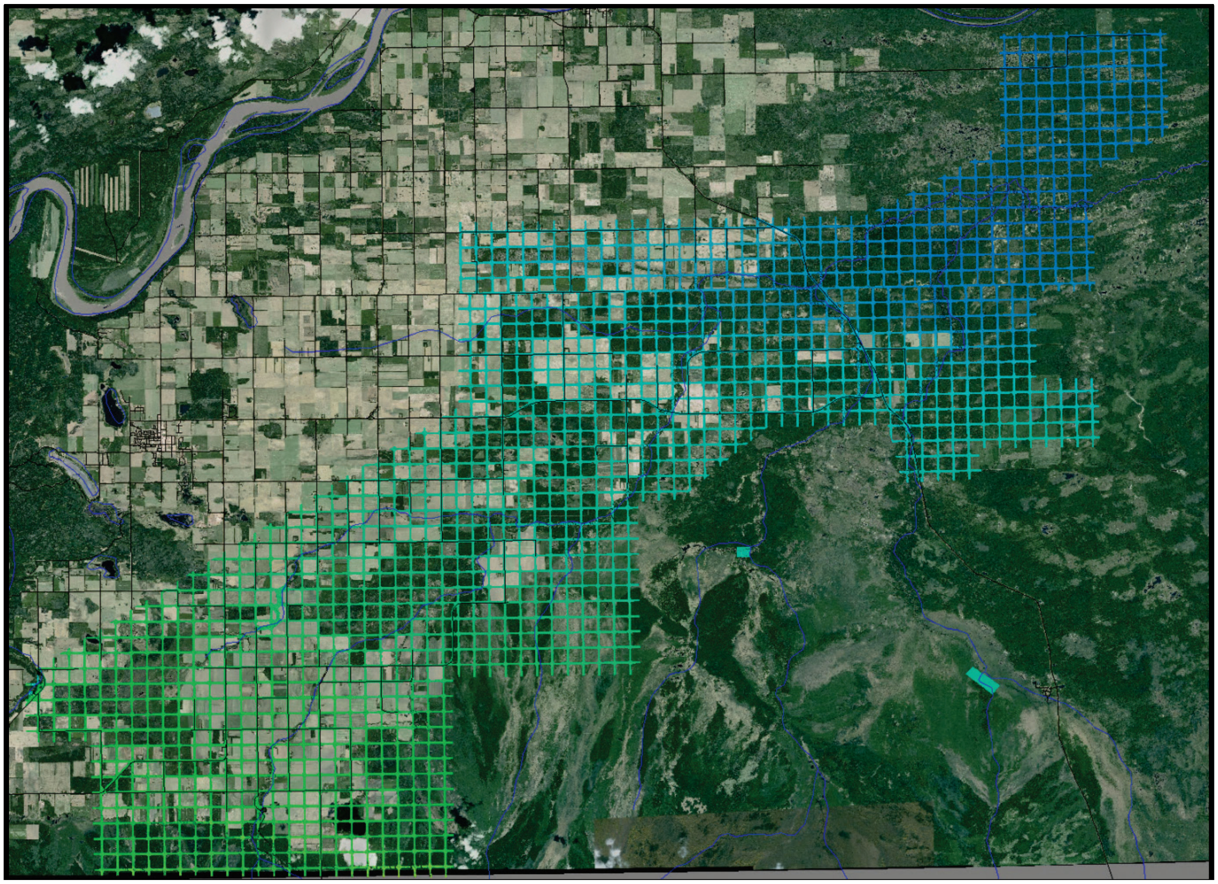


Figure 7-3 LiDAR data is shown with a resolution of 1 m. The colors represent the elevation with green representing the highest elevation and blue as the lowest elevation. The main watercourse is colored in blue.

7.2 GENERAL INFORMATION

Water within the project area generally flows from Buffalo Head Hills to the south. The Bear River basin starts in the southern hills and flows north, collecting tributaries along the way as it turns east across Highway 88 and into the Wabasca River.

Most flat developed areas within the study area have established drainage systems that collect runoff and either directly or indirectly feed the Bear River. Flat areas that are undeveloped areas are marshy and dominated by muskeg.

Figure 7-4 shows a general cross section of the Bear River from the Buffalo Head Hills to Wabasca River. This is a typical representation of the topography within the study area.

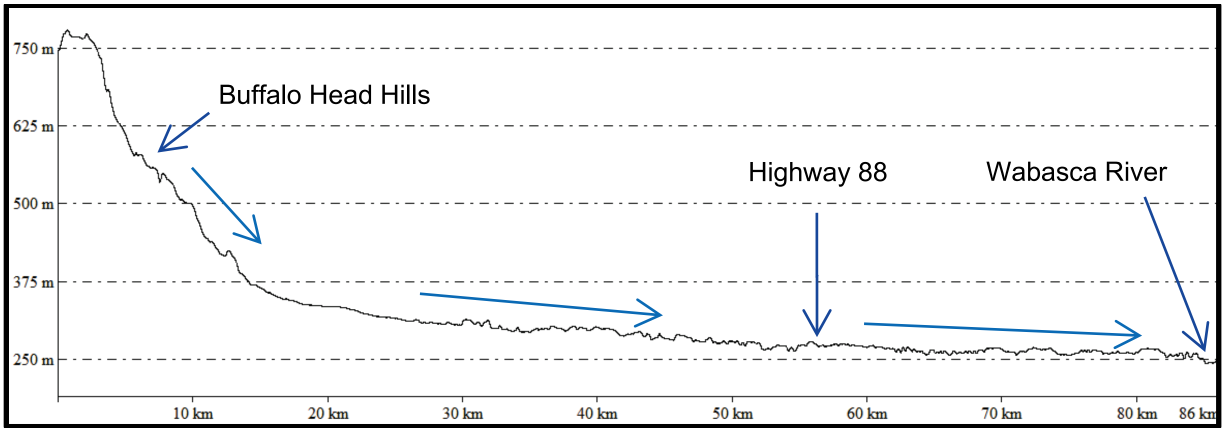


Figure 7-4 Typical Cross Section of the study area within the Bear River basin

The northwest half of the study area is almost entirely cleared for agriculture. Roads, ditches, and drainage works have been constructed throughout the area and although the overall natural drainage patterns may not have been affected, patterns on a local scale are greatly altered.

7.3 DRAINAGE NETWORK

All significant drainage ditches, channels and rivers within the drainage network were identified, mapped, and assessed for their function in the overall system. Sources of information used to identify and map the drainage ditches and channels within the study are the Field Investigation, AESRD Maps, Air photos, County Staff, County Maps, and Previous Reports.

The drainage system in the study area includes bridges, culverts and other structures such as gabion drop structures and ford crossings. Small channels and road ditches are also plentiful throughout. Due to the size of the study area and the high level purposed of this report, it was not possible to detail and include the small channels and crossings. Some larger crossings that are classified as being "Bridge Sized" were addressed in the report.

A map of the drainage network in the Bear River basin is identified in Figure 7-5. The dark blue lines show the natural rivers and creeks. The light blue lines indicate drainage ditches.

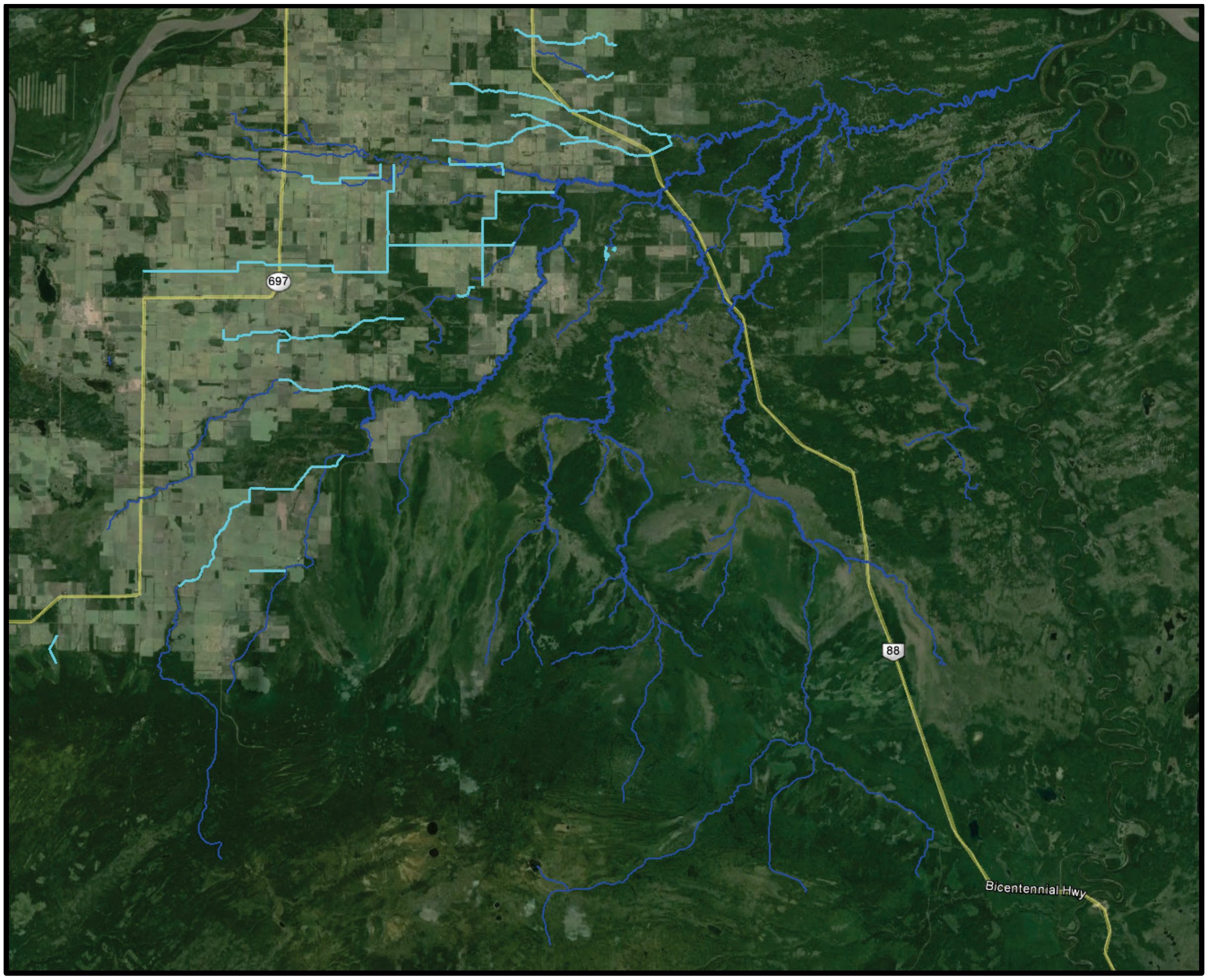


Figure 7-5 Location of Rivers, Creek and Drainage Ditches Located in the Bear River Basin

7.4 HISTORICAL INFORMATION

The Review of Existing Information section in this report summarised historical of drainage ditches in the Bear River basin. The drainage ditches are typically designed for a flow frequency roughly euqualy to a 1:10 year flood event. For model calibration purposes, a comparison 1:100 year flood event was used to reference to past bridge designs. The data is summarised in Table 7-1.

Table 7-1 Historical Hydrology Information for Drainage Ditches

Return Period (Years)	Maximum Instantaneous Discharge (m^3/s)	Unit Discharge (m^3/s per km^2)	Drainage Area (km^2)	Drainage Ditch
1:100		0.20[1]	88.5[4]	La Crete (South)
1:100		0.12[2]	44.0	La Crete (East)
1:100	16.5	0.11[3]	148.1[4]	Wilson Prairie
1:10		0.11[1]	88.5[4]	La Crete (South)
1:10		0.04[2]	44.0	La Crete (East)
1:10	8.8	0.06[3]	148.1[4]	Wilson Prairie

1; Flood Frequencies Derived By Estimating The Snowmelt Runoff Volumes During The Normal Spring Runoff Period Using WSC Gauge 07HF002 At Keg River Near Highway 35 (1980, Alberta Environment)
2, Maximum Daily Mean Flow Values (1976, Alberta Environment)
3, Wilson Prairie Drainage Flood Frequency (1998, Alberta Environment).
4, Calculation conversion was completed by WSP.

7.5 WATERSHEDS AND DRAINAGE BASINS

The Bear River is a tributary of the Wabasca River, which eventually discharges into the Peace River. In general the topography of the study area is quite flat, except for the steeper grades of the Buffalo Head Hills to the south. The Buffalo Head Hills area is the headwaters for the south portion of the study area. Runoff from the hills will be relatively quick, feeding the lower channels quickly.

For the west portion of the study area the headwaters originate east of Peace River near La Crete. In contrast to the water coming off of the Buffalo Head Hills, this runoff is relatively slow with long shallow flood waves.

Topographic analysis was required to establish the drainage areas for the entire study area. Using existing topographic maps (1:50,000, and 1:250:000 scale), LiDAR, and DEM data for the area, we were able to generate contours at varying resolution to establish flow patterns. Existing significant drainage channels were also considered as they have been used to change flow patterns.

Sub-basins were defined such that each major drainage course was represented, while the number of basins was kept to a reasonable level. This was done to make the model effective, reflecting the scope of the project. The total drainage area including all sub basins is approximately 2,580 km^2. The sub-basins are outlined in green in Figure 7-6. The combined sub-basins show the boundary of the study area and generally contribute directly to a larger watercourse.

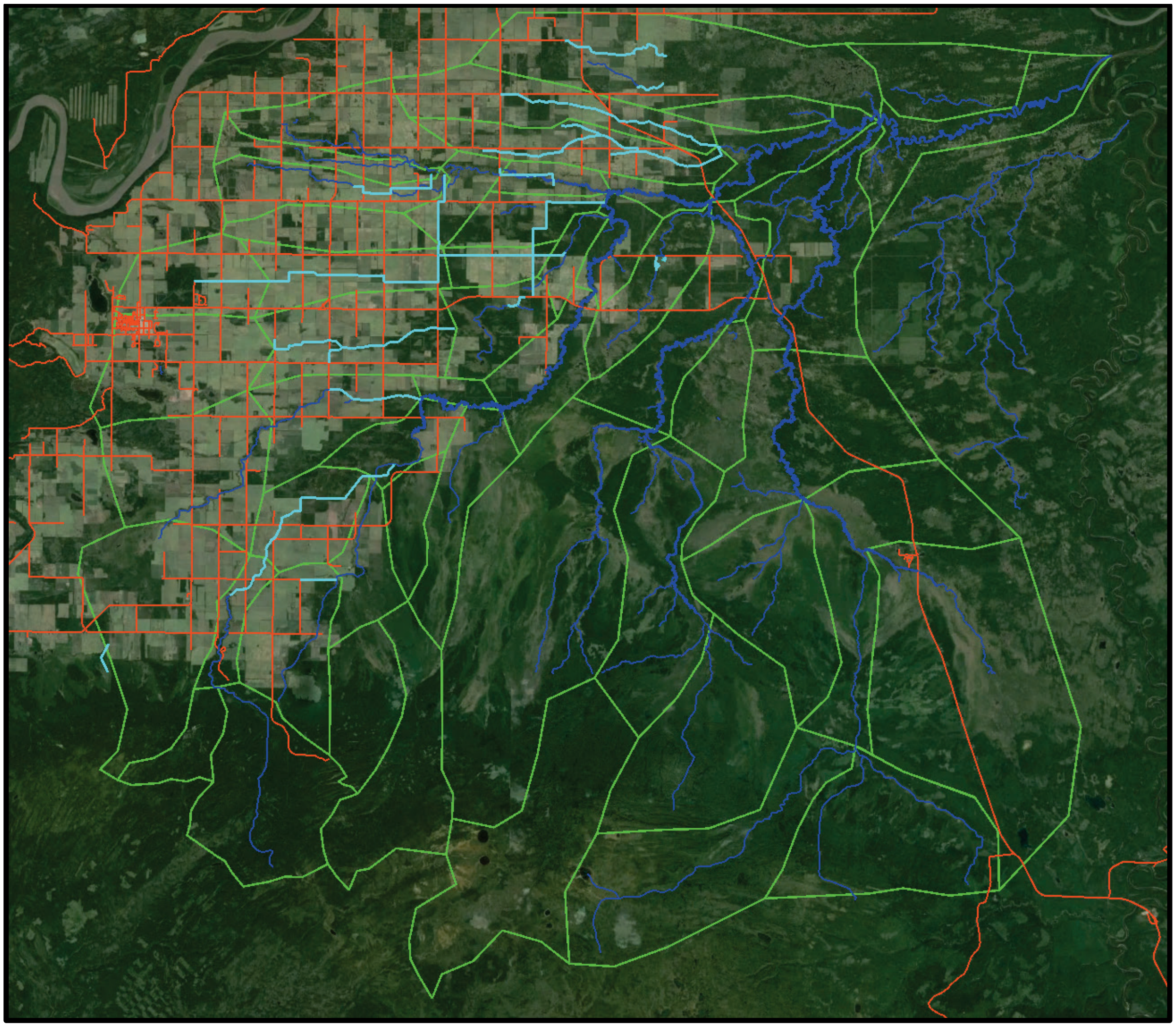


Figure 7-6 Sub-Basin Map - Green lines display the sub basins for the Bear River drainage area. The natural watercourse is colored in blue and the main roads are displayed in orange.

7.6 CLIMATE DATA

Rainfall runoff models require representative climatic data for the area. Primary climatic data generally includes precipitation, temperature and evapotranspiration. Precipitation (rainfall) is input into the model. The rate of evapotranspiration and evaporation determines the amount of water returning to the atmosphere, which has little effect on event based models.

7.6.1 ALBERTA AGRICULTURE DATA

The closest weather gauge to the study area is a gauge owned and operated by Alberta Agriculture and Rural Development (La Crete AGCM, ID 3073730), located southeast of La Crete. The gauge logs temperature and precipitation information, which is shown in Figure 7-7 for the 2014 year. Information was sourced from the Current and Historical Alberta Weather Station Data Viewer, AgroClimatic Information Service (ACIS) – Alberta Agriculture and Rural Development.

Based on the information below, assuming that that precipitation is snow whenever the average air temperature is below 0 degrees (roughly April 1 – October 31), the average snowfall during a winter is approximately 105 mm.

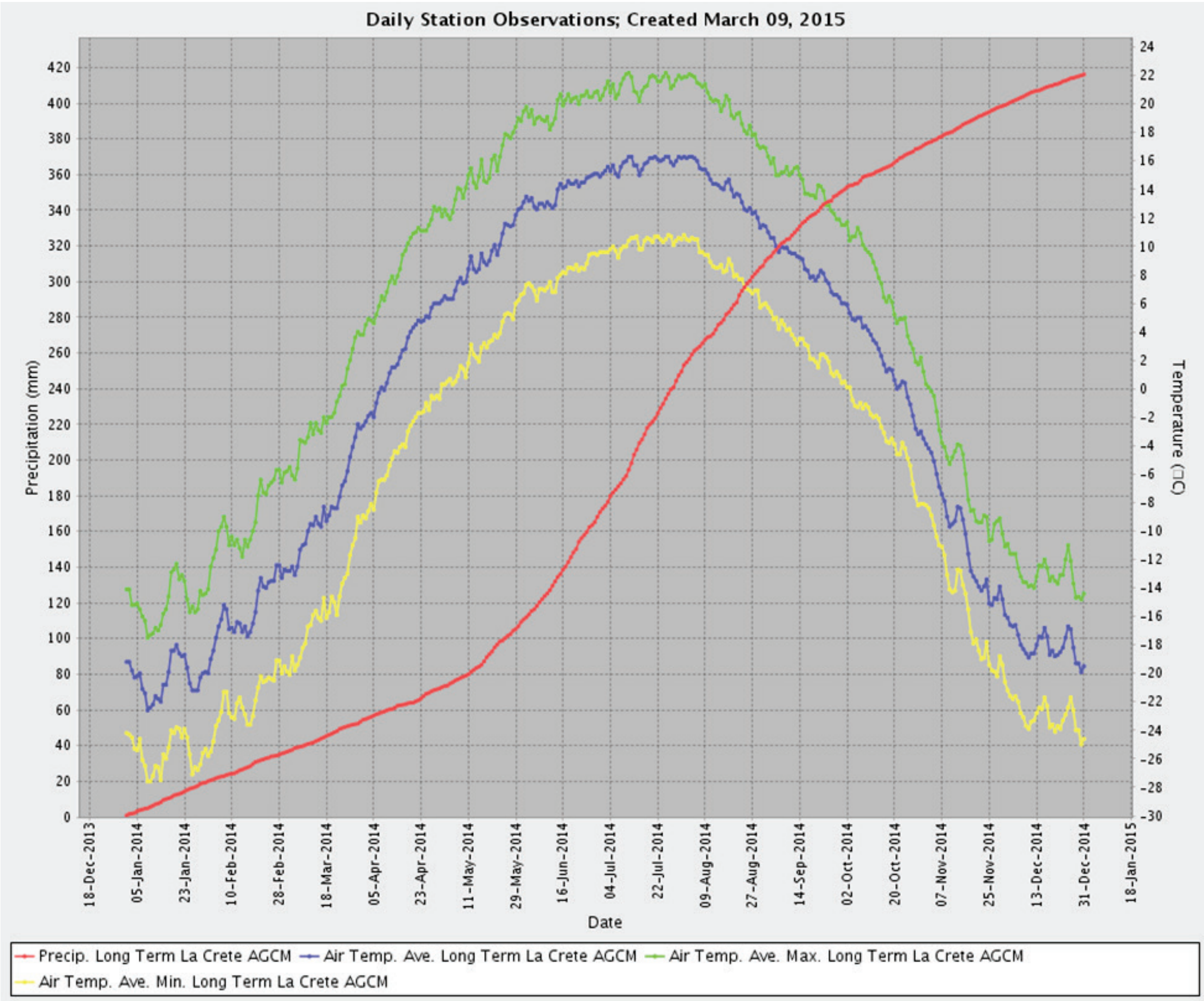


Figure 7-7 Temperature and precipitation information for the 2014 year (data from AgroClimatic Information Service)

7.6.2 ENVIRONMENT CANADA DATA

The nearest meteorological station to the current study area is the "High Level A" (Climate ID:3073146), located at the High Level Airport. Table 7-2 displays a summary of the Canadian Climate Normal (1981-2010) data available from Environment Canada's website.

Table 7-2 Summary of Canadian Climate Normal Data (1981-2010)

Data Name	Unit
Station Elevation	**338 m**
Total Mean Rainfall	260 mm
Total Mean Snowfall	156 mm
Total Mean Precipitation	394 mm
Highest Recorded Daily Rainfall (July 13, 1998)	103 mm
Highest Recorded Daily Snowfall (May 20 , 1989)	426 mm
Highest Recorded Temperature (August 9, 1981)	35.2 °
Lowest Recorded Temperature (January 13, 1972)	-50.6 °

Figure 7-8 displays a summary of the Temperature and Precipitation (1981-2010) data available from Environment Canada's website.

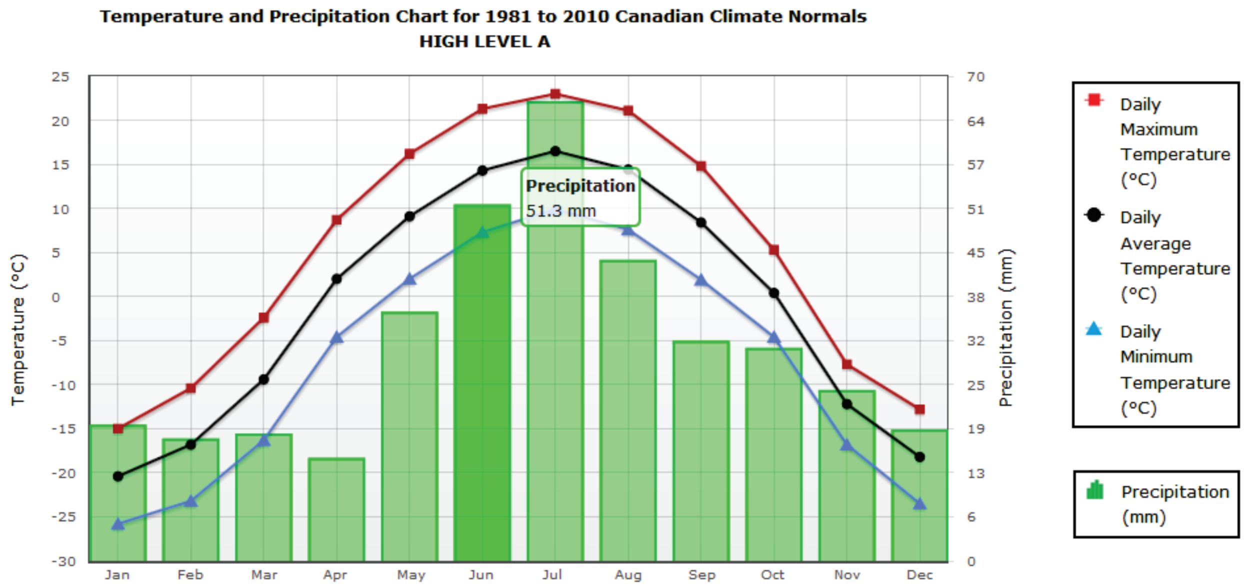


Figure 7-8 Temperature and Precipitation Data for 1981 to 2010 (data from Environment Canada's website for Canadian Climate Normal (1981-2010))

Intensity, Duration, Frequency (IDF) data is also published by Environment Canada in Figure 7-9. This information indicates anticipated rainfall intensities for that area for a given design frequency and storm duration. The model uses this information to simulate different storm events.

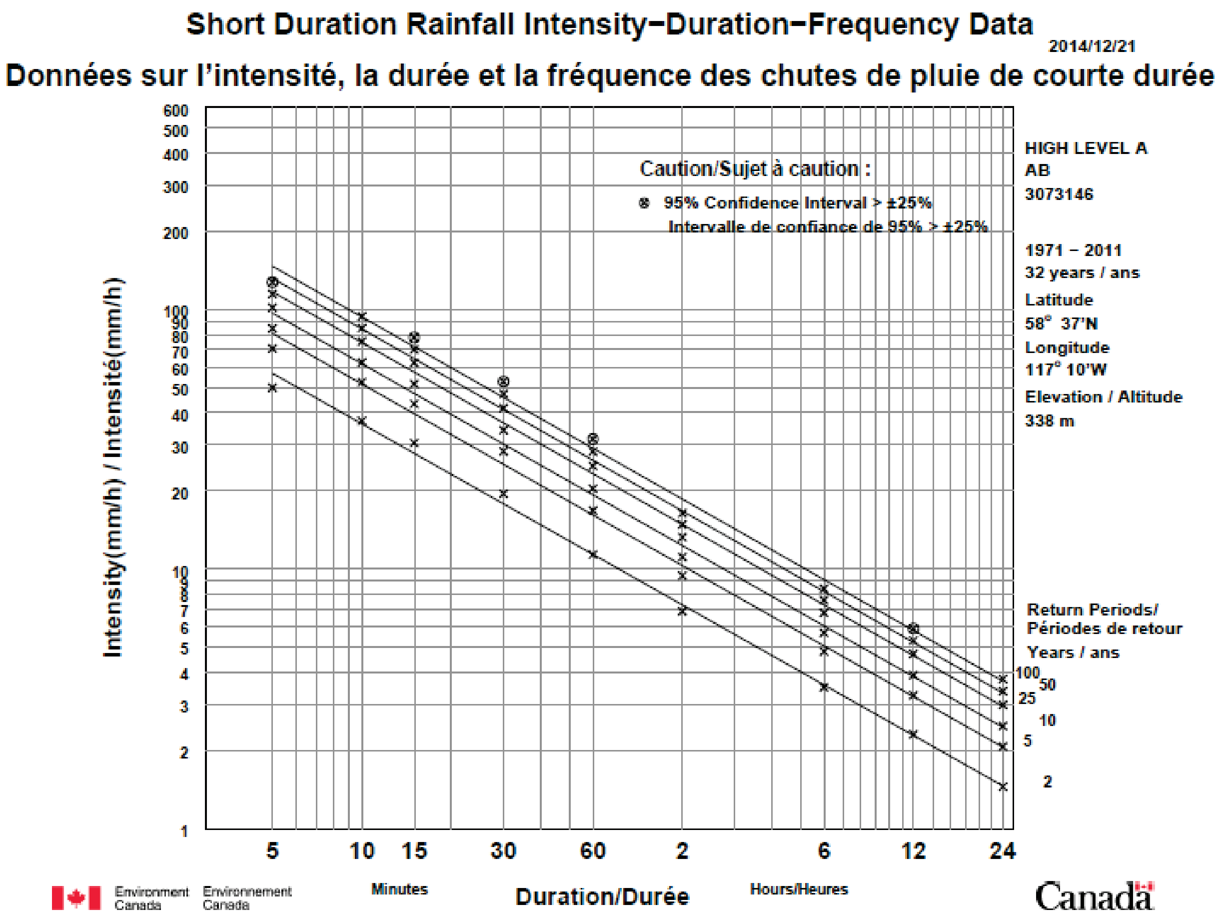


Figure 7-9 Short Duration Rainfall data (data published by Environment Canada)

7.7 WATERCOURSE GAUGE DATA

There are a few Water Survey Canada (WSC) gauges in the nearby areas of the study area. The location of the WSC gauging stations are shown in Figure 7-10. The Teepee Creek gauge and the Jackpine Creek gauge are located within in the study area. The North Star gauge has similar basin characteristics and was useful for obtaining flow information in the region.

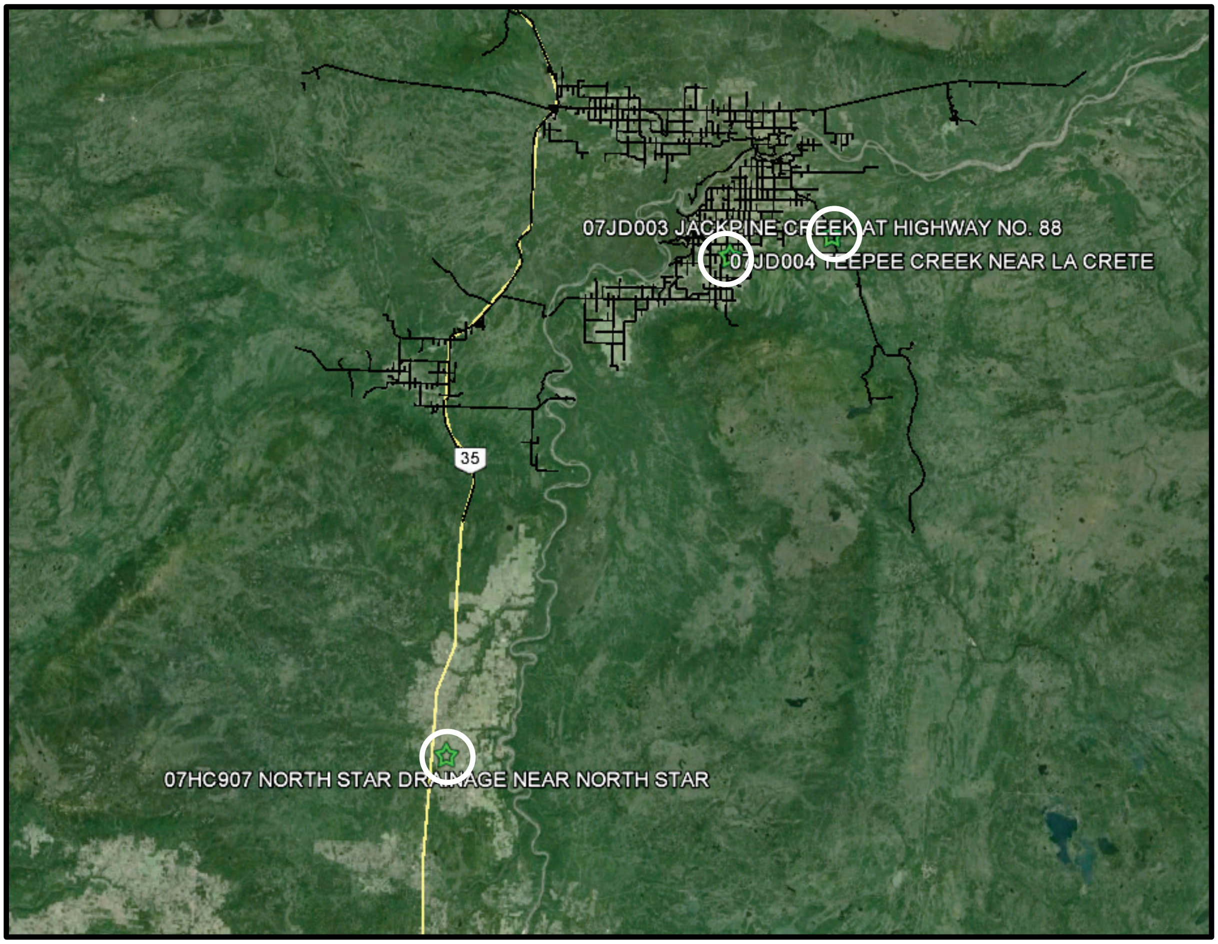


Figure 7-10 Location of WSC Gauges

The data record details for the WSC Gauges displayed in Figure 7-10 are displayed in Table 7-3:

Table 7-3 Data Record Details for Various WSC Gauge Stations

WSC Gauge	Description	Years of Records	Drainage Area (km^2)
07JD004	Teepee Creek near La Crete	1981 - 2010	136
07JD003	Jackpine Creek at Wadlin Lake Road	1971 - 2010	582
07HC907	North Star Drainage near North Star	1991 - 2009	31

The Tepee Creek WSC Gauge 07JD004 is located near La Crete. The five largest flows occurred during April snow melt events. A Rating Curve and Peak Discharges for WSC Gauge on Teepee Creek (07JD004) is displayed in Figure 7-11.

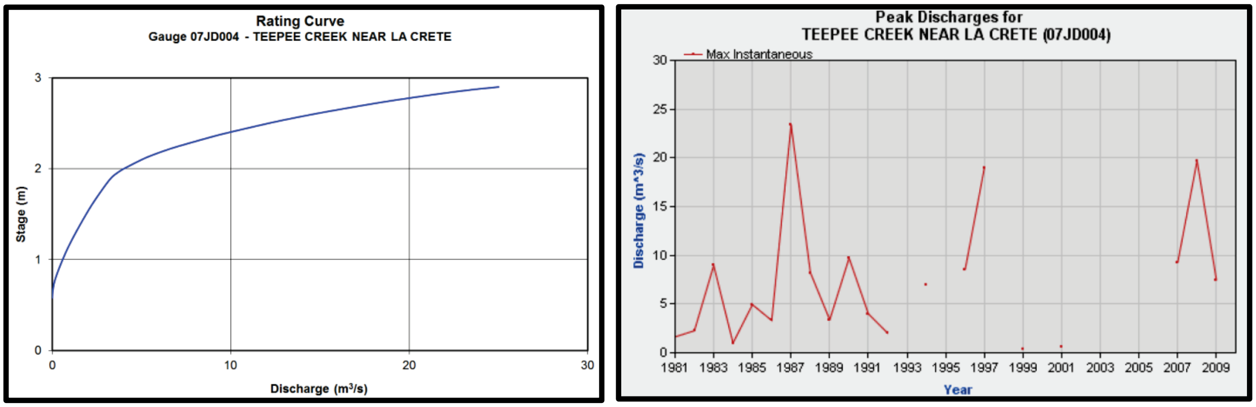


Figure 7-11 Rating Curve and Peak Discharges for WSC Gauge on Teepee Creek (07JD004)

From the rating curve, three of the largest flows were recorded as given below.

- April 1987, Qi = 23.4 m^3/s, q = 0.17 m^3/s/km^2 (Y ~2.9 m from Rating Curve)
- April 1997, Qi = 19.0 m^3/s, q = 0.14 m^3/s/km^2 (Y ~2.7 m from Rating Curve)
- April 2008, Qi = 19.7 m^3/s, q = 0.15 m^3/s/km^2 (Y ~2.7 m from Rating Curve)

North Star Drainage gauge is also applicable to this study. It is located in the County of Northern Lights and has basin characteristics similar to those in the study area. The basin starts on hills near Highway 35, descends a slope to a flat area with agriculture, water then runs through a ditch system and through the gauge location before going in to the Peace River. It is located on a drainage ditch with the same type of system being studied, and it is also a size that can be correlated to the sub basins established for this project.

Of the 19 years of records peak flows occurred during the spring melt months 12 times (March and April), with only 5 years attributed to months where rainfall would govern. This is consistent with the documented flood issues in the area. Also, the 6 highest recorded peak and mean daily flows occurred in April. It should be noted that in 1990, the year before the gauge was installed; there was a flood in the area that would likely have been larger than the events captured to date. Including that event would likely raise the resulting flows. A summary of this data is shown in Table 7-4.

Table 7-4 Summary of Data North Star Drainage near North Star (WSC Gauge Station 07HC907)

Return Period	Average Flow (m^3/s)	Unit Flow (m^3/s / km^2)
2	1.92	0.06
5	4.40	0.14
10	6.66	0.21
20	9.35	0.30
25	10.3	0.33
100	17.7	0.57

7.8 BRIDGE FILES

Hydrology has been done in the past for this area when larger culverts and bridges have been replaced. Historical crossing design information was collected from Alberta Transportation (AT) for use with this study. In the past AT typically designed the culvert crossings on local roads for a 1:25 year event, and bridges for a 1:50 year event. AT has since changed their hydrology methodology and currently designs crossings for the 'maximum expected flood'.

The following information in was found in the Alberta Transportation Hydrotechnical Information System (HIS). It should be noted that most flow information in HIS is based on rough data and is only meant to be a conceptual snapshot of the estimated flow based on the Alberta Transportation Channel Capacity and Runoff Depth methods of hydrology. The summary of this data is displayed in Table 7-5.

Table 7-5 Summary of Bridge Files and Hydrology Information

River / Creek	Bridge File	Drainage Area (km^2)	Slope (m/m)	Q (m^3/s)	q (m^3/s / m^2)
Teepee Creek	74853	70	0.0013	-	-
Teepee Creek	76507	118	0.0013	20	0.17
Teepee Creek	76738	115	0.0013	20	0.17
Teepee Creek	78209	105	0.0013	20	0.19
Teepee Creek	81120	85	0.0013	-	-
Teepee Creek	81125	136	0.0013	20	0.15
Teepee Creek	81336	137	0.0013	20	0.15
Bear River	74740	100	0.004	-	-
Bear River	74852	100	0.004	-	-
Bear River	77975	105	0.004	-	-
Bear River	78194	1600	0.0004	-	-
Bear River	78318	90	0.0035	60	0.67
Bear River	78319	65	0.004	-	-
Bear River	79552	106	0.004	-	-
Bear River	80939	870	0.0005	-	-
Bear River	81737	335	0.0007	-	-
Trib. to Bear River	13368	625	0.00065	-	-
Trib. to Bear River	76506	151	0.002	-	-
Trib. to Bear River	78103	150	0.002	-	-
Trib. to Bear River	78195	585	0.00065	-	-
Trib. to Bear River	80938	415	0.0006	-	-
Trib. to Bear River	81124	11	0.002	-	-
Trib. to Bear River	81553	570	0.00065	-	-
Trib. to Bear River	79238	56	0.0018	-	-
Trib. To Peace River	75204	20	0.0035	-	-
Trib. To Peace River	75205	155	0.0015	-	-
Trib. To Peace River	80970	32	0.003	-	-
Trib. To Peace River	80971	12	0.0035	-	-
Trib. To Peace River	81941	6	0.004	-	-
Steephill Creek	75206	250	0.0035	-	-
Trib. To Steephill Creek	80930	57	0.0045	-	-

* Drainage Area and Slope values are from HIS. The Q and q values were provided if design information was available.

Based on the HIS summary and historical design information a typical unit discharge used in this area is in the range of 0.15 to 0.67 $m^3/s/km^2$.

Most of the historical designs for bridge files were completed on Teepee Creek. The work came through BIM inspections, assessments, or design projects. There is also a WSC Gauge on Teepee creek to correlate the high water mark data. Figure 7-12 shows a map of the bridge structures located on Teepee Creek along with the WSG Gauge location.

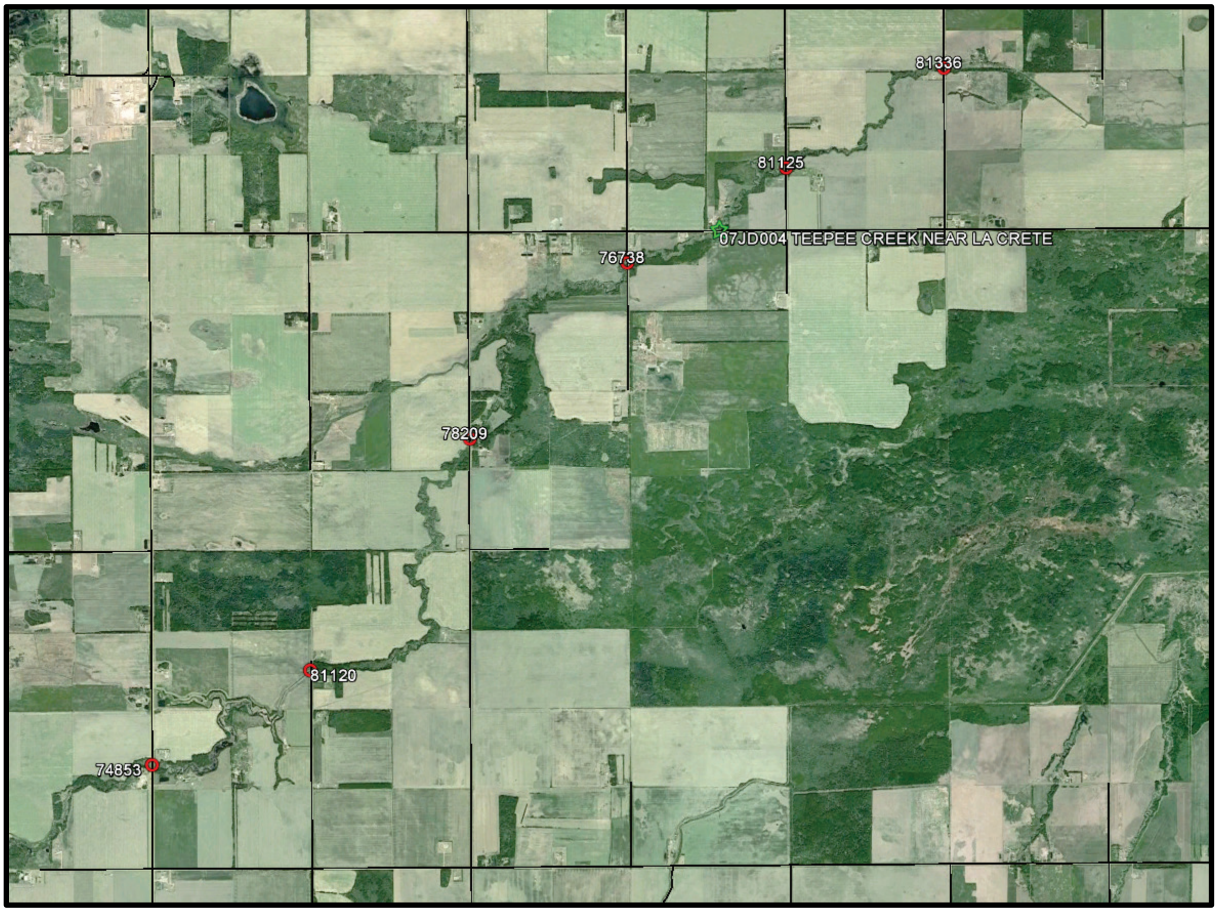


Figure 7-12 Map of the Bridge Files and WSC Gauge located on Teepee Creek

In addition to the Bridge Files locations shown in Figure 7-12, a ford crossing is shown as Photo 49 in Appendix B.

For Bridge Files 76507, 76738 and BF 81336, HIS Hydrotechnical Data Summary Sheet Summaries are available. These three structures have the same values as shown below;

- Channel Capacity: B = 4.0 m, H= 1.6 m, T = 8.0 m.
- Y= 2.4 m, Q = 20 m3/s, V = 1.2 m/s.

The addition to the HIS Summary Sheets, 2012 BIM Inspections completed on Teepee Creek revealed some additional hydrotechnical information.

Bridge File 76738 had a High Water Mark of ~2.9 m (~0.2 m below top of deck, ~3.1 m deck to SB) while Bridge File 76507 had a High Water Mark of ~3.2 m (~0.5 m below top of deck, 3.7 m deck to SB). In addition to these updated High Water Mark values, Bridge File 81125 was recently replaced. The previously existing low levels crossing with a temporary portable oilfield bridge. The design parameters were;

- Y = 2.5 m, Q = 27 m3/s, V = 0.9 m/s (Full design)
- Y = 2.2 m, Q = 21 m3/s, V = 0.8 m/s (75% design)

In Figure 7-13, a photo of the old low levels crossing is shown to the left. The new temporary portable oilfield bridge is displayed on the right.

Figure 7-13 Left: Old low level crossing. Right: New temporary portable oilfield bridge.

7.9 UNIT RUNOFF VALUES

As a test for the future model calibration data to be used for the Bear River drainage basin, we investigated recorded structure flows and WSG gauge information in a larger scale.

It has been assumed that the flow data recorded at various bridge structures is roughly equivalent to a flow frequency of a 1:100 year flood event. This flow frequency can be obtained for the WSC gauge information to help correlate the model data.

Figure 7-14 is a plot of Unit Discharge vs. Drainage Area. The structures in the Bear Creek basin are highlighted in red boxes below. The green triangles represent the WSC Gauges in the NW quadrant of Alberta with the purple triangles representing the three WSC Gauges referenced in Table 7-3.

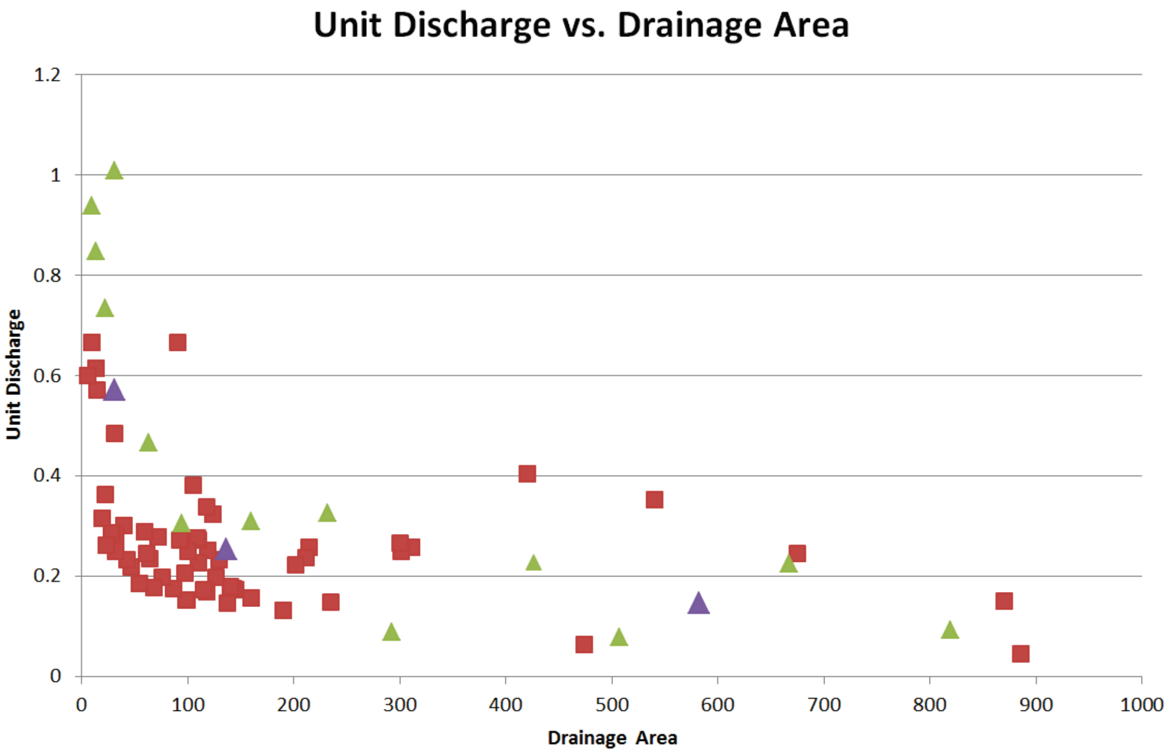


Figure 7-14 Graph of Unit Discharge vs. Drainage Area for the Bear River Basin

Based on the WSC gauge data, which appears to be a relatively good match with the study area, the runoff rate, or unit discharge, for a 1 in 100 year flood event is in the range of 0.15 to 0.67 $m^3/s/km^2$.

This value is relatively well supported by other information. It should be noted that the runoff rate for a given basin can vary significantly based on the following conditions:

- Land Use Type (Forested / Agricultural)
- Runoff Event Characteristics (Rain / Snowmelt)
- Basin Characteristics (Size / Topography / Storage)
- Drainage System (Ditches, Culverts, etc.)

8 HYDRAULIC MODEL

8.1 GENERAL

A computer model developed in XP-SWMM (Version 12), which is based on the Environmental Protection Agency's stormwater management model, was used to analyze the study area's drainage system. The model consists of two primary components; the hydrologic model which determines the amount of runoff and the resulting hydrograph from each basin, and the hydraulic model which uses the hydrographs as inputs and routs the flows through the drainage network.

Basin areas were delineated using LiDAR data to establish overall drainage patterns and a representative model network was created. The sub-basins are the same as the ones identified in the hydrology section of the report. The model basins and network were then further refined with the analysis of significant ditches and topographic features.

The model concept was then structured using 'links' and 'nodes' in a network that match drainage patterns within the study area. Each primary model element is described as follows:

- Basins – Each drainage basin was delineated using available data.

- Links – Links in the model represent creeks, rivers, channels, and ditches. Channel cross section information was taken from detailed LiDAR data and checked against known channel geometry from the file review. Culverts are not included in the model.

- Nodes – Nodes in the model represent catchments areas. This is the interface between the links, which convey the water, and the basins which receive storm water. A drainage area is typically associated with each node. Links can also converge at notes, modeling a confluence.

8.2 HYDROLOGIC (RUNOFF) MODEL

A hydrologic model of the study area was created based on the information collected and discussed in the hydrology section of this report. The hydrologic model was set-up based on proposed sub basin areas for the project area drainage system and runoff was analysed for the project area using XP-SWMM.

The runoff model incorporates design hyetographs to develop hydrographs for each sub basin and is shown in Table 8-1 below. Run-off hydrographs corresponding to 1:10 and 1:100 year, 24 hour duration storms were simulated for the project area using the XP-SWMM runoff model. The use of the 24 hour duration storm events is recommended in the AESRD Drainage Guidelines.

It is important to note that rainfall events were used for the model instead of snowmelt event. Accurate modeling of snowmelt requires highly variable input parameters. In addition, icing snow drifts and other variables cannot be modeled. It was felt that including snowmelt would increase the complexity of the model without increasing the accuracy. Using rainfall information maintains consistency and will be a good indicator of the drainage system capacity. Model results were correlated with historical hydrology analyses and gauge data both of which include snowmelt, rainfall and combination events.

Table 8-1 Storm Data used for Runoff Model

Storm Type	Return Period (Years)	Duration (Hours)	Total Rainfall (mm)
Chicago Hyetograph	100	24	87
	50	24	78
	25	24	70
	10	24	57
	5	24	48

The “Stormwater Management for the Province of Alberta” discussed using the Chicago Hyetograph method vs other methods. While there are pros and cons for using any method, the Chicago Hyetograph is relatively simple, and is considered adequate for the conceptual purposes of this study.

8.3 HYDRAULIC (ROUTING) ANALYSIS

The hydraulic analysis was conducted using the XP-SWMM hydraulic model. Hydrographs generated in the runoff model are used as input for the hydraulic model and the program then runs a dynamic simulation that routs flows through the links defined through the entire network.

8.3.1 CHANNEL GEOMETRY

LiDAR was used for establishing the geometry of each channel (model link). Numerous natural cross sections were assessed for each reach and typical geometry was then established in terms of a trapezoidal channel. Due to the length of the each reach natural a single representative natural cross section was not possible and trapezoidal shapes were used. The slope from each channel is also based on LiDAR, averaged over the length of each reach. A typical manning’s roughness (n) of 0.035 was used for all the channels.

The flood plain (over bank flow width) for each reach of the channel is modeled with a finite width, generally between 30 to 100 m, and enough height to contain anticipated flood elevations.

Several sections of the model include areas where the channel is poorly defined and where overland flow through muskeg is prevalent. In these cases a small main channel was defined forcing the majority of flow into overbank conditions.

At the downstream end of the study area, flood conditions at the outfall of the network into the Wabasca River were modeled using an initial depth of water of 4 m. This is to account for anticipated flood levels in the Wabasca River creating a backwater effect in the Bear River.

8.3.2 GROUND / SOIL CONDITIONS

The imperviousness, depression storage, and infiltration rate of a watershed are key parameters in predicting the amount of runoff generated. For rural, agriculturally based watersheds, land conditions can range from frozen ground (which simulates impervious ground cover in the winter), to barren ground in the spring, to a robust crop cover in the summer and early fall, then back to barren ground after harvest. An identical storm will generate different runoff volumes and rates during each of these ground-cover conditions. Typically, the ground cover condition which creates the most critical runoff condition is modeled for sizing conveyance system components and detention basins.

For this model, ground runoff values were adjusted to simulate spring melt conditions. During a snow melt event the ground surface is either snow covered or primarily frozen and infiltration, depression storage, and surface roughness is reduced.

Impervious surfaces in the model represent roads, driveways, and other hard packed paths. Pervious surfaces include fields and farmland (post developed condition), and un-cleared land (pre-developed condition).

Ground infiltration was modeled by Horton's equation using values based on anticipated soil conditions. Parameters used for this analysis are listed in Table 8-2 which include pre and post development flow parameters.

Table 8-2 Ground / Soil Conditions used for Hydraulic Model

Description	Unit	Pre-Development Condition	Post Development Condition
Depression Storage			
Impervious Surface	mm	2	2
Pervious Surface	mm	17	17
Manning's Roughness			
Impervious Surface	mm	0.02	0.02
Pervious Surface	mm	0.20	0.035
Horton Ground Infiltration			
Initial Rate	mm/hr	50	
Final Rate	mm/hr	1	
Decay Rate	1/sec	0.004	
Zero detention = 50 %			
Horton ground infiltration rate is given by; $f(t) = f_c + (f_o - f_c) \times e^{-kt}$; where f_o is the initial infiltration rate, f_c is the final infiltration rate, k is the decay rate and t is the time.			

8.3.3 LAND USE

Land use in this model is divided into the category of 'pre-developed', meaning any land that has not been cleared, and 'post-developed', meaning land that has been cleared for agriculture or any other purpose. The two different land uses require different parameters which determine the amount of run-off generated during a rainfall event.

Changing land use in the study area is a primary focus of the project and the pre-development and post-development conditions were used to model existing conditions, and future conditions to predict increased runoff due to additional clearing.

With increased development, the percentage of imperviousness of the land increases, subsequently causing a reduction in the infiltration rate, thereby increasing the amount of run-off produced on the land surface due to a rainfall or snowmelt event.

It is well understood that clearing and cultivating land increases runoff rates, however the exact measure of that effect is highly variable and depends on many factors. In order to input land use data into the model ground soil conditions were prorated within each basin based on the corresponding pre-development and post-development land area ratio. For simplicity two primary parameters were selected to represent the change in land use; impervious surface area (%) and pervious surface area roughness. The parameters shown in Table 8-2 were used in the model.

8.4 CALIBRATION

Calibration of this type of model would typically be completed using known flood information in combination with known storm data. In this case, we have some flood information from the field visit; however, we have no data corresponding to flow information at that time. Traditional calibration is not possible for this study and the following techniques were used to establish a reasonable level of certainty:

- Teepee Creek and Jackpine Creek gauge data at the estimated 1:100 year flood event was compared to model results at the estimated 1:100 year 24 hr storm event. Calibration was conducted using the 1:100 year storm event so that design information from Bridge Files could also be used for a model comparison.

- Overall results for links in the network were compared globally to the estimated unit discharges predicted by the unit discharge analysis in the hydrology section of this report. See Figure 8-1, which is similar to Figure 7-14 included in the hydrology section that showed Unit Discharge vs. Drainage Area for gauges and bridge files. Figure 8-1 now adds the model data which is displayed by blue squares.

- Results were reviewed for flow velocities and peak flows. If any obvious erroneous data was observed, errors were traced and corrections made where possible.

Depression storage and the Manning roughness was used as global calibration factors, with local adjustments made to the model within reason for accuracy. Overall the calibration was successful in establishing a model that is relatively accurate for the conceptual level required for this report. Inconsistencies for each calibration method were noted during the calibration processes which are further discussed in the “Model Limitations” section.

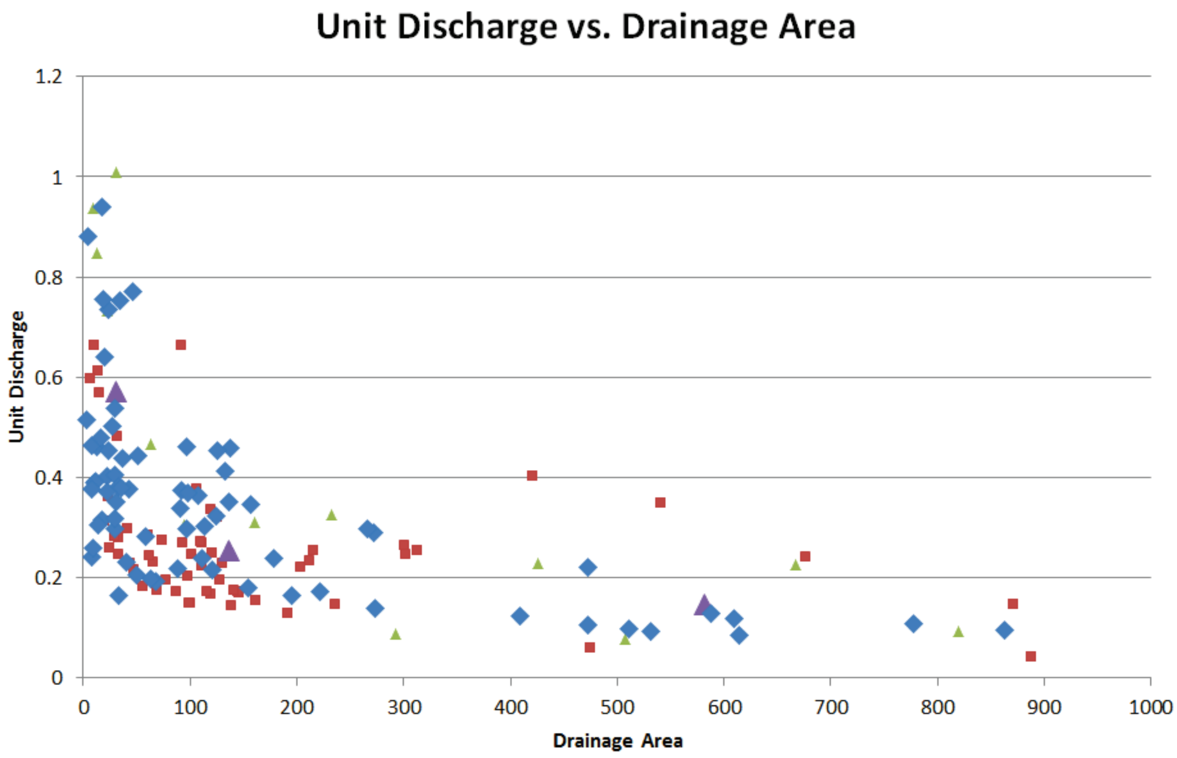


Figure 8-1 Unit Discharge vs Drainage Area for Gauge, Bridge, and Model Data

In Figure 8-1, the blue diamonds are model data, the red squares are structures in the area, the green triangles are the WSC Gauges and the purple triangles are the three WSG Gauges used for modeling the Bear River basin area.

8.4.1 MODEL SENSITIVITY ANALYSIS

Sensitivity of parameters can be an indicator of confidence in the model. A highly "sensitive" variable could indicate uncertainty in the model if that variable is not adequately refined.

Based on similar models it was found that parameters were either very sensitive, or not sensitive. Parameters did not fall into the moderate range. The following parameters were noted as being sensitive:

- Drainage area
- Imperviousness
- Pervious depression storage

Basin Area and Imperviousness are the most sensitive parameters, with changes to the peak flow directly correlating with the changes to each parameter they are "extra sensitive". This is expected as they are the primary factors relating to water quantity and water storage in the basin. The variation of pervious surface depression storage resulted in a changes in peak flow of 9.4% also giving that parameter a "very sensitive" label. All other parameters were considered to be "not sensitive".

8.5 MODEL RESULTS

In order to provide a range, the model simulation was carried out using a range of storm events, however, the 1:10 year storm was used as the basis for this report. New drainage ditches are typically designed to the 1:10 year event, which is also a reasonable reference for flooding in the study.

Output values from the model used primarily for this study are the following:

- Maximum Flow – The maximum flow in a given network link as a result of the model analysis.

- Maximum Flow Height – The maximum flow height (above the specified bed elevation, corresponding to the maximum flow)

- Overbank Flow Height – The maximum height of water above the top of the specified bank. This is the depth of water in the flood plain at the channel. Overbank flow height results are depicted in Figure 8-2 where red lines indicate links in the network where overbank flow is predicted to be the deepest. The colors in Figure 8-2 are; red corresponds to an overbank height of 1 m and above; orange represents a value between bank full and 1 m overbank; yellow is bank full; green is below the bank height. Note that some link locations where flooding is predicted is in undeveloped ‘storage’ areas where flooding is expected. It is also expected that some flooding will occur at the 1:10 year storm event.

Results from the base model were also compared to a version of the model that was adjusted to account for anticipated recent and future clearing. Results from that analysis are shown in Figure 8-3 where brighter red lines indicate a greater effect in that particular link from potential clearing. The bright red lines represent a 30% flow increase while black lines represent no change in flow.

Analyses of the model results are included in the Analysis section of the report.

Detailed tables of model input data and results from XP-SWMM are presented in Appendix B.

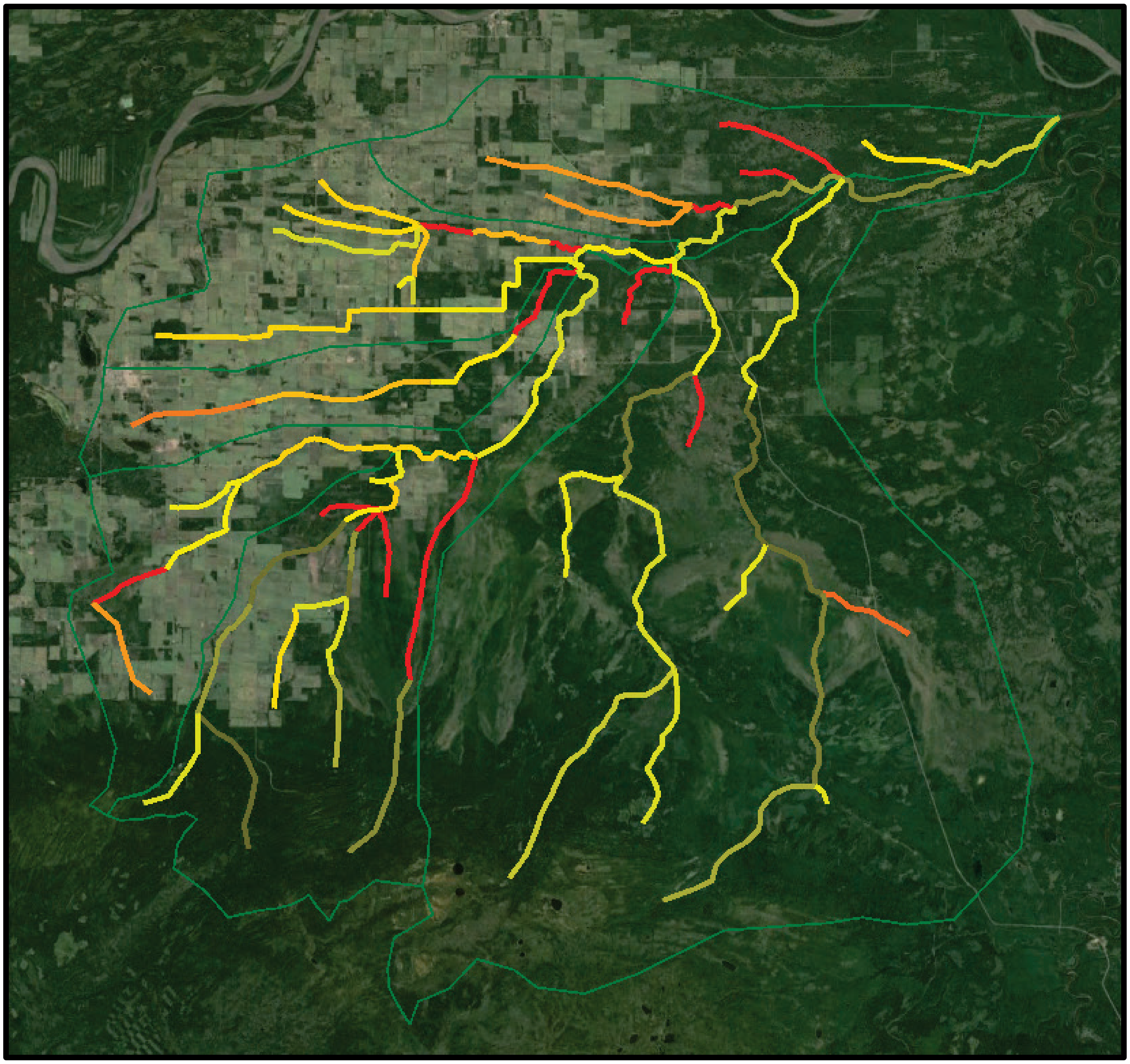


Figure 8-2 Relative overbank flow height (red)

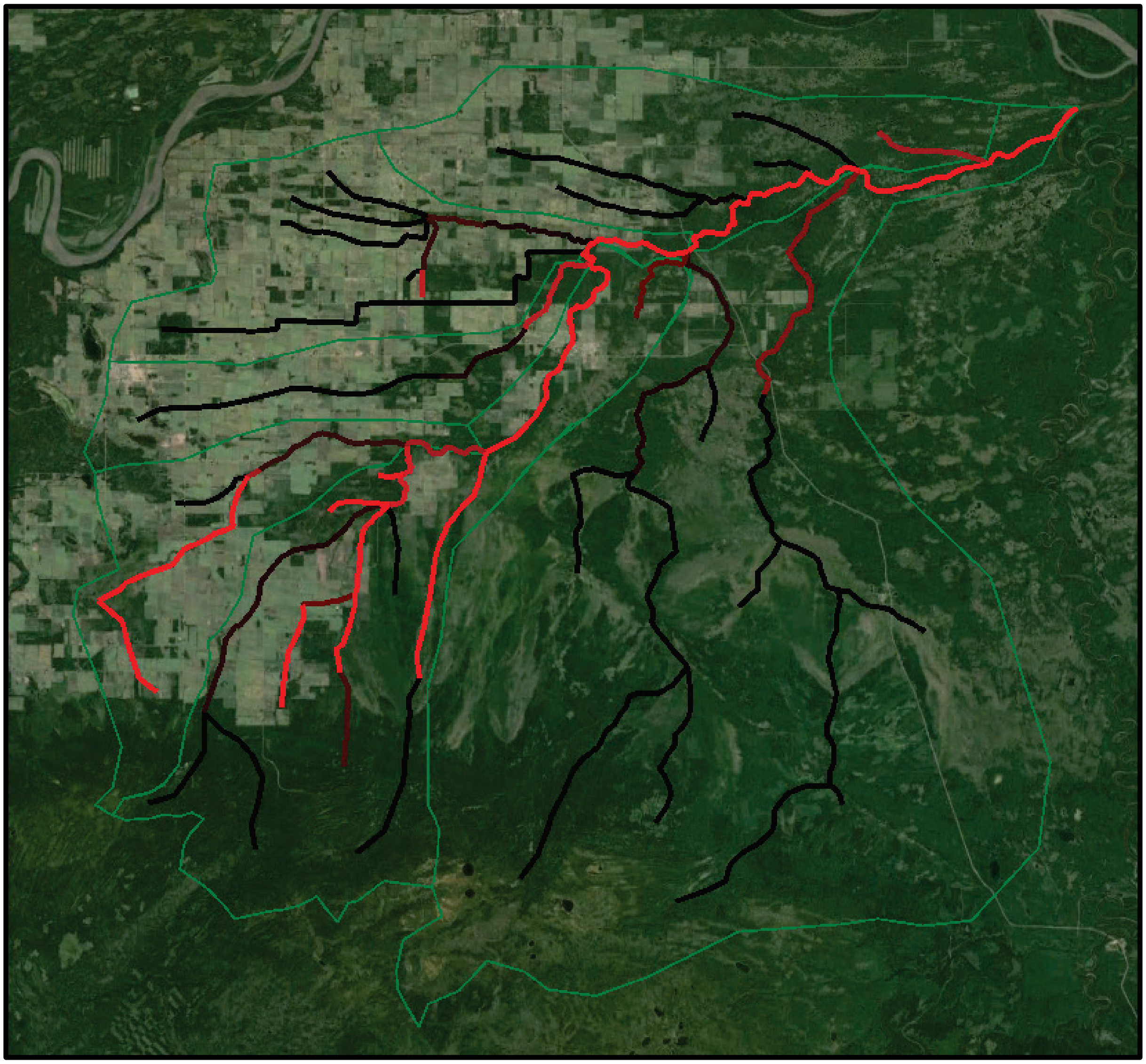


Figure 8-3 Relative increase in flows due to clearing from new land parcels (red)

8.6 MODEL LIMITATIONS AND ASSUMPTIONS

The model used for this study is a conceptual representation of the actual drainage patterns and flows within the study area. Therefore, there are inherent limitations to the precision of the model that should be understood before implementing the results.

Assumptions used for entering ditch and channel information are discussed in the hydraulic analysis section above. The assumptions are reasonable approximations of actual conditions within the study area.

A significant factor in the flooding issues during the spring melt within the study area is snow and ice. The effect on flooding will vary considerably depending on climactic conditions such as snowfall, rainfall, wind, temperature, and others that combine to create different flow situations every year. Further, there is limited specific data about snow and ice conditions that lead to flooding in this area. Decreased capacity of the drainage network due to snow and ice was not included in the model. The intent is that capacity information from the model can be assessed based on the knowledge that its capacity could be reduced due to those conditions.

Due to the relatively flat nature of the study area, snow and ice blocking channels, ditches, and culverts can divert flow from one basin to another basin. This is known as bifurcation, or basin transfer. The amount of water diverted depends on unavailable climactic and seasonal variables that cannot be modeled accurately. The model network has been established based on assumed flow patterns during the spring melt.

Another unpredictable factor related to modeling spring melt is the fact that runoff rates will vary depending on climactic and ground conditions at the time. For example, bare frozen ground will have a higher runoff rate than frozen ground with a heavy snowpack. This has been considered in the imperviousness factor used, which was increased to account for frozen ground conditions.

9 PRE AND POST DEVELOPMENT FLOW ANALYSIS

9.1 GENERAL

Pre-development and post-development flow rate are common measures used to design stormwater management facilities for urban development projects. Typically urban development guidelines require that post development runoff is limited to the pre development runoff rate. In rural areas that requirement may not be feasible and AESRD suggests that the "imposition of rigid flow regulation policies for rural drainage based on pre - and post - development conditions should be avoided".

Although the same restrictions may not be applied, pre and post development conditions should still be considered to assist with drainage planning and to assess potential impacts of the development on the existing drainage system.

9.2 FACTORS AFFECTING RUNOFF RATES

Pre-development conditions within the study area would typically be forested land. Development increases runoff rates in the following ways:

- When prepared for agriculture the imperviousness of the ground and soil is increased overall. This reduces overall infiltration and increases runoff.

- Surface storage is reduced. Relatively small depressions in the natural land are eliminated to properly drain the new field.

- Swales, ditches, and roads are constructed which, by design, drain land more efficiently thus increasing runoff.

- Trees and bush are removed that would otherwise provide shade and reduce the rate of snowmelt.

- Removal and drainage of wetlands and other water storage features can have an exponential impact on downstream runoff rates.

9.3 CONCEPTUAL ANALYSIS

It is well understood that clearing and cultivating land increases runoff rates, however the exact measure of that effect is highly variable and depends on a complex combination of all factors. Environment Canada has estimated that urbanization of a natural drainage basin can result in increase in stormwater runoff of 400 percent or more.

Model analysis was completed for a test basin to compute a theoretical pre and post development flow. Runoff parameters as described earlier in this report were used. A test basin with a drainage area of roughly 10 km^2 was used where there is no existing development.

- Drainage Area = 10 km^2
- Pre-development Flow (1:10 year event) = 1 m^3/s
- Post Development Flow (1:10 year event) = 3 m^3/s

From this analysis it is suggested that the post development peak flow condition could be roughly 3 times that of the pre development flow immediately downstream of the development. Caution is advised when using this value as there are many factors that could affect the actual change in peak flow. Distance downstream of the development, amount of development, size of the basin, design storm, basin characteristics, and channel characteristics are only a few

This analysis is provided as a guide only to help understand the possible effects due to clearing. It should not be used directly for design purposes.

10 FLOOD MITIGATION METHODS

10.1 GENERAL

There are only two effective ways to reduce flooding problems in a certain area; limiting the water that reaches the site (retention or diversion) and draining water from the site (conveyance). Within those broad categories there are a limited number of common solutions available for rural and agricultural drainage. Many documented flood mitigation solutions are aimed at urban development and are not applicable to the rural setting; however there are several effective solutions that can be used.

Traditionally, small scale 'lot level' urban techniques of reducing runoff have not been adopted for rural agricultural applications. This is due to the fundamentally different land use being serviced. Agricultural land is cleared for the purposes of productive farming and most cases methods used to retain water or reduce runoff would reduce productivity. Also, the efficiency of runoff reduction methods during freezing spring runoff conditions, when they are needed the most, is suspect subject to debate.

10.2 PLANNING

Planning is an important part of any functional drainage system. In the past drainage networks were installed based on limited future planning and development of individual land parcels was not typically considered. Drainage is an issue that can have complicated effects and proper planning should be done to prevent problems as a whole system. The municipal Development Plan, this Drainage Plan, and the existing drainage studies done in the area are a good base for instituting a well-planned drainage system. Below are general guidelines related to drainage planning.

- Implement recommendation in this report.
- Conduct site specific designs where necessary.
- Review the plan every 10 years, or if significant changes are needed.

10.3 DITCHES

Ditches are the primary component of a drainage system. They can effectively remove large quantities of water away from an area, and can be used to convey that water as required for the system design. Proper design may include drop structures.

Design criteria:

- Design Flow = 1:10 year (minor ditches), 1:25 year (major ditches).
- Follow provincial guidelines for ditch and drop structure designs.

Similar to a culvert, a ditch can be sized appropriately for the design flow but could still be inadequate when considering snow and ice. The following are some alternatives that can help prevent flooding:

- Over sizing ditches should be considered in areas that are prone to icing. Beyond the standard 0.3 m of freeboard and additional 0.3 m should be considered in areas where icing has been documented. Dykes can be used to separate the ditch from the adjacent land to prevent flooding.

- Ditches should not be shaded from the south or west. If a ditch can be exposed to afternoon and evening sun snow and ice will melt faster from the ditch.

- Offsetting a ditch from the adjacent road by a minimum of 10 m would provide room for snow windrows from road clearing.

- Redundancy can be gained by using ditches on each side of a road for accommodating flow. If ice builds up in one ditch, the other may be free to accept flow. Additional carefully placed centerline culverts would be needed to equalize flow.

10.4 CULVERTS / CROSSINGS

Wherever drainage crosses a road, field access, or any other infrastructure a culvert is typically required. If the flow is large enough a bridge or other structure may be needed. The crossing structure is designed to protect both the ditch and road being crossed without affecting the performance of either one.

Adequate flow conveyance and the reduction of flow velocities are the primary design factors which will prevent flooding of the road and minimise scour and erosion in general. Due to the relative expense of crossings they tend to be constraining points in a drainage network. They are also prone to icing during the winter, which can further reduce their capacity. Determination of the correct structure type and size needs to be done on a site specific bases and needs to include flow, level of service, and environmental factors.

Design criteria:

- Design Flow = 1:10 year (minor crossings), 1:25 year (road crossings)

- Follow provincial guidelines for culvert designs.

A culvert in this area can be sized appropriately for the design flow but could still be inadequate or fail because it was not designed for snow and ice. Design choices can mitigate flooding caused by snow and ice in culverts. The following alternatives are possible:

- Over sizing culverts should be done in areas that are prone to icing. It is recommended to oversize a centerline culvert by a minimum of 200 mm diameter compared to a normal design flow criteria. Also, the use of culverts below 900 mm in diameter in locations where drainage is a concern is not recommended. The additional diameter is relatively inexpensive insurance to help reduce annual maintenance costs and flooding.

- Redundancy (multiple culverts) is beneficial to prevent plugging of a crossing, especially if one culvert is placed higher than the other. Alberta Transportation guidelines suggest that overflow culverts are placed at a higher elevation when icing concerns are noted.

Structure height is critical in preventing flooding due to icing. The higher the crown of the structure, the more water it can accommodate if the bottom does freeze up. A low road may not accommodate larger culverts or overflow culverts due to cover limitations. Concrete box culverts are an excellent choice in these cases due to their low cover requirements (zero in some cases), and wide flow width at the top of the structure. For larger crossings, bridges achieve the same result.

10.5 LAND GRADING

Proper land grading typically involves filling in low areas, and maintaining general surface flow to a desired collection point (swale or ditch). Prior to land grading the overall drainage plan for the area should be established and the grading should complement that plan.

10.6 GRASSED SWALES

Swales are an intermediate conveyance system which can be effective to accommodate localised excess water to a larger drainage system. They have low banks allowing easy crossing with equipment, and provide for shallow flow depths with a broad wetted width, and need minimal maintenance. Grassed swales should only be used in locations that experience intermittent flow and need to be graded and vegetated adequately.

10.7 OUTFALL STRUCTURES (FOR EROSION)

The outlet of a drainage ditch or culvert into a larger channel, typically natural, requires careful consideration and design of an outfall structure. The structure is typically used to reduce flow velocities at the outlet and to protect both the drainage infrastructure and outlet channel. Improper outfall designs can lead to erosion of infrastructure and the natural channel causing extensive environmental and functional damage. Gabions, concrete, culverts, rock, riprap, turf reinforcement matting (TRM) or a combination are typically used. Site specific designs are required for outfall structures.

10.8 RETENTION AREAS

Construction of ponds, dykes / berms, or wetlands can all be used to reduce runoff to an area. Each needs specific planning and design to function properly within the drainage system. Development planning should avoid elimination of natural retention areas.

- Wet Ponds or Dugouts are used to temporarily store runoff. They are also beneficial because they promote the settlement of suspended solids.

- Wetlands retain runoff for a prolonged period of time and as a result, provide water quality and quantity control. Wetlands generally have a larger surface area than the wet ponds and consequently they have a higher efficiency than wet ponds. They also have other environmental benefits providing habitat for wildlife.

Dykes and Berms can be built is some locations to retain water upstream. In certain areas large volumes of water can be impounded with relatively small berms. Environmental impacts need to be considered as well as possible risks due to upstream ponding. As the berm, essentially a dam, risks of downstream flooding in case the berm breaks should also be considered.

10.9 MAINTENANCE

All components of an effective drainage system require maintenance. A drainage maintenance program should be developed to ensure the system retains its original capacity and is protected from erosion.

10.9.1 ANNUAL MAINTENANCE

Culvert steaming and ditch cleaning is common during the spring. These methods are effective but can be expensive and may need to be done during a short window before spring melt. It is also time consuming and may not be viable for large numbers of culverts. Nevertheless, inspection of culverts identified to be undersized in problem areas is recommended prior to spring melt to assess if steaming may be required.

10.9.2 PREVENTATIVE MEASURES

A common problem with centerline culverts is damage caused by graders. Flags could be installed at each end of culverts so that graders and snow plow operators can avoid them. A higher priority for flagging is on roads with higher use where maintenance is more common.

Snow plowing should be planned such that snow is not directed into critical drainage ditches. If possible it should be plowed to the opposite side of the road. If both ditches are needed for drainage it may be necessary to remove snow from the road or ditch before spring.

10.9.3 INSPECTIONS

Inspection of all centerline culverts should be completed to assess the need for repairs. Any culverts with damaged ends should be repaired. Damaged ends can reduce flow capacity. Other forms of damage such as scour, corrosion, or sink holes may also need repairs.

In addition, an inspection of the drainage system should be completed every 5 years. Inspection for scour and erosion should also be done after a significant flood event.

10.9.4 DITCH MAINTENANCE

Vegetation removal from all significant ditches should be completed every 3 years. This includes mowing and cutting all woody vegetation growing in and near the banks of the ditch. Vegetation reduces the capacity of the ditch, slows runoff, reduces snowmelt, and can promote icing.

Over a period of time ditches will eventually fill in with silt that has been transferred from upstream. The accumulated silt can reduce the ditch capacity if built up enough. The frequency required for silt removal will be different for each ditch. In general this should be assessed every 10 years.

11 ANALYSIS AND OPTIONS

11.1 INTRODUCTION

Using the Model results, LiDAR data, aerial photos and hydrology information, WSP assessed flood capacities, development area, and future flood areas in the vicinity of the Bear River basin.

The study area was divided into 6 zones to simplify the assessment of each area. Delineation of the zones was an overall summary of the existing drainage network. Figure 11-1 shows a map of the zones listed below.

- Teepee Creek – Zone 1
- Upper Bear River – Zone 2
- Wilson Prairie – Zone 3
- La Crete East – Zone 4
- Bear River North – Zone 5
- Jackpine Creek – Zone 6

Each zone has been reviewed and assessed for the following:

- Model results.
- Identified problem areas, possible causes, and conceptual solutions.
- Proposed development areas and possible future development areas.
- Conceptual solutions for problem areas and future development.
- Maintenance Requirements (existing ditch inventory).

Particular attention has been given to providing solutions and recommendations that can be used for future planning and drainage improvements.

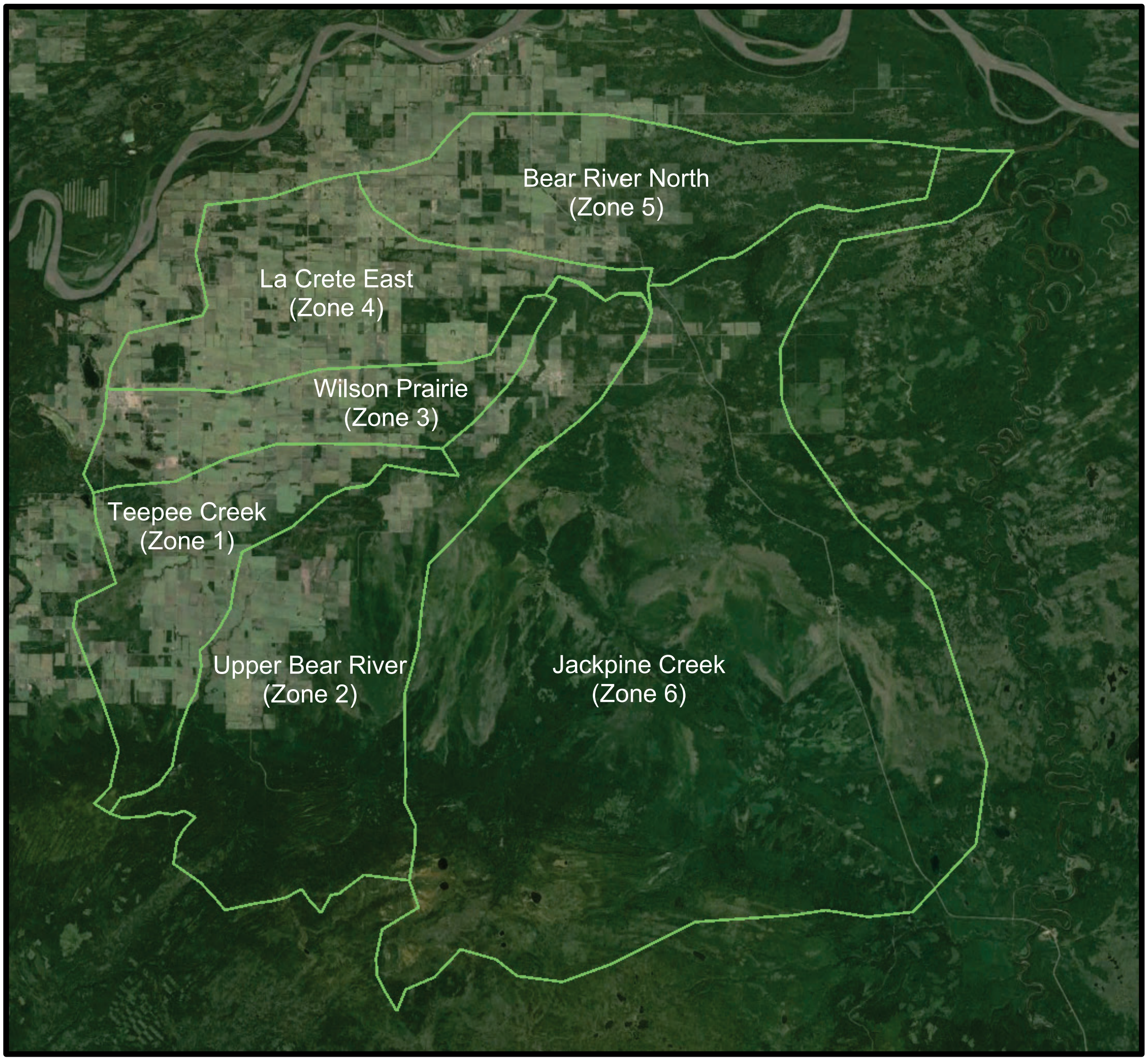


Figure 11-1 Map of zones used for future planning and drainage improvements

Provincial public land use green and white zone mapping is shown over the study area in Figure 11-2. The highlighted white region coverall all existing white zone areas. The black boxes represent the land parcels that have been recently sold. The road network is displayed in orange.

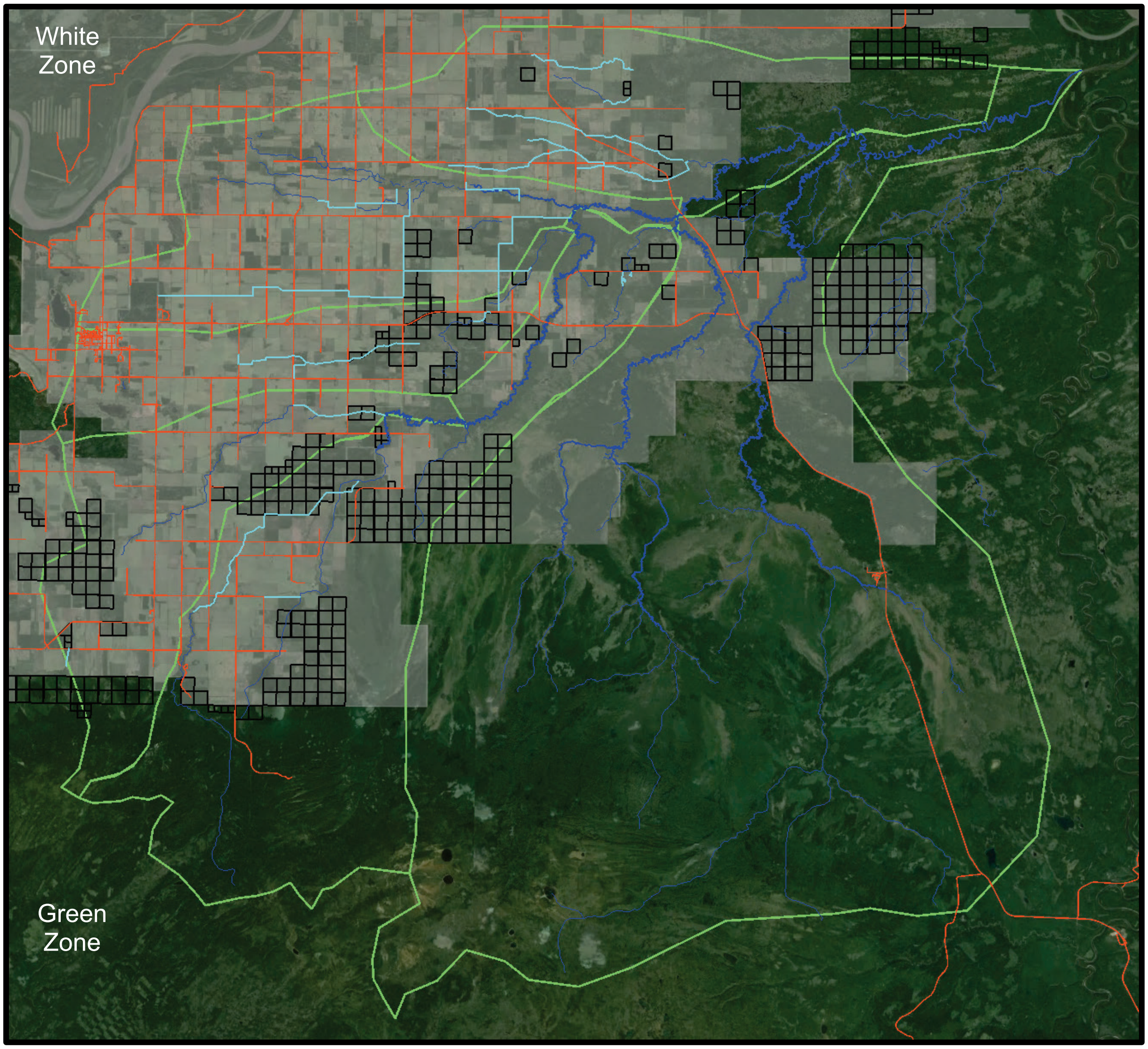


Figure 11-2 Green and White Land Use Map. The black boxes are parcels that have been sold. The road network is shown in orange (data from AltaLIS dated 2010).

11.2 TEEPEE CREEK – ZONE 1

Teepee Creek originates in the Buffalo Head Hills (the Hills) near Buffalo Head Prairie. Water flows from the Hills, flows north across Highway 697, then turns north east again crossing the Highway before flowing roughly 20 km to the Bear River.

There are several existing drainage ditches in the Teepee Creek area, which historically has been problematic for flooding. Several areas have been identified as current problem areas of flooding, and there is significant future land development which will add to the drainage issues.

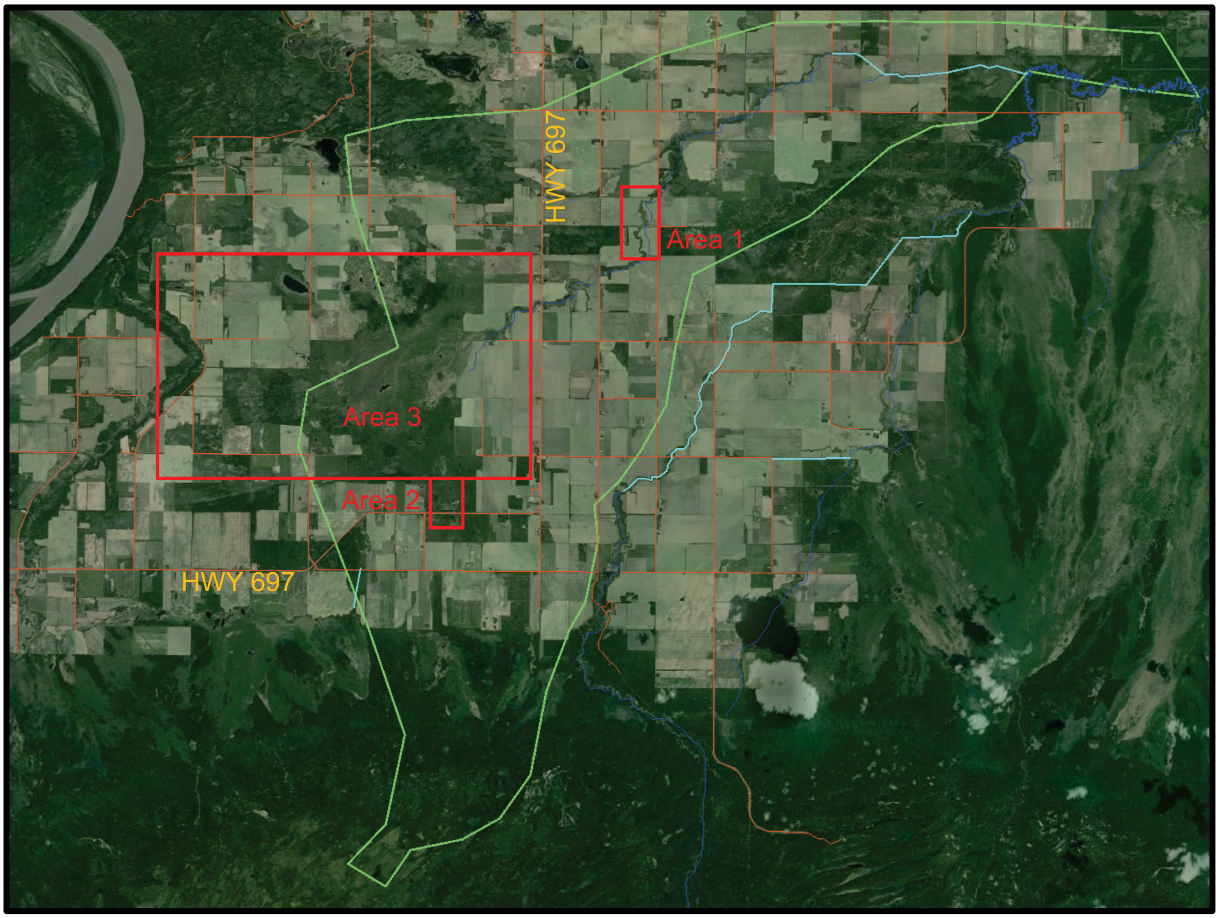


Figure 11-3 Teepee Creek (Zone 1) Limits and Areas of Interest

11.2.1 PROBLEM AREA – AREA 1, WEST OF RR 145

Based on information obtained during the field visit, it is understood that there is an area of Teepee Creek, located immediately west RR 145, which is currently prone to flooding. Adjacent farmland is commonly inundated in the spring, which extends to the roadway and sometimes over the road. See Figure 11-4 and photos 7-12 in Appendix B.

Figure 11-4 Teepee Creek located immediately west RR 145

Based on Model results anticipated flow through this area are in the range of 6 m/s (1:10 year flow), with depths near the bank height. Any snow or ice in the channel could raise water into flood conditions.

There are several possible reasons for this issue. Starting upstream of Highway 697, Teepee Creek has a relatively wide channel which continues past the highway and is joined by two tributaries that contribute additional flow to the creek. Immediately downstream of the tributaries there is a 500 m section of Teepee Creek has been channelized, presumably because there was flooding in that area in the past.

The channel through the problem area then becomes narrower (bed width) and becomes increasingly sinuous, both factors resulting in a constriction to the flow. This in combination with increased flow from the tributaries results in increased flow height. Banks heights through the problem area are an average of roughly 1.3 to 1.5 m high. However, there are localized sections with lower banks that would also contribute to flooding in those areas. Icing effects and snow are also likely a compounding factor.

Most of the bridge files in the area are adequately sized single span bridge structures and are not likely causing backwater. A change in the channel profile (slope) is also not a factor in the flooding.

A solution to the flooding could include channelization (straightening and widening the creek) which has been done for other sections of Teepee Creek with success. Channelization would likely reduce flooding issues; however, it would also further increase flows downstream, where there is another flood area. Environmental permitting may also limit this option.

Reducing upstream flows to this area would be the most effective solution which will be discussed in the following sections of the report.

11.2.2 PROBLEM AREA – AREA 2, HIGHWAY 697

It is understood that there is flooding over the highway west of RR 151 in 2013, identified during the site visit and as shown in Figure 11-5. See photo 46 in Appendix B.

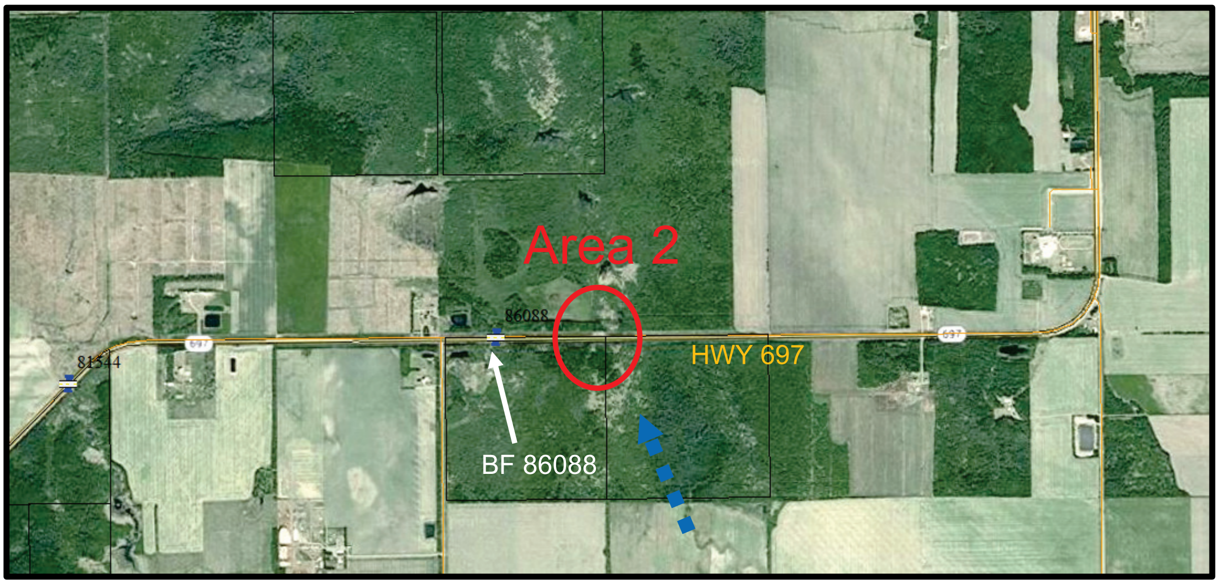


Figure 11-5 Location Map of Highway 697, BF 80600, and a Nearby Flood Area

Bridge File 86088 is located roughly 600 m west of the problem area, consisting of two 1500 mm diameter CSP culverts.

There are centerline culverts under the highway at the flood location which are likely undersized, or prone to icing, and cause back water to the south. Flood water at this location is shared with the Bridge File, however the highway elevation at the flood location is roughly 0.8 m lower than the highway at the Bridge File, and it would flood before the Bridge File is overtopped. See Figure 11-6.

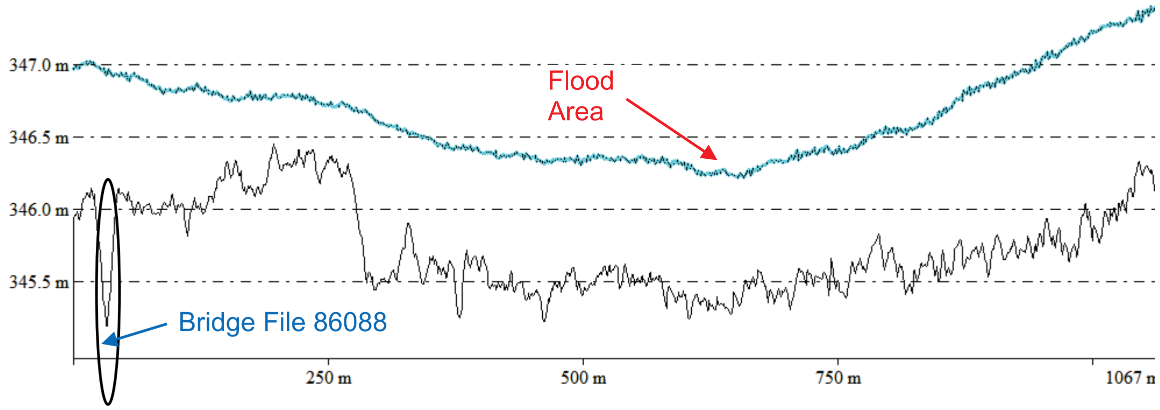


Figure 11-6 Highway 697 Profile (Highway and SOD)

The proposed development to the south will increase flows at this location. Further, the land parcel immediately south of this location was part of the recent land auction and any backwater from the crossing will impact that parcel directly.

Improved downstream drainage would likely ease the flooding at this location, which will be discussed in the following sections of the report.

11.2.3 PROPOSED DEVELOPMENT

The proposed development area within the Teepee Creek basin is primarily divided into two locations in the Buffalo Head Prairie region. Land at the foot of the Buffalo Head Hills, south of TR 1042, has recently been sold, as well as previously undeveloped land in a flat area north, and west of Highway 697.

Clearing and drainage of the land north of the Highway (approximately 18.5 km^2) is expected to significantly increase flows downstream. This area is currently acting as a storage area for a large area of flow originating from the south. Runoff from the Hills is retained in that area which acts to decrease peak flows downstream. Development will remove that storage effect, and will compound the effect by increasing runoff from the cleared land.

Based on results from the model, the increase in flows at the 1:10 year flood could be in the range of 20-30%. This increase will be most evident immediately after the development area and will dissipate further downstream. The model predicts a 25% increase in potential flows at an identified area prone to flooding west of RR 145.

There is no existing network of channels routing flow downstream and a drainage network will invariably be needed when the land is cleared for agriculture. Planning of this network should be completed in advance. If work is completed, new ditches should be integrated with the Steep Hill Creek Drainage.

Development of land south of the highway will impact runoff, but only as a direct result of the clearing. The steeper slope of the land in that area already has a relatively high runoff rate, and clearing will have less impact than in area of flat ground. Further, runoff is divided into small channels and only small areas of development will affect each channel.

11.2.4 STEEP HILL CREEK DRAINAGE DITCH PROPOSAL, AREA 3

The need to reduce flows in general through Teepee Creek has already been identified and the County is looking at the feasibility of a ditch diverting flow from the upper reaches of Teepee Cree to the west, toward Steep Hill creek. The ditch would start at (or near) the highway and TR 1044 and would take water from towards an existing drainage channel, culvert crossing, and outlet into Steep Hill Creek.

Based on the model results, the Steep Hill Creed Ditch could reduce flows at the problem area west of RR 145 by approximately 55%. Further downstream it could reduce flows in Bear River at the tributary to Teepee Creek by roughly 7%. This will depend on the final alignment and size of the channel, however, the benefit would be significant.

The new ditch alignment as proposed by the County is shown as a solid red line in Figure 11-7. Alternative alignments are also shown with corresponding profiles shown in the following figures.

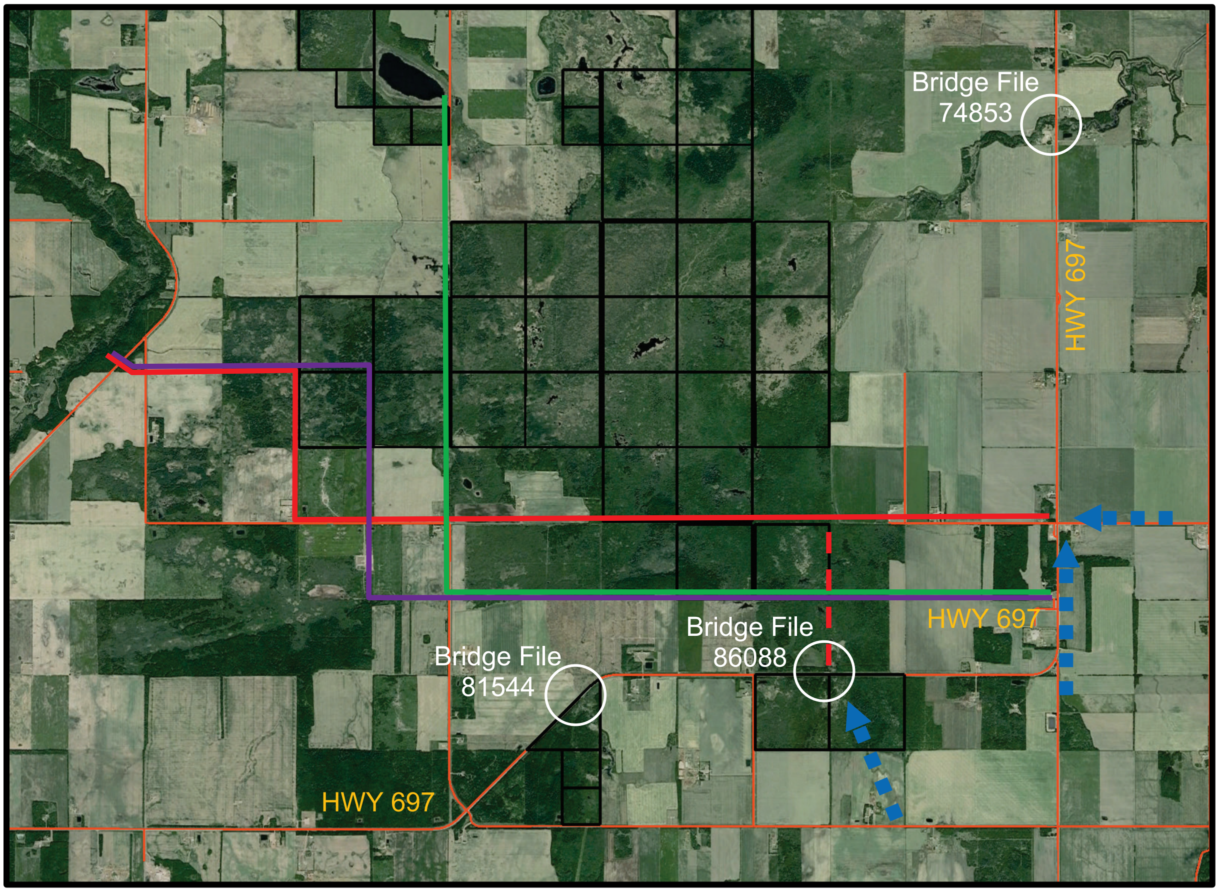


Figure 11-7 Steep Hill Creek Alignment and Options

The alternative alignments above were created to provide optimization to the ditch concept (red, purple, and green lines) as discussed below.

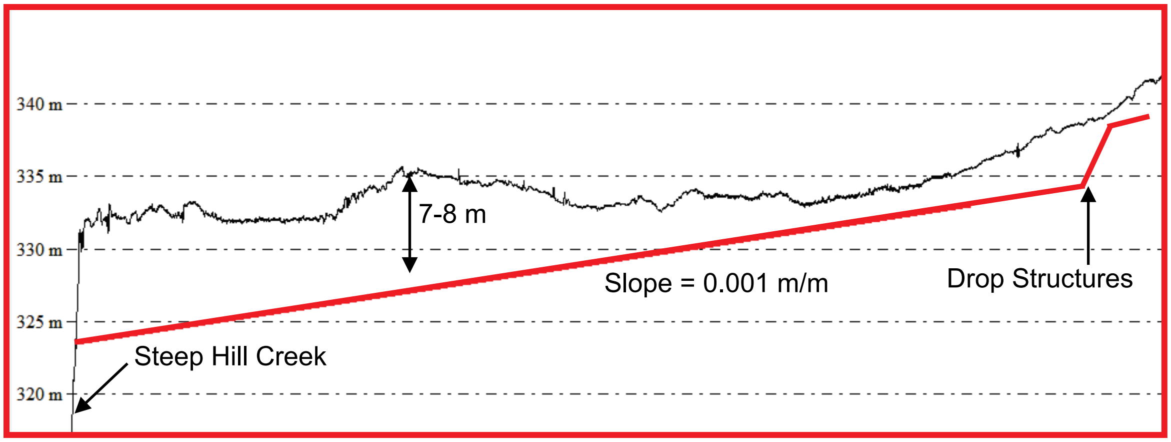


Figure 11-8 Steep Hill Creek Ditch Conceptual Profile (Red, 11 km length)

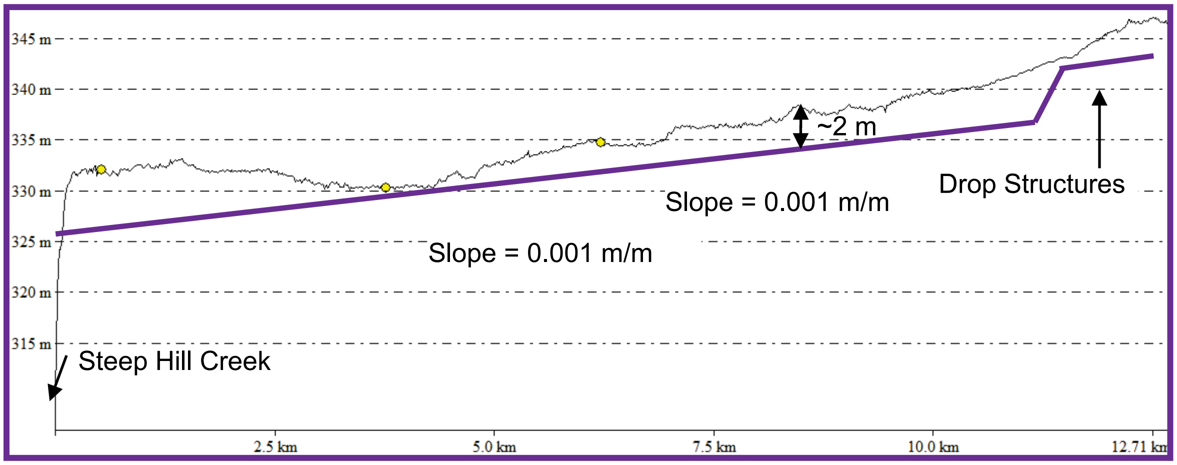


Figure 11-9 Steep Hill Creek Ditch Conceptual Profile (Purple, 13 km length)

The profile of the proposed alignment in Figure 11-8 shows a relatively steep section of land (0.3%) for the first 3 km, followed by a long section which is almost flat. Ideally a drainage ditch would be constructed at a slope of roughly 0.1% (0.001 m/m). This will result in a relatively deep cut (approx. 8 m) required for the downstream half of the ditch. The required excavation for that section could be in excess of 1 million cubic meters.

By moving the start of the ditch to the south, where the ground is slightly higher, and adjusting the bend locations, the slope of the profile can be flattened out (purple option), thus reducing excavation requirements. Although the channel length would be roughly 1 km longer the cost would be significantly reduced.

At the downstream end of the alignment there is an outfall to Step Hill Creek. Figure 11-14 displays the profile down the valley into the creek below. As shown, there is a significant 15% slope over 300 m with an overall drop of roughly 40 m. An outfall at this location would require a significant erosion protection and an energy dissipation structure.

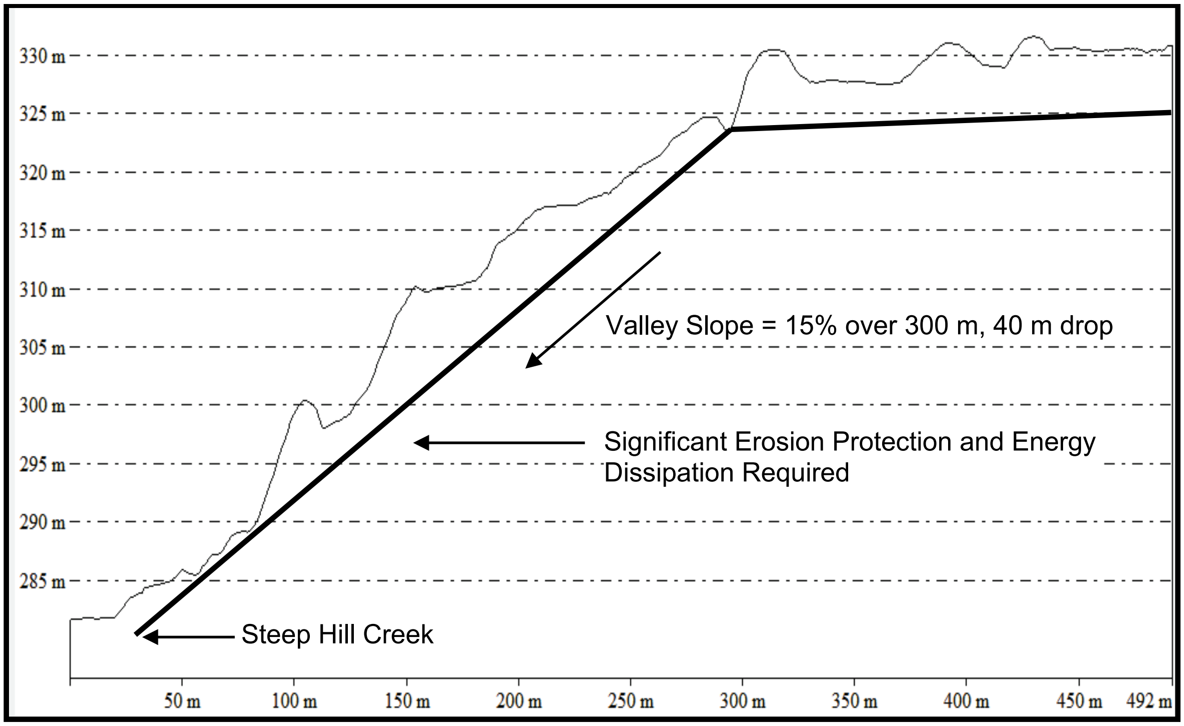


Figure 11-10 Steep Hill Creek Ditch Profile at Steep Hill Creek Valley

A third conceptual alignment was investigated to alleviate the need for an expensive outfall into Steep Hill Creek. By taking the ditch north, flow could be routed to a small lake. There is an existing drainage ditch that leads from the lake to a smaller tributary to the Peace River. That existing ditch would likely need to be upgraded for an additional length of roughly 3 km (not shown in the Figure). The advantage of this option is that existing ground profile follows a grade close to 0.001 m/m, thus reducing excavation requirements, and the need for a large outfall is eliminated. The profile is shown in Figure 11-11.

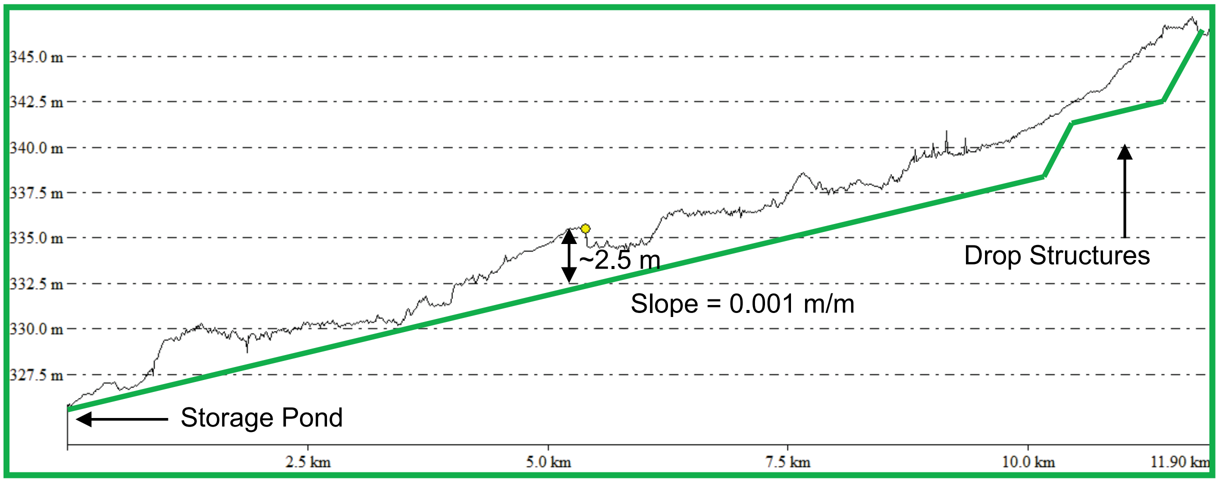


Figure 11-11 North Ditch Conceptual Profile (Green, 12 km length)

A fourth alternative to the ditch would be to move the alignment roughly 3 km south of the Highway. A ditch could take water from that location east to the upper reaches of Steep Hill Creek. There is an existing drainage patch at the headwaters of Steep Hills Creek that could be used as the outlet. The advantage of this alternative is to simplify the outfall. The ditch would be similar in length to the other alignments; however it may require additional drop structures. The primary advantage would be that an outfall structure would not be needed. The main disadvantage is that it would intersect roughly half of the drainage area as the drainage alignments to the north; thus it would be a less effective alternative and was not investigated further.

To address the flooding near the highway at BF 86088, a short ditch line (0.8 - 1.6 km) can be connected from the Highway to the chosen ditch alignment. This is shown in Figure 11-7 as a red dashed line.

Conceptual costs for the ditch work are presented in the 'Priorities and Costs' section of the report. For comparison purposes the green alignment and the purple alignment are shown. It is recommended to investigate the green alignment further and if the downstream portion is feasible, it would likely be the best overall option.

11.2.5 CONCLUSION

Construction of the Steep Hill Drainage project has several critical merits, primarily to decrease existing and future peak flows in Teepee Creek and downstream areas, and both problem areas would benefit from the ditch. A secondary benefit is that the ditch would also serve as part of the drainage management plan for the immediate surrounding area of future development. The concept is feasible and will likely be required in the near future depending on how fast the area is developed. Some additional planning, input from the County, and input from local landowners and regulatory agencies will be required to finalize an alignment. If routing the flow north to the small lake (green alternative) is feasible, it is likely the most economical option.

11.3 UPPER BEAR RIVER (LA CRETE DRAINAGE) – ZONE 2

11.3.1 GENERAL / INTRODUCTION

The Upper Bear River zone is located immediately east of the Teepee Creek zone. The zone includes the headwaters (southern portion) of the Bear River, La Crete Drainage (located on the Bear River), and several associated tributaries.

This area includes a large number of recently sold parcels of land, and also a relatively large area of possible future development (undeveloped white zone). Development has already increased runoff resulting in increased flooding and additional clearing and land drainage will further increase runoff.

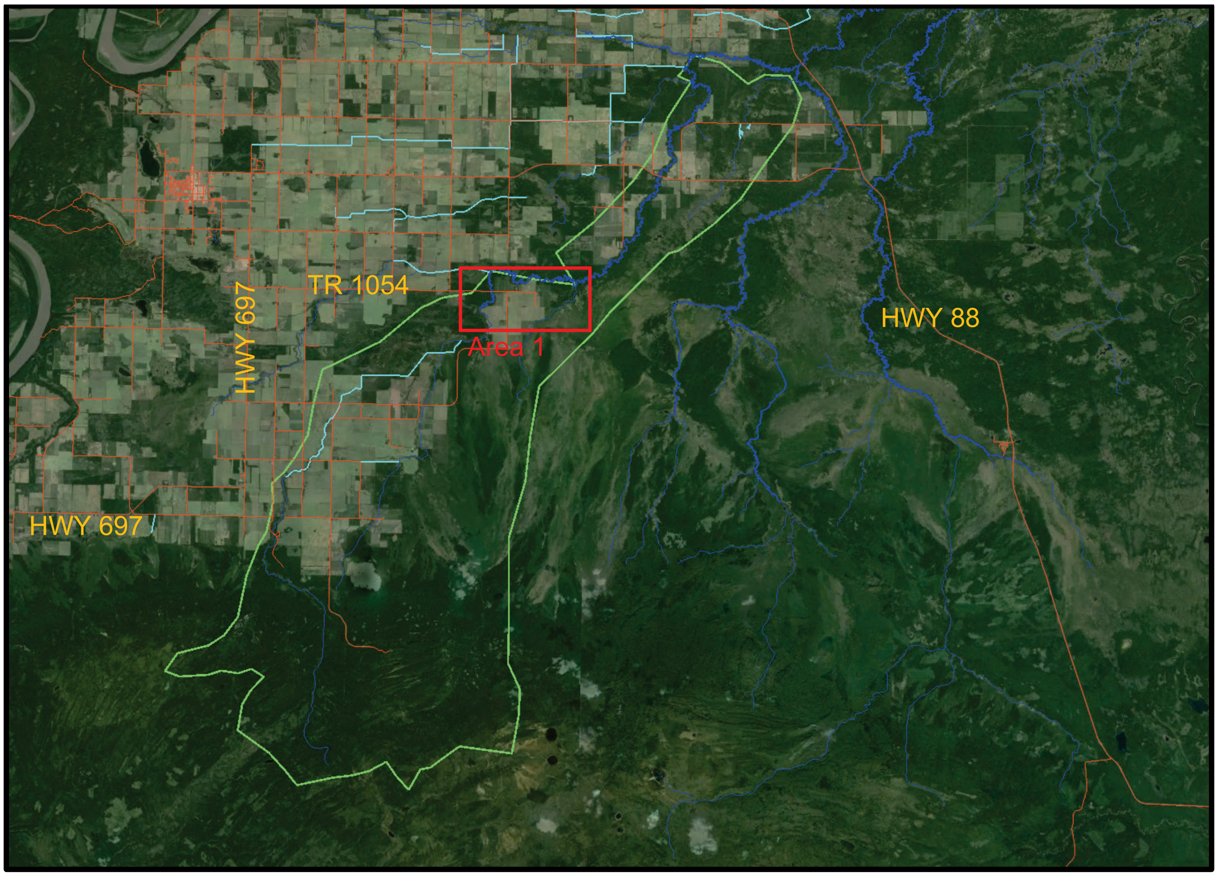


Figure 11-12 Upper Bear River (La Crete Drainage), Zone 2 Limits

11.3.2 PROBLEM AREA – AREA 1

One problem area was identified during the field visit, located at TR 1054 just before the confluence with Teepee Creek. There is a history of flooding here with recent flood waters filling the ditches leaving large amounts of drift at high water. See Figure 11-13 below and photos 35 – 42 in Appendix A for images of the location.

Based on results from the model, an increase in flows to this area can be expected to increase roughly 8% as a result of upstream clearing and development. The primary change resulting in increased flows at this site is the development area near the Hills.

The estimated current flow and future flow and height information at this location is:

- Estimated Flow (Future) – 22 m^3/s (24 m^3/s)
- Estimated Flow Height (Future) – 2.2 m (2.3 m)

Bridge File 81737 is located in the center of the problem area. The crossing structure is a 2 span major bridge with a total length of 24 m. The bridge does not appear to be constructing the channel and is not likely contributing to the flooding issue. Drift on the pier does not appear to an issue; however, large amounts of drift from recently cleared land could have created a log jam and added to the flooding problem.

An overflow ditch has been suggested near the problem area at TR 1054. The ditch would take excess water from the crossing, likely on the north side of the road, and would convey it to the east as shown in Figure 11-13.

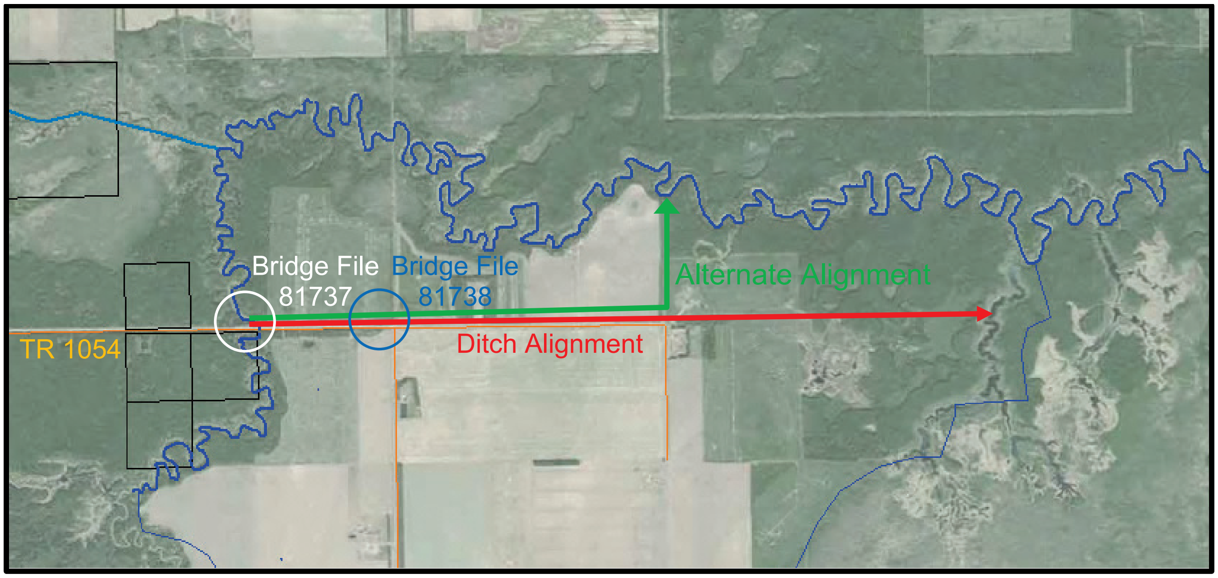


Figure 11-13 Overflow ditch proposed near the problem area at TR 1054

This ditch would bypass the constricted area in Bear River and would take the water to a nearby tributary. The amount of water that the ditch conveys from the area would be determined by the elevation set at the Bear River as displayed in Figure 11-14.

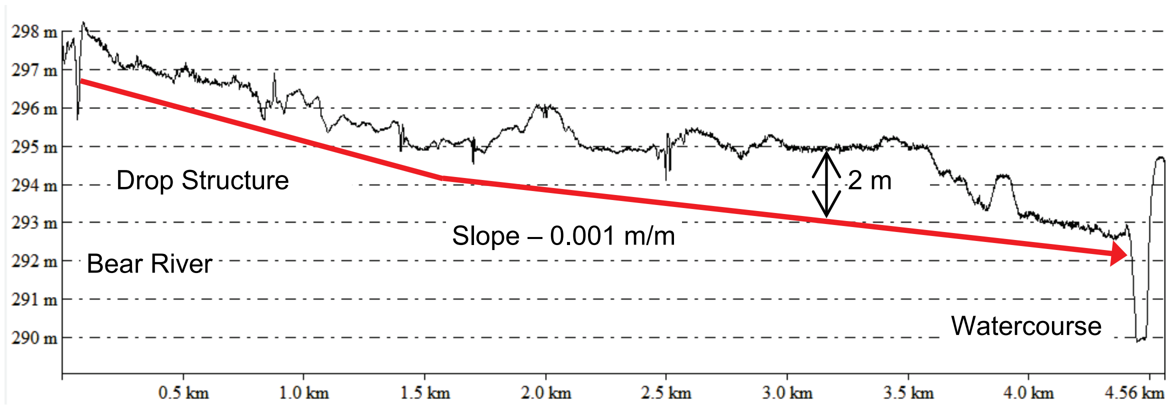


Figure 11-14 Overflow ditch proposed near the problem area at TR105-4 (red alignment)

The ditch would be roughly 4.5 km long. A drop structure may be required in the first section of channel to control velocities, and the remaining channel would follow the original ground line at roughly 0.001 m/m. Depending on the nature of the outlet some erosion protection may also be required.

An alternative alignment is also possible, which is shorter, and can possibly eliminate the need for a drop structure. The profile is shown in the Figure 11-15 below. The length of the ditch is only 2 km long and the grade is very consistent which is optimal for ditch construction. If feasible, this is likely the best option overall.

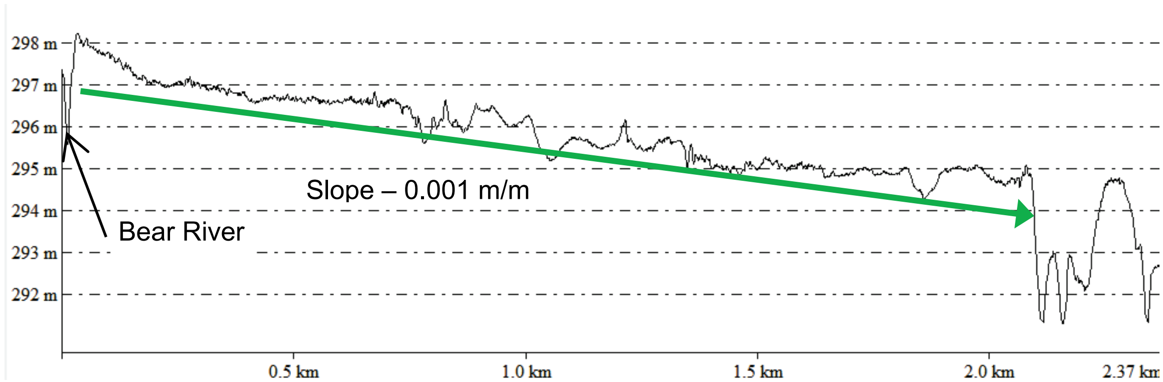


Figure 11-15 Overflow ditch proposed near the problem area at TR105-4 (green alignment)

Alternatives other than an overflow channel are limited in this location. Channelization of the river downstream of the flood area could solve the localized flooding issue; however it would also add to potential flooding problems downstream. It also may not be feasible from a regulatory perspective.

11.3.3 PROPOSED DEVELOPMENT

Areas of land recently auctioned are significant in this zone. The parcels of land are concentrated in three distinct locations as described in the following sections.

11.3.3.1 EAST OF TR 1042

An area of land roughly 23 km^2 is currently being cleared east of TR 1042. The land is at the base of the Buffalo Head Hills and has a north/south slope of about 0.7%. A significant amount of water from a basin roughly 70 km^2 in area currently approaches this area from the hills. That water is routed through this area where there is no large channel, thus the water is temporarily impounded. A drainage network will likely be needed through the area which will further increase downstream flows.

The channel immediately downstream of this location (from TR 1044 to the La Crete Drainage ditch) appears to be adequate to handle the increased flows. The model shows additional capacity available even after the area is fully developed. During the field visit information from a local landowner indicated that the area had never flooded in the vicinity of BF 76506 (TR 1044). Clearing has already been done for much of this area, which could be contributing the recent flooding downstream.

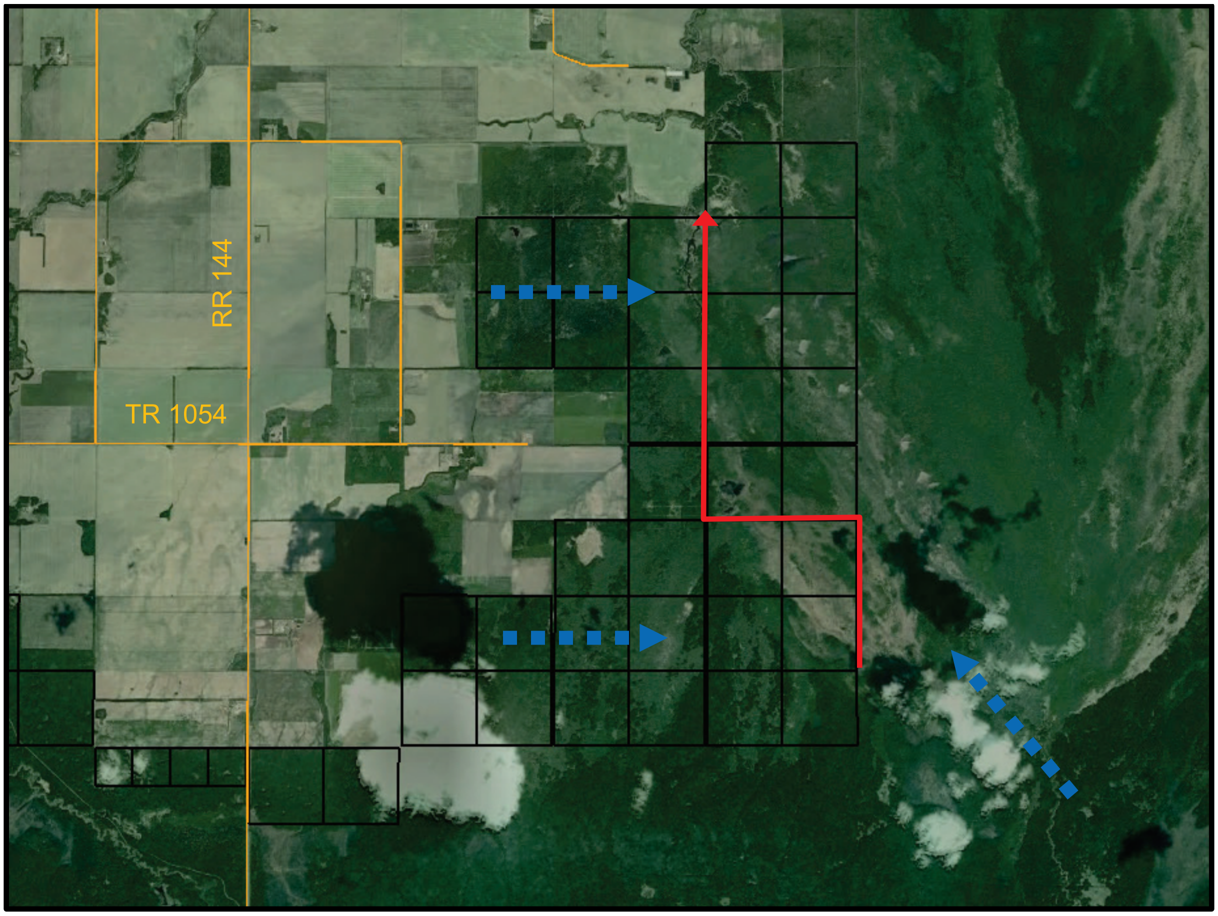


Figure 11-16 Ditch alignment near TR 1042 - Drainage Concept

A profile of the alignment concept is shown in Figure 11-22 below. Due to the natural slope of the land in this area, multiple drop structures may be needed to prevent high flow velocities and erosion.

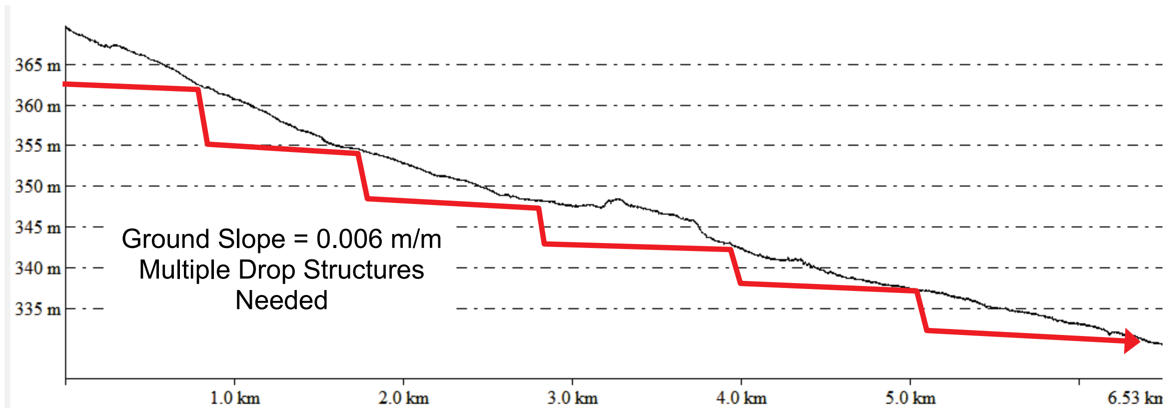


Figure 11-17 Ditch profile near TR 104-2 - Drainage Concept

The alignment was chosen to intercept water approaching the site from the south, to collect water from the neighbouring land, and to end the ditch at a natural watercourse at the north end.

11.3.3.2 SOUTH OF TR 1054, NORTH OF THE BEAR RIVER

An area between TR 1050 and TR 1054, and west of RR 135A includes roughly 20 km^2 of previously undeveloped land. Parcels of land in this location border the Teepee Creek Basin and in some cases may naturally belong in the Teepee Creek drainage basin.

Water in this area naturally drains to the east into Bear River. Being relatively flat, it is expected that drainage ditches will be required to adequately drain the new land being cleared. A possible alignment is shown in Figure 11-19. If the outlet can be placed away from the Bear River, storage would also reduce peak flows downstream.

Most of the water retention capacity of this area was reduced when the Bear River was channelized with the construction of the La Crete Drainage line. Additional clearing of the land was taking progress when the imagery was captured in Figure 11-18. Additional clearing will increase runoff rates, but will not have an additional effect on the storage capacity.

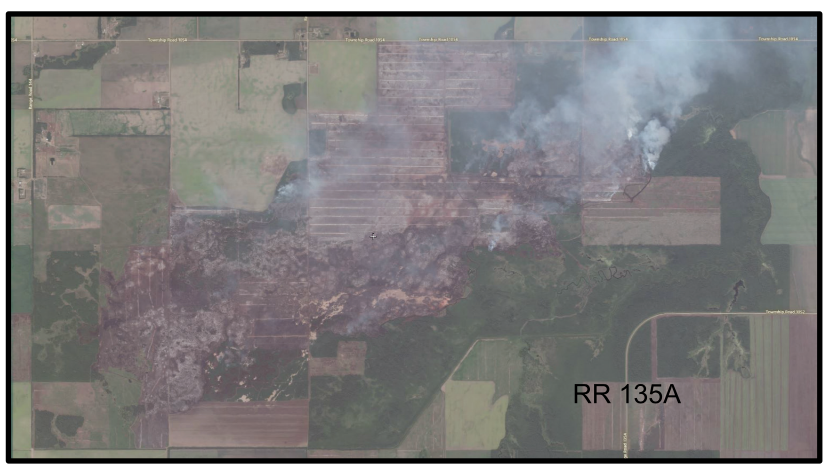


Figure 11-18 Land being actively cleared land North of Bear River

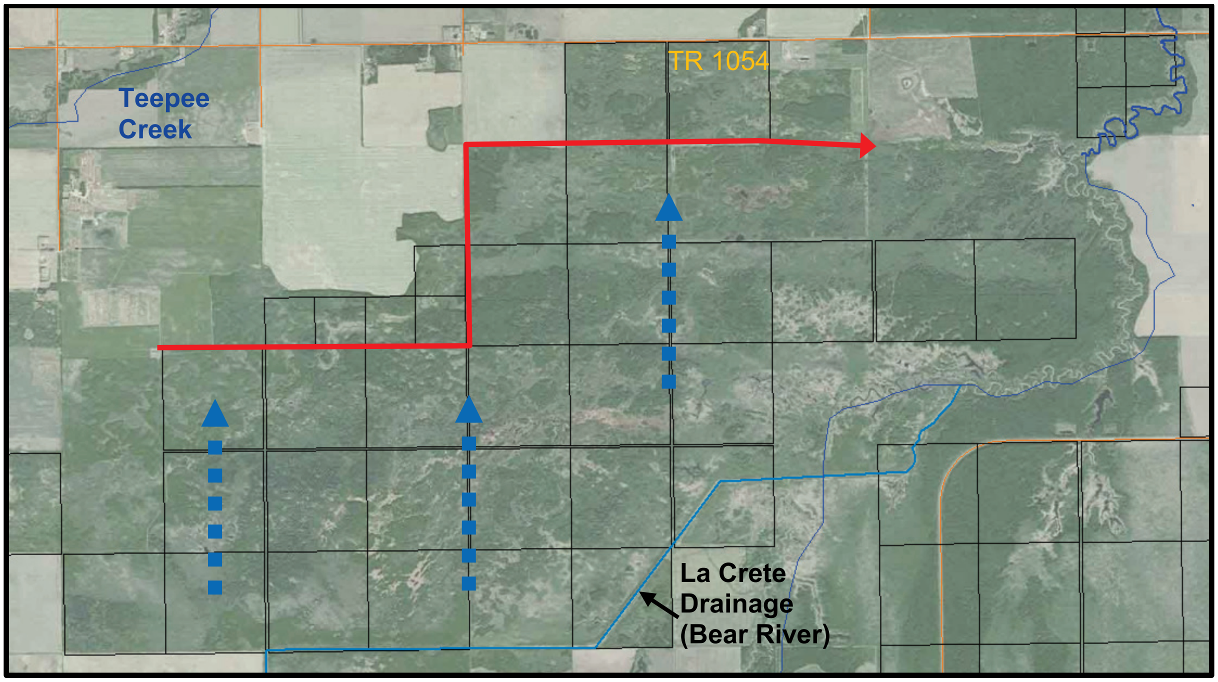


Figure 11-19 Land south of TR 1054 - Drainage Concept

A possible ditch alignment is shown in Figure 11-19 above, which captures water flowing north through the area. The ditch ends at a natural draw entering Bear River. An alternate alignment could bring the water north to Teepee Creek, however, there is a steep section of land there and a 5 m drop to the north which would require drop structures. The associated profile is shown in Figure 11-20 below.

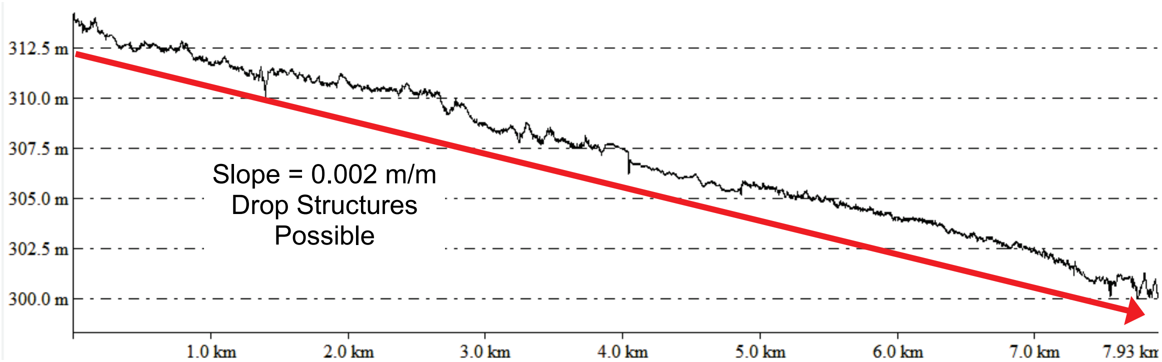


Figure 11-20 Land south of TR 1054 - Drainage Concept Profile

11.3.3.3 SOUTH OF TR 1054, SOUTHEAST OF THE BEAR RIVER

An area between TR 1050 and TR 1054, and east of RR 135A includes roughly 40 km^2 of previously undeveloped land. Parcels of land in this location border the basin for the neighbouring tributary to Bear River to the east.

Much of the land has already been cleared as shown in Figure 11-21.

Figure 11-21 Newly cleared land Southeast of Bear River

Drainage from this area naturally flows south towards a tributary to the Bear River; however its proximity to the neighbouring basin to the east provides an opportunity to drain some water out of the upper Bear River system, which is becoming overwhelmed. There is an existing ditch (Savage Prairie Ditch)at the south end of the project that follows an alignment to the east. Profiles for the two alignments below are shown in Figure 11-23 and Figure 11-24.

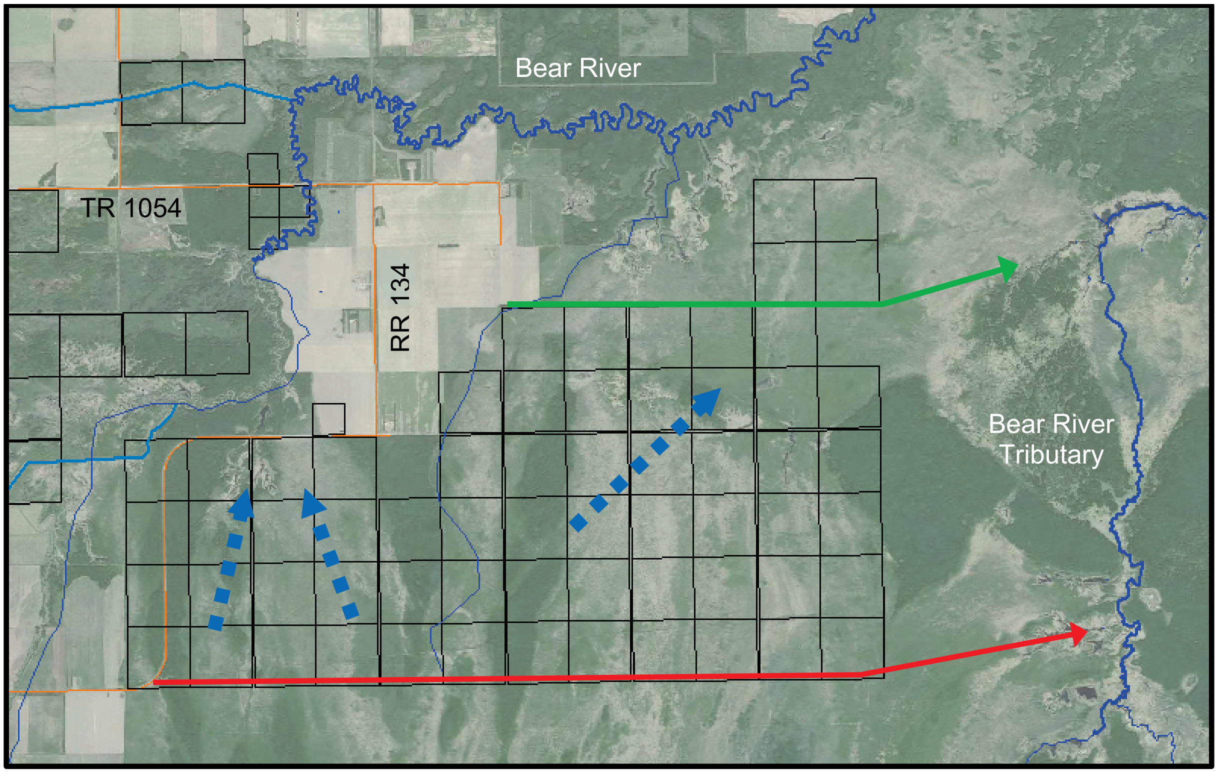


Figure 11-22 Land south of TR 1054 - Drainage Concept

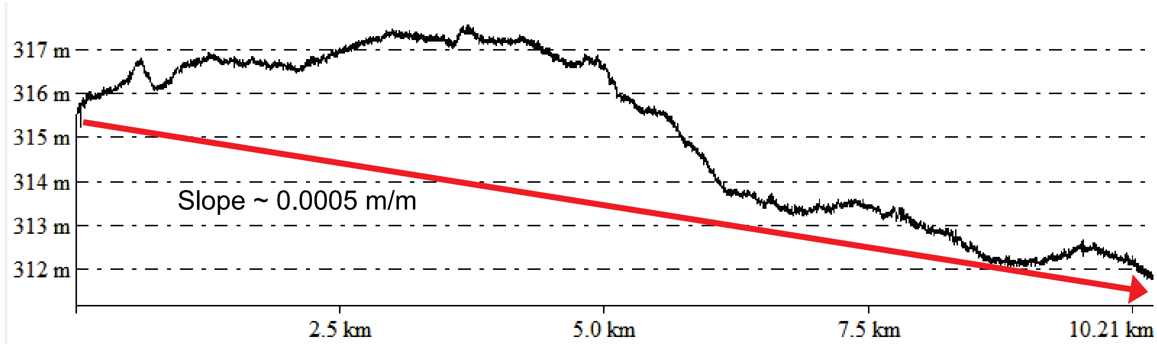


Figure 11-23 Land profile along existing ditch alignment, south of TR 1054

Information about the design and construction of the existing ditch is unknown, however, based on the profile above, it is not in an optimal location. The overall slope of the ground in that location is very flat, at 0.05% and there is a steep section of 0.2% in the center. The ditch should be assessed for scour risk and efficiency and rehabilitation may be required. The ditch should be adequate to handle a flow of roughly 4 m^3/s.

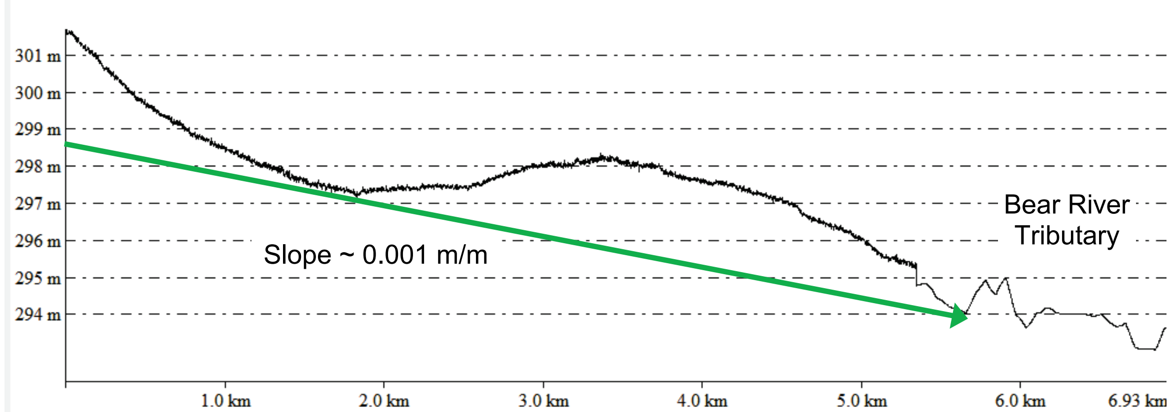


Figure 11-24 Land south of TR 1054 - Drainage Concept Profile

A separate ditch alignment is also shown in green. This ditch could be used in addition to the existing ditch to accommodate runoff from the cleared land. It could also be used to handle excess water from upstream.

11.3.4 CONCLUSIONS

There are large areas of clearing and development in this area, and there is more development possible in the future. In general, draining water east away from Teepee Creek and the Bear River is the recommended solution if possible. Concepts for several drainage options for newly developed areas are proposed which should reduce flooding in those areas and limit increased runoff downstream.

11.4 WILSON PRAIRIE – ZONE 3 AND LA CRETE EAST – ZONE 4

11.4.1 GENERAL / INTRODUCTION

Wilson Prairie Drainage and the La Crete East Drainage Ditch (Main Line) start east of La Crete and carry water west towards Bear River. A long history of flooding issues in this area has resulted in an existing complex drainage network consisting of the AJA Friesen Ditch and La Crete East Lines 1 through 5. The La Crete East ditch also includes a constructed flood water retention area in the vicinity of Line 1. Figure 11-25 displays the location of the flow network.

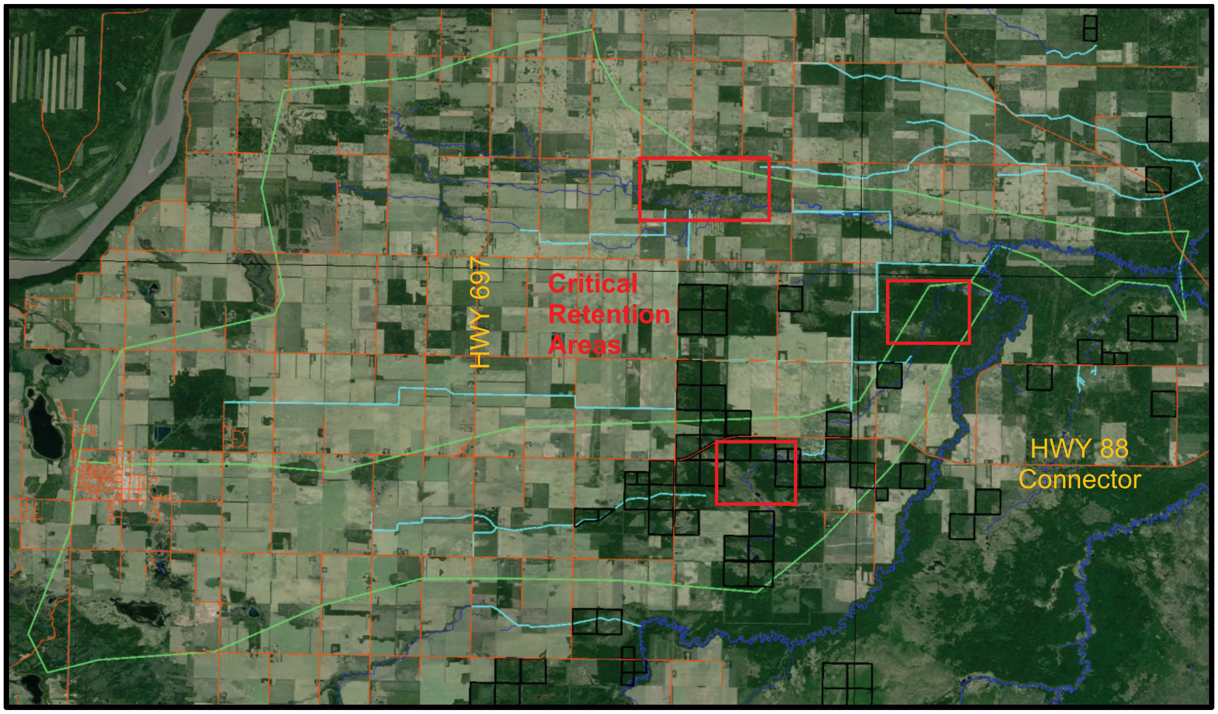


Figure 11-25 Wilson Prairie Drainage (Zone 3) and the La Crete East Drainage Ditch (Main Line, Zone 4) Flow Network Drainage adequacy / Problem Areas

11.4.2 DRAINAGE ADEQUACY / PROBLEM AREAS

No current problem areas were reported by the County for additional attention in this area. The AJA Friesen Project was completed in 2011 and is the most recent significant drainage project in the County. It was constructed to relieve flooding from the downstream sections of the La Crete East Lines 3 and 5.

Based on model results the primary channels and ditches in this area appear to be adequate with the exception of the flood retention areas which are undersized by necessity. Flood retention areas are discussed further below.

It is noted previously that there are flood issues east of Highway 697 in the vicinity of TR 1064 and TR 1070. Water backs up against the Range Roads and can overtop the road in some cases. Flow naturally flows to the north in this area to La Crete East Line 2. Based on the hydrology and model results the capacity of that ditch should be adequate for typical flows. Localized drainage issues may be the issue including undersized or icing in culverts, or downstream blocks to flow. This type of localised drainage issue would require a more detailed analysis including a culvert assessment.

11.4.3 FLOOD RETENTION AREAS

There is a critical storage area consisting of six quarter sections located roughly 1 km south of TR 1072. La Crete Drainage Line 2 is located at the outlet of the storage area which drains water to the east. Two natural tributaries contribute to the area from the east while Lines 2 and 3 contribute from the south. The flow peak through that area is dampened from roughly 19 m^3/s to 10 m^3/s as it enters the Bear River downstream.

A flood retention area is also located at the end of Wilson Prairie Drainage. This area significantly decreases the downstream peak flow into the Bear River.

All existing flood retention areas should be protected from further clearing. If additional clearing is planned, impacts downstream should be reassessed.

11.4.4 FUTURE DEVELOPMENT

The majority of land within this zone has been previously developed. Approaching the Bear River there are 34 quarter sections of land that have recently been sold. Unlike other areas of the study the parcels of land are not in a large block, but are spaced out between existing private and crown land. In general the auction land is in the vicinity of the Highway 88 Connector Road.

Many of the new land parcels have already been cleared.

Based on results from the model, development will increase flows as follows:

- Downstream of Wilson Prairie Drainage – 20%. This number is variable depending on how clearing will affect the retention capabilities at the end of the Wilson Prairie Line. This is a conservative estimate

- Downstream of AJA Friesen Drainage – Negligible

- La Crete East Line 1 – 5%

11.4.5 SOLUTIONS

Additional drainage ditches are not required within this area. Ditch maintenance in the form of clearing and silt removal will be required to maintain the extensive ditch network.

Drainage ditches in this area are relatively clear of vegetation. One location was noted at La Crete East Line 3 where there is a short section of ditch with trees immediately to the south side of the channel west of RR 140. Dense brush and trees on the south side of the ditch could limit snow and ice melt there and promote flooding upstream.

Preservation of the storage areas at the end of each ditch is necessary to avoid significant increases in downstream flows.

11.5 BEAR RIVER NORTH – ZONE 5

11.5.1 GENERAL / INTRODUCTION

The Bear River North drainage zone starts south of Fort Vermillion and carries water east towards Bear River. This zone includes the Fort Vermillion South drainage, Bear River North – Lines 1 through 5, and an unnamed drainage channel. The limits of Zone 5 are shown in Figure 11-26.

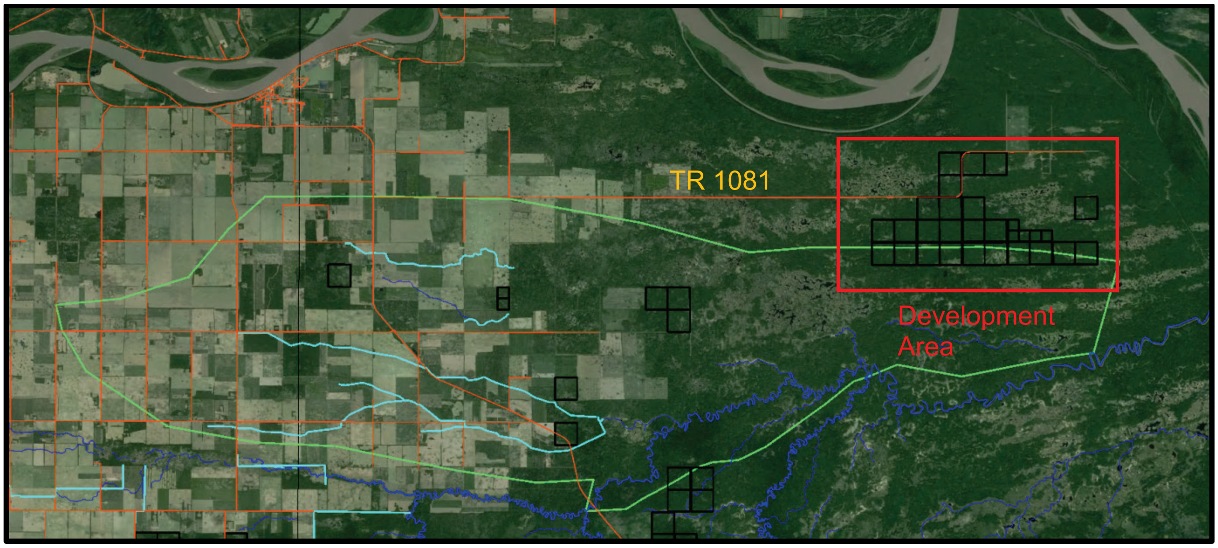


Figure 11-26 Bear River North (Zone 5) Limits and Drainage Network

There were no current problem areas reported by the County and the current drainage network appears to be functioning adequately. Based on results from the model the drainage ditches here are likely operating at capacity, but are not undersized. Flooding is expected to occur in channels through undeveloped flat area near the Bear River. The watercourse at the end of Bear River North Drainage is relatively undefined and acts as a small storage area before flowing in to the Bear River.

It was noted during the site visit that there some clearing is required for the Bear River drainage lines to prevent icing and to maintain drainage efficiency.

11.5.2 FUTURE DEVELOPMENT

The west third of the land within this zone has been previously developed. There are approximately 35 quarter sections of land that have recently been sold, including a group of sections in the extreme northeast corner of the area (at the end of TR 1081) which is shown in further detail in Figure 11-27. The few parcels of land in the center of the zone spread out and are not significant to drainage concerns.

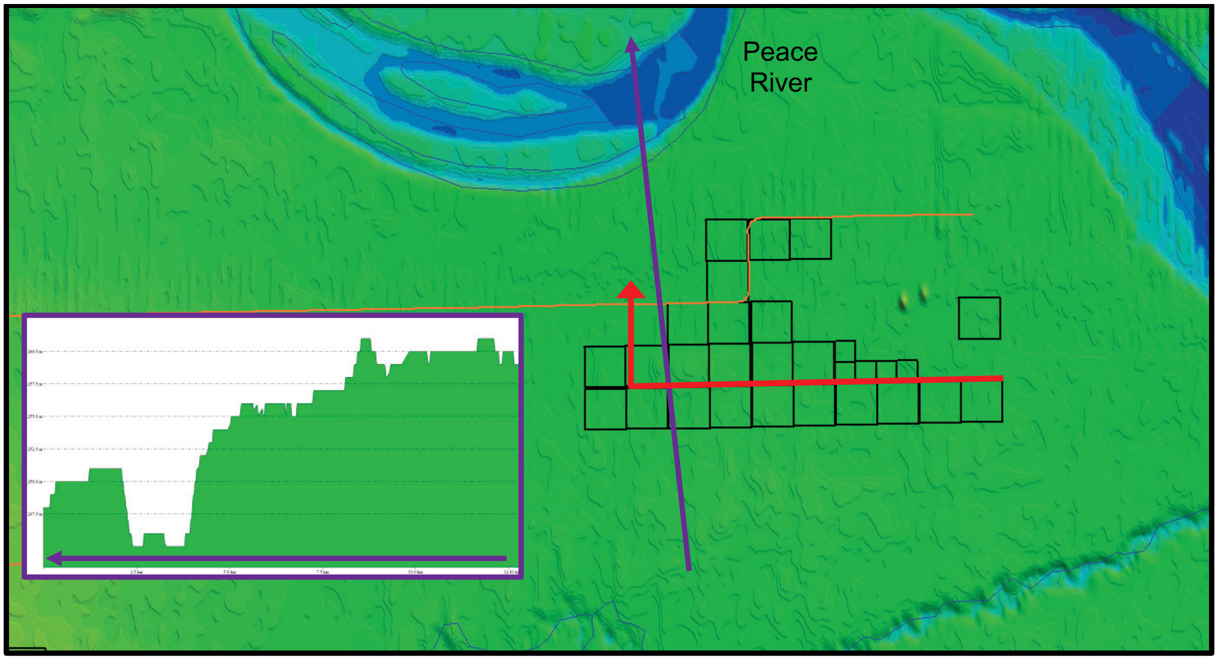


Figure 11-27 Section of Parcels to the north in Zone 5

Land in the vicinity of the parcels shown above is relatively flat and drainage will be problematic. In this area water is naturally retained in depressions and does not readily flow as can be seen in the aerial photography in Figure 11-29. The location is situated at the top of a very shallow rise in the topography and upstream drainage will not be an issue, however, local drainage may be slow.

Drainage for the area is likely possible to the northwest, where there is a small depression that leads to the Peace River. Figure 11-27 shows DEM data with 1 m contours including a cross section through the lower area. The local low area is also shown in Figure 11-29 which shows a possible ditch alignment with the corresponding profile in Figure 11-28. The ditch would have a flatter slope and would not be efficient at conveying excess water from the area.

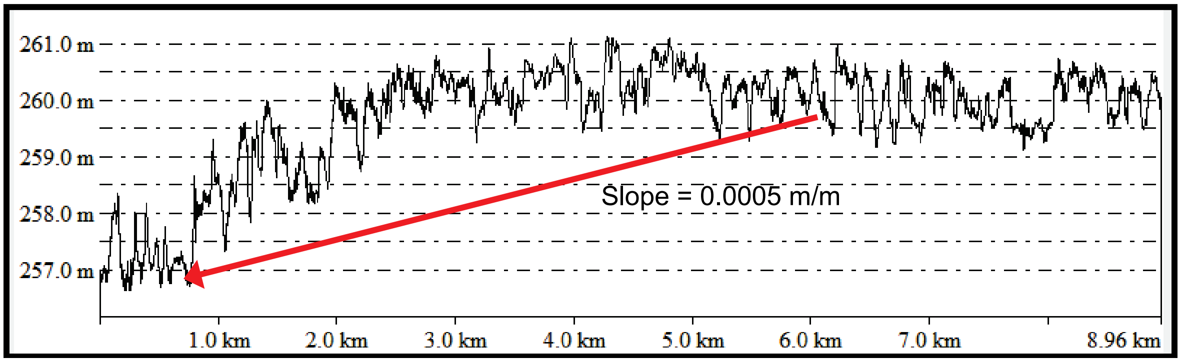


Figure 11-28 Low area and low efficiency ditch profile concept shown in Zone 5

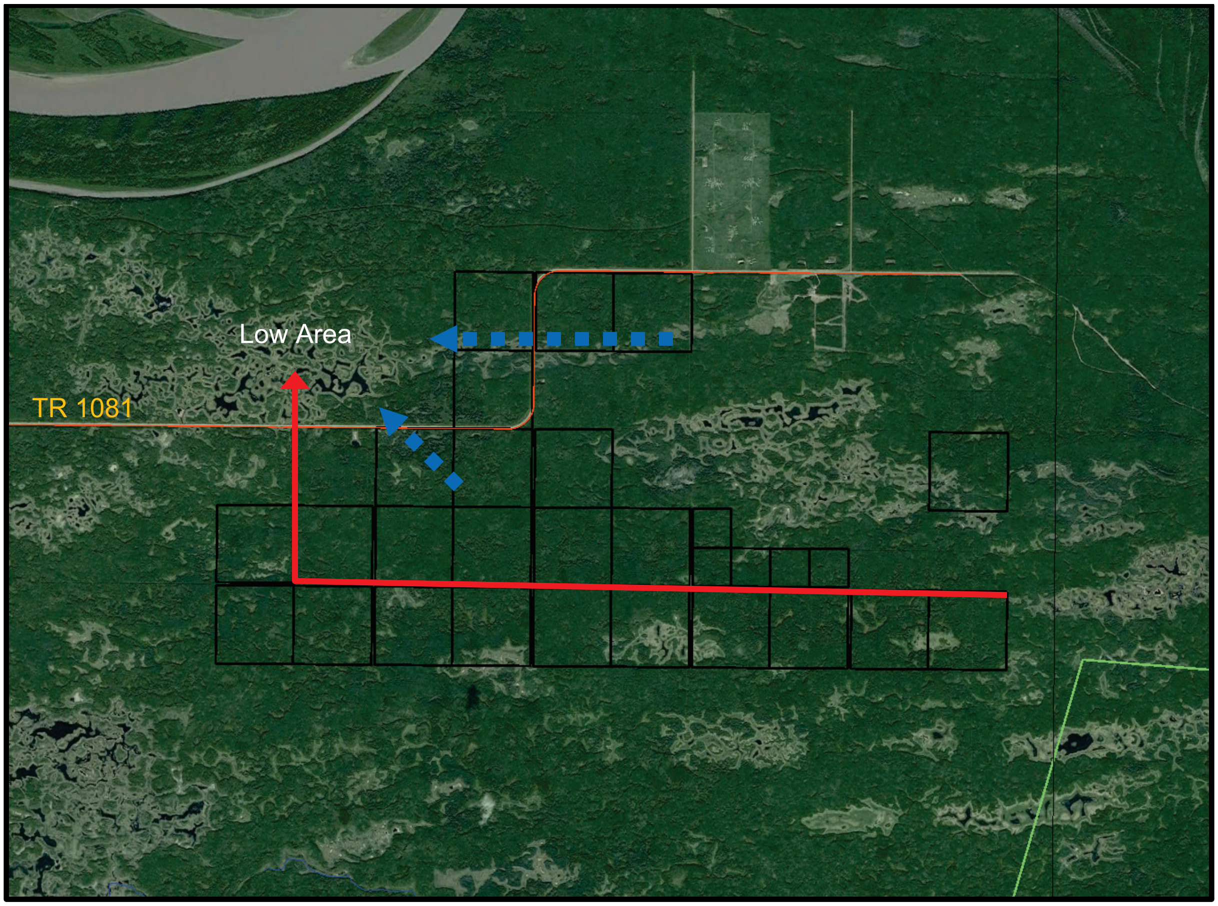


Figure 11-29 Low area and low efficiency ditch concept shown in Zone 5

Although not anticipated to be required, if additional drainage capacity is needed a ditch would need to lead to either the Peace River to the north, or the Bear River to the south. This would be relatively costly and should only be considered if there are significant drainage issues.

It should be noted that there is a large area of land in the center of this zone that is undeveloped and is within the AESRD White Zone. Therefore there is a possibility of extensive development in this area. Drainage for the undeveloped land generally flows east at a grade of roughly 0.1%. Drainage within the area would need to consider upstream drainage as well as local drainage, which would flow into a natural draw leading to the Bear River.

11.5.3 CONCLUSIONS

The existing ditch network requires some clearing but is otherwise performing adequately. Future development within the White Zone should be drained to the east. Current development at the end of TR 1081 is in a very flat area and water should be drained as much as possible to the northwest. If this alternative is not adequate, water from these land parcels could be ditched to flow into either the Peace River or Bear River drainage basin.

11.6 JACKPINE CREEK – ZONE 6

11.6.1 GENERAL / INTRODUCTION

Jackpine Creek drainage zone starts from the Buffalo Head Hills and carries water northeast towards Bear River. The overall Bear River drainage area is separated two distinct zones, with the Jackpine Creek Zone taking up the southeast half of the basin. This zone does not include any drainage ditches; however, it does include Highway 88, a few bridges, and a WSG Gauge.

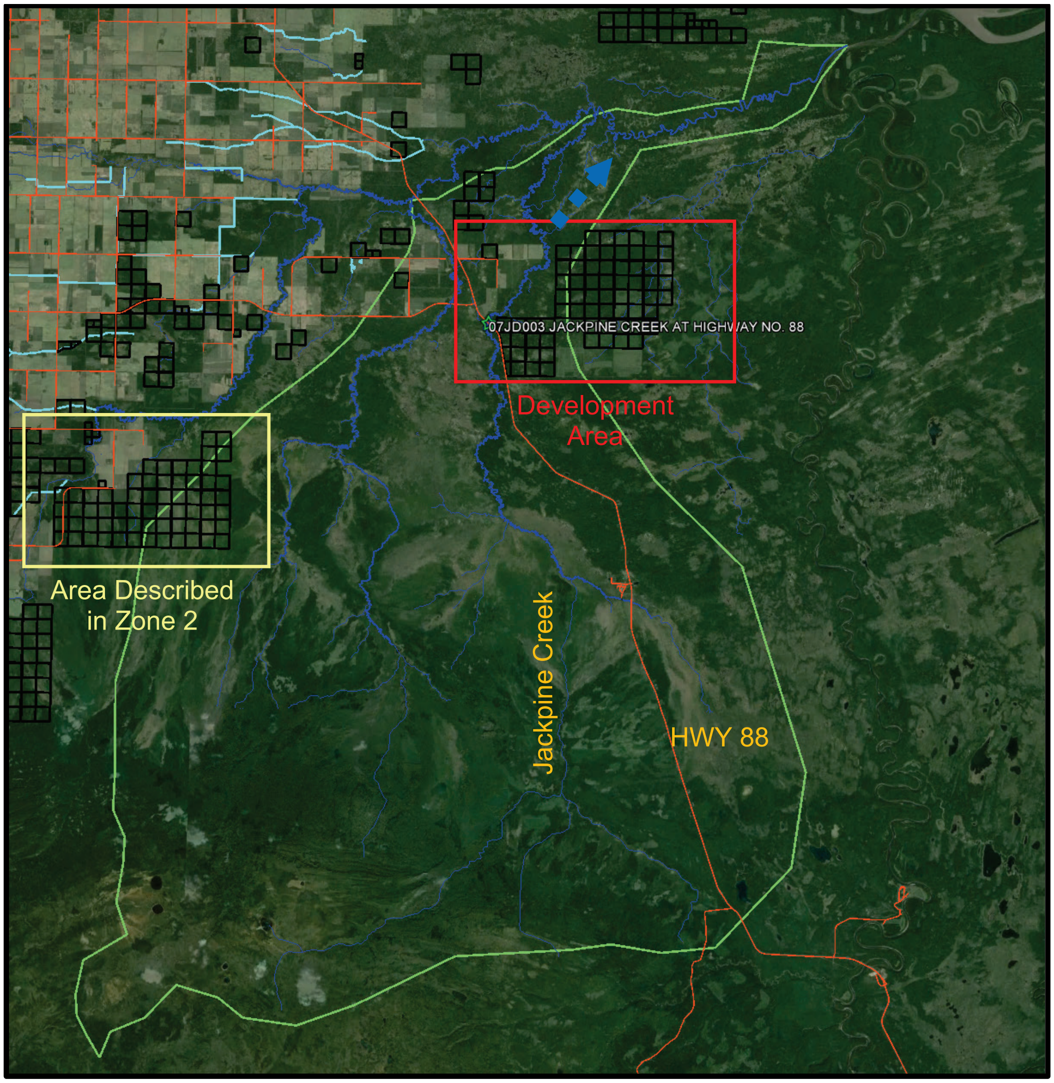


Figure 11-30 Jackpine Creek – Zone 6 Overall View

11.6.2 DISCUSSION

Being relatively undeveloped, there is no existing drainage improvements in this area and no problems were reported by the County for additional attention.

The WSG Gauge information shows that rainfall is the dominant form of flooding in this zone. The other zones in the Bear River basin have historical information that indicates snow melt events are the dominant form of flood events.

11.6.3 PROPOSED DEVELOPMENT

There are roughly 70 quarter sections of land that have recently been sold east of Highway 88 in this zone. The parcels are currently being cleared for development. The area is shown in Figure 11-31 with cross section profiles for these parcels shown in Figure 11-32.

Based on the cross sections, drainage for these areas will be relatively simple, following the natural drainage patterns to the northwest and northeast. The slope of the ground in this area is roughly 0.2 to 0.4% towards the north.

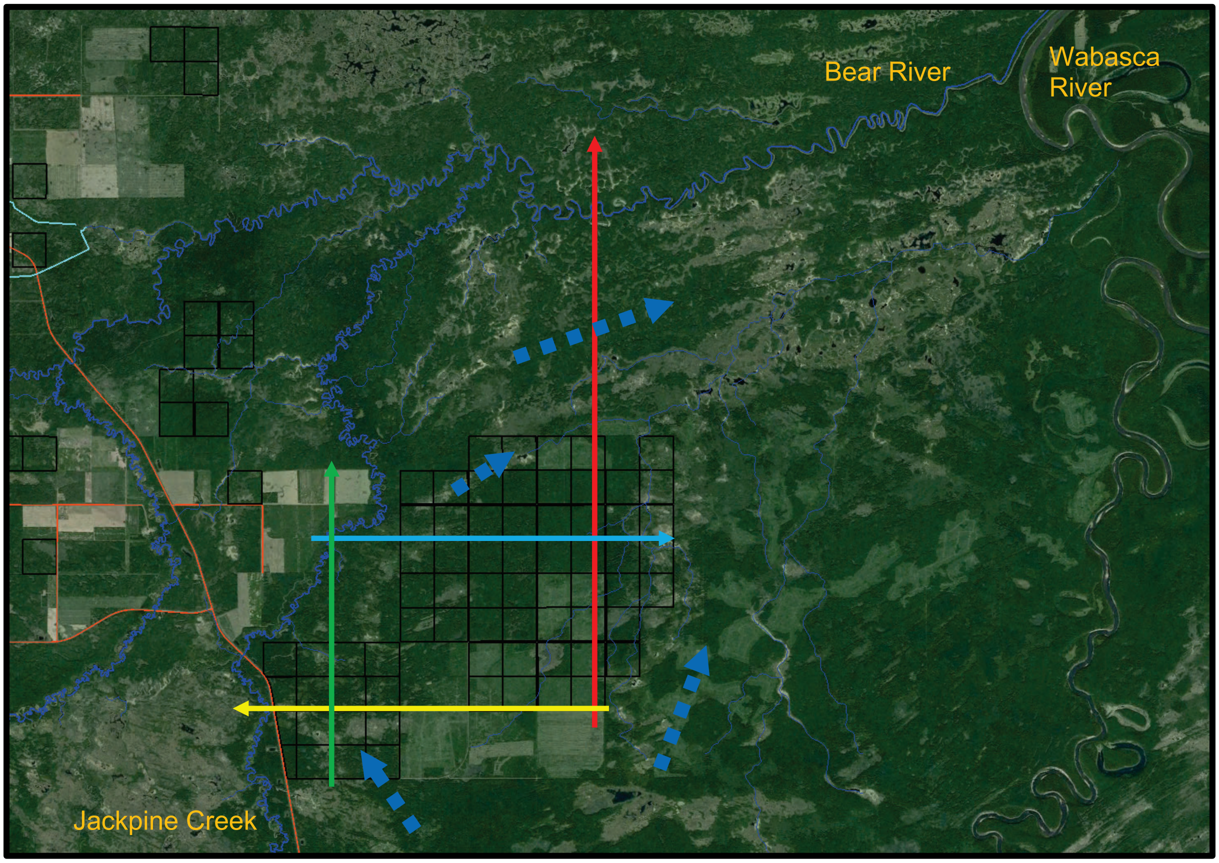


Figure 11-31 Section of Parcels to the north in Zone 6

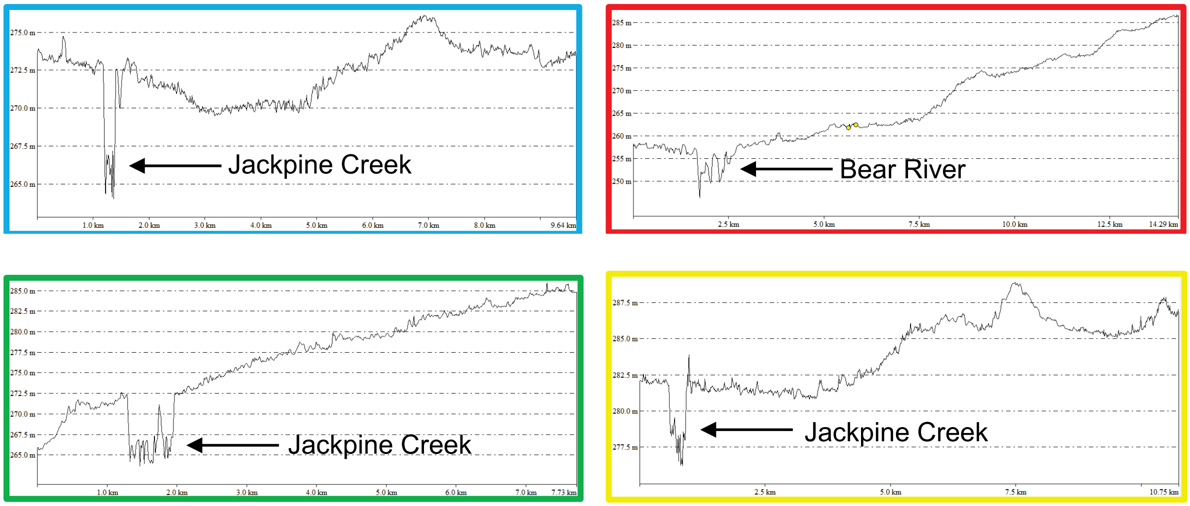


Figure 11-32 Profiles for the Section of Parcels to the north in Zone 6

Flooding in the east portion of the area may become problematic and a ditch may be required to convey upstream water through the developed sections. Flow from the remaining area can flow to the north and into an existing draw that takes flow to the east.

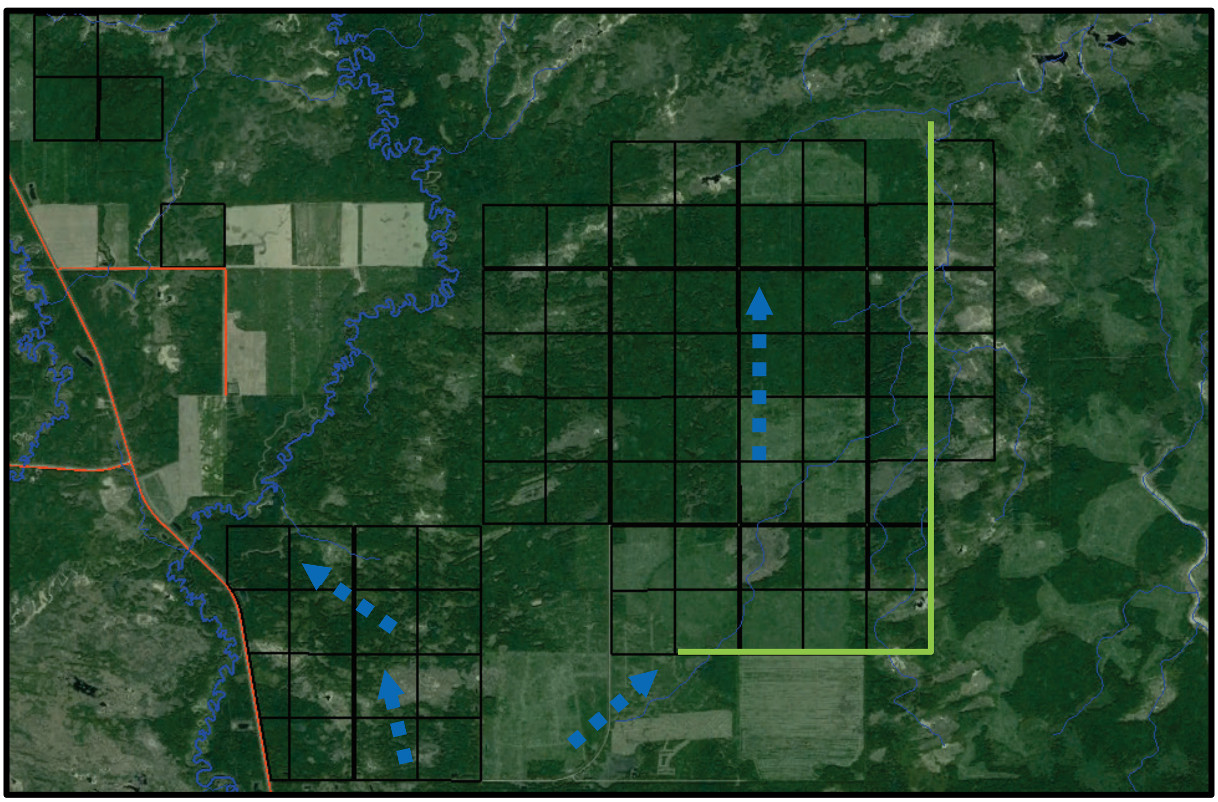


Figure 11-33 Watercourse in Parcel Map Area in Zone 5

A ditch that flows north is estimated to require 5-10 m of drop structures over a 10 km long ditch. The profile for a potential ditch is shown in Figure 11-34.

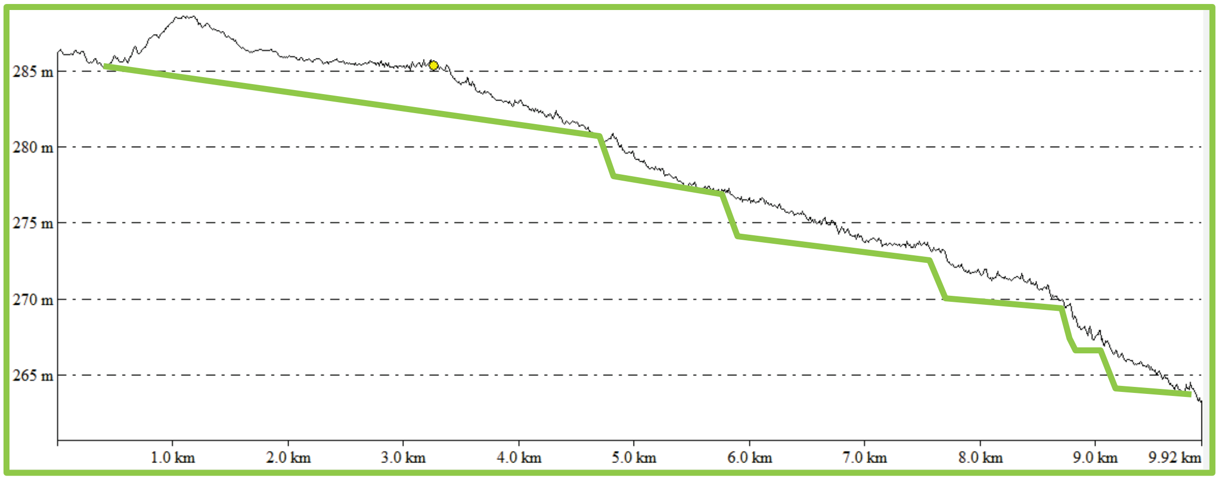


Figure 11-34 Potential ditch line in Zone 6

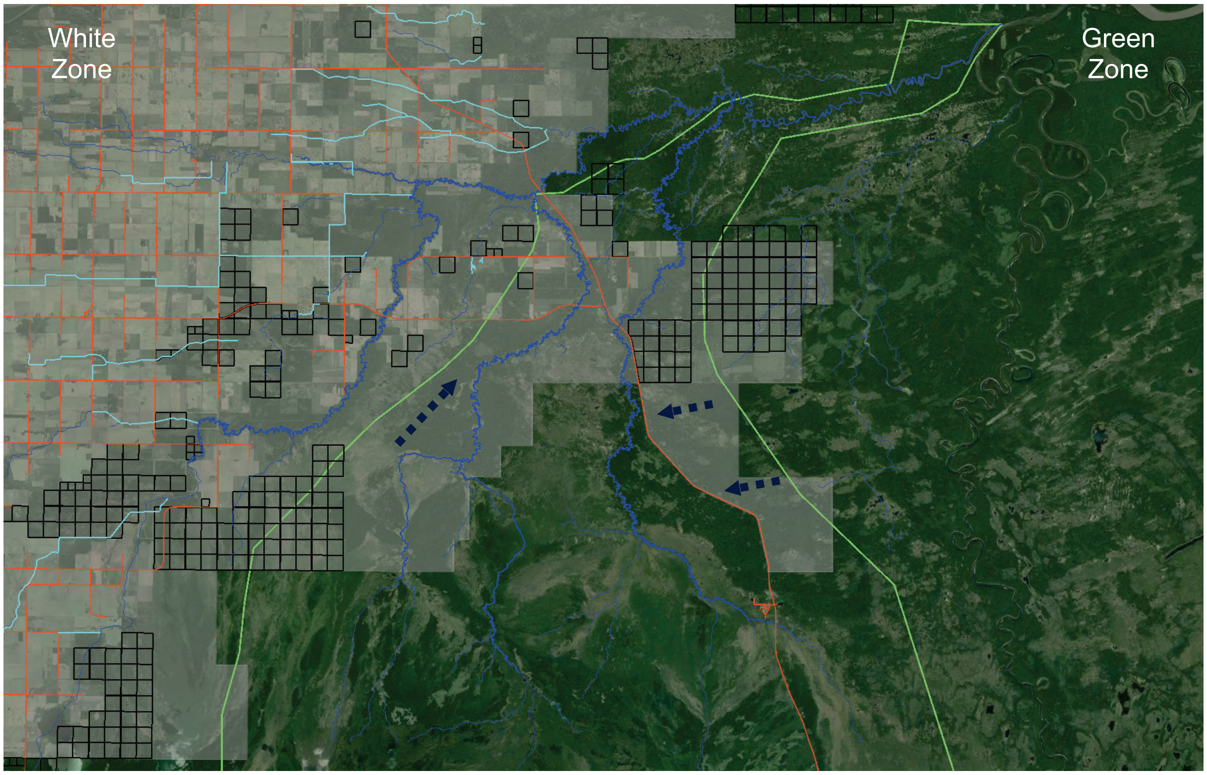


Figure 11-35 Green and White Zone Area – Potential Future Development

11.6.4 FUTURE DEVELOPMENT

In addition to the parcels of land that are currently being developed, there is a large area of undeveloped land that is currently within the AESRD White Zone, shown in Figure 11-35.

Development along the Bear River Tributary and Jackpine Creek will increase runoff, however those watercourses are well sized and downstream flooding is not considered to be a concern at this time. Significant developments should consider the downstream flows.

11.6.5 CONCLUSIONS

The Jackpine zone is relatively undeveloped however, there is development encroaching from the east and west. In addition, a potential option for the Upper Bear River (Zone 2) may have water diverted into this zone. The basin area is vast and it capacity for additional runoff is also large.

Drainage for the new auction land the north is naturally flowing from south to north and any local drainage improvements there will need to follow that pattern. A ditch with drop structures may be needed along the east portion of the area if drainage becomes a problem.

12 PRIORITIES AND COSTS

12.1 PROJECT PRIORITIES AND PLANNING

The work on the Steep Hill Creek Drainage Ditch and the TR 1054 Flood Area are the highest priority projects as they address existing flood issues that have been previously identified. The Steep Hill Creek Drainage could then be considered to be the highest priority as it has the potential of benefiting many landowners in the local area and downstream.

Priorities for drainage improvement projects through areas that are currently being cleared cannot be determined with certainty at this time. The urgency for each project will depend on rate of development, observed flooding, and landowner input. In terms of flood risk, the development at the end of TR 1081 is expected to result in flooding issues and that area may take earlier priority over the others. An assessment of the Savage Prairie Ditch should also be done relatively soon so that potential flood and erosion risks can be addressed accordingly.

It should be noted that other problem areas may be revealed in future years. Priorities for future work identified will need to be assessed accordingly.

12.2 DRAINAGE INFRASTRUCTURE - CONCEPTUAL COSTS

Conceptual costs have been estimated for conceptual drainage work for each Zone within the study area as proposed in the Analysis and Options section of the report. The estimates are based on results from previous similar projects, Alberta Transportation published prices, and experience.

Table 12-1 lists conceptual unit price costs for common drainage work. The costs are meant for rough budgeting and prioritization purposes only. Prior to proceeding with a project, a specific engineering design should be completed which will determine accurate project details and costs.

Table 12-1 Conceptual Unit Price Costs for Common Drainage Work

ACTIVITY	UNITS	ESTIMATED UNIT COST ($)
Ditch Construction / Major Rehabilitation	Km	$75,000
Ditch Rehabilitation	Km	$30,000
Gabion Drop Structure	Per meter drop	$40,000

Ditch construction costs are general averages that include clearing, excavation, culverts, general sediment and erosion control, topsoil, seeding, and other typical ditch construction requirements.

The unit prices have been applied to the work recommended for each problem area as shown in Table 12-2.

Table 12-2 Conceptual Costs for Conceptual Drainage Work

WORK	DITCH LENGTH (KM)	DROP STRUCTURES (M)	OTHER	COST
Teepee Creek – Zone 1				
Steep Hill Creek Drainage (Option 1 - Green Alignment)	16	4		$1.3 M
Steep Hill Creek Drainage (Option 2 - Purple Alignment)	14	3	*40 m Outfall Structure* *$500,000*	$1.6 M
Upper Bear River – Zone 2				
TR 1054 Flood Area	2	0	*5 m Outfall Structure* $50,000	$0.2 M
East of TR 1042	6.5	20		$0.9 M
South of TR 1054, West of Bear River	8	4		$0.7 M
South of TR 1054, East of Bear River	6	0		$0.5 M
Savage Prairie Ditch Assessment	10	0	Engineering $20,000	$20,000
Bear River North – Zone 5				
TR 1081	6	0		$0.5 M
Jackpine Creek – Zone 6				
East of Hwy 88	10	10		$1.0 M

Note – There is no ditch construction work proposed for Wilson Prairie / La Crete East – Zone 3/4

Refer to the Analysis and Options section for details on the Zones and specific locations for each ditch concept.

12.3 DRAINAGE INFRASTRUCTURE – MAINTENANCE COSTS

Maintenance of existing drainage infrastructure as described in the Flood Mitigation Methods - Maintenance section of the report, should be budgeted each year. Inspection, clearing brush, and occasionally clearing silt is required. A high level estimate of the annual cost to maintain a ditch is roughly $200 to $300 per kilometer of ditch per year. The County currently has roughly 140 km of ditches in its inventory.

13 ENVIRONMENTAL CONSIDERATIONS

The agencies that regulate most common aspects of drainage work are listed below. Depending on the work being completed, other permits and approvals may be needed.

13.1 ALBERTA ENVIRONMENT AND SUSTAINABLE RESOURCE DEVELOPMENT (AESRD)

The Water Act, enforced by Alberta Environment and Sustainable Resource Development (AESRD), requires that an Approval be obtained before conducting any activity within a watercourse. The definition of an activity in the Act is broad and can include any work done to a ditch. In general, any major ditch construction or maintenance will require an Approval, whereas minor maintenance work done on small ditches may not require an Approval. Maintenance and minor upgrades done within licensed ditches do not require a separate approval under the Water Act. Discussion with AESRD is recommended for projects where the need for an Approval is not clear.

The “Code of Practice for Watercourse Crossings” can be followed which then allows for work on culverts without a full Approval from AESRD. There is also a similar “Code of Practice for Outfall Structures”. If being used, AESRD requires notification a minimum of two weeks before the activity.

The Public Lands Act is also enforced by AESRD and would be applicable if any proposed work encroaches on Crown Lands or the ‘Bed and Shore’ of a waterbody. Water bodies within an existing road right of way (i.e. a ditch) is exempt from this regulation. A disposition or licence from AESRD would be required if Crown Lands are being affected.

13.2 FISHERIES AND OCEANS CANADA (DFO)

The Fisheries Act requires that projects avoid causing serious harm to fish unless authorized by the Department of Fisheries and Oceans Canada. This applies to work being conducted in or near water bodies that support fish that are part of a commercial, recreational or Aboriginal fishery.

Submission of the proposed work for review by DFO is not required if the work is taking place in an artificial waterbody that is not connected to a waterbody that contains fish at any time during any given year, such as:

- Private ponds, stormwater management ponds, or irrigation ponds,
- Agricultural drains and drainage ditches,
- Roadside drainage ditches,

If review is not required by DFO, all work needs to avoid causing serious harm to fish by following best practices such as those described in DFO’s Measures to Avoid Harm.

13.3 TRANSPORT CANADA (TC)

The Navigation Protection Act (NPA) requires that an Authorization be obtained for any work done that may impact navigation on certain watercourses and water bodies in Canada. The Peace River is regulated under the NPA and any work that may directly impact the Peace River will likely require an Authorization from TC.

14 SUMMARY AND RECOMMENDATIONS

14.1 SUMMARY

Mackenzie County commissioned WSP to prepare a study to evaluate surface drainage and to address drainage related issues within the watershed of the Bear River. The Bear River drainage basin covers a large area including the Buffalo Head Hills to the south, extending north and west to the Peace River, and east past Highway 88. The majority of the basin consists of relatively flat agricultural land and muskeg.

Agriculture development over the past century has resulted in large areas of cleared land in the study area, which has increased runoff rates, and has created ongoing flooding issues. Drainage channels have been constructed, typically in a reactionary approach to convey water downstream end ease flooding. The existing drainage system is effective to an extent but water issues are still frequent.

Development has recently increased when the Alberta Government sold roughly 136,000 acres (~550 km^2) of public land in Mackenzie County, with many of the new land parcels located within the Bear River basin. The new parcels of land are currently being cleared and ad-hoc drainage works are being constructed.

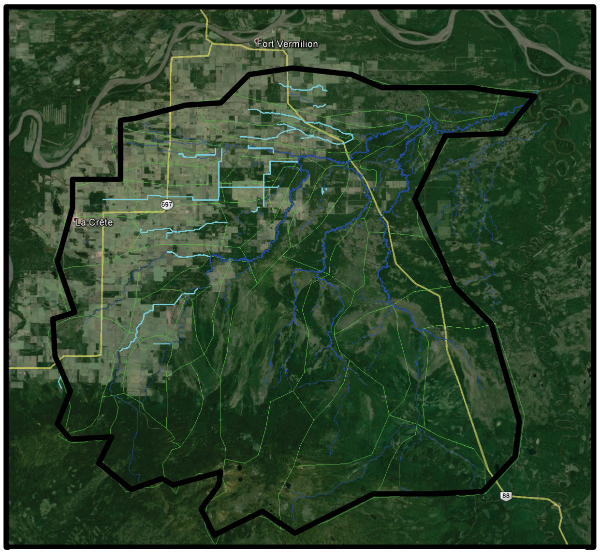


Figure 14-1 Study Area – Bear River Basin

There is concern that planning and proper drainage management is not being done with the development of the new land parcels and that the result will be additional flooding of existing and newly developed land.

This Drainage Plan is a high level comprehensive assessment of drainage that will assist the County and landowners with direction for addressing problems related to current and future development.

The study is focused on impacts of drainage from the new land within the Bear River Basin and has proposed some conceptual solutions for addressing both present and future drainage concerns within the study area.

General information regarding drainage issues is provided in Section 6, which includes details on some common mechanism behind flooding related to snow and ice, which is common in this area. General flood mitigation measures are also included as Section 10 which provides a helpful overview of information for the County and Landowners that can assist with land development.

A review of existing drainage information was completed. The data collection involved a file review of past drainage projects that started in the 1970's. These file reviews included the following drainage ditches;

- La Crete (East)
- Teepee Creek
- Bear River North
- Wilson Prairie
- AJA Friesen
- La Crete (South)
- La Crete Drainage
- Fort Vermillion (South)

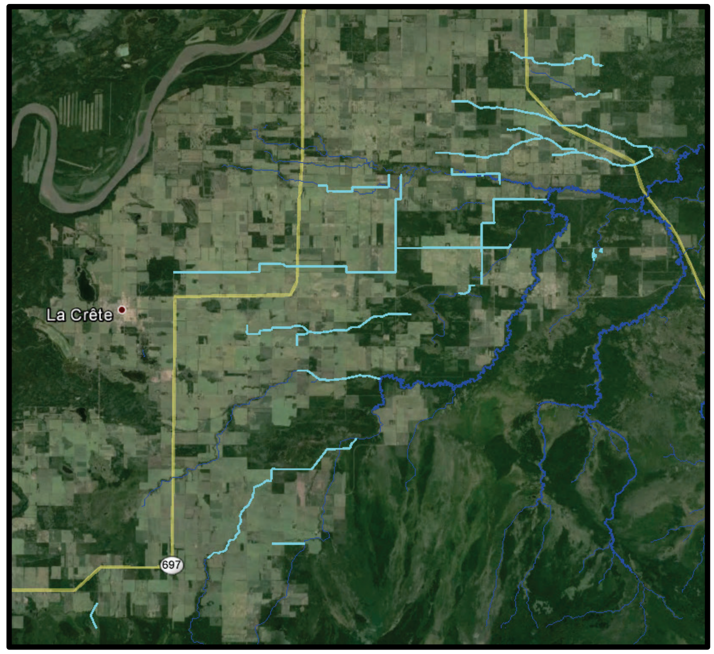


Figure 14-2 Existing Drainage Network. See Figure 4-1 for details.

WSP staff also conducted a tour of the study are with County representatives. The primary investigation was completed in November 2013 and a second visit was timed in April 2014 to coincide with spring runoff. Problem areas were documented, and photos were taken of the area.

LiDAR data was obtained for a large portion of the study area. A grid of data along all quarter section lines was purchased to provide the most value to this project and to any future projects in that area. Drainage area and sub-basins were delineated using LiDAR data to establish overall drainage patterns and a representative network was established.

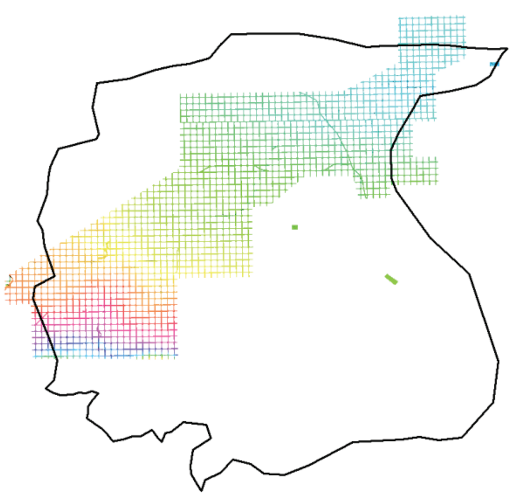


Figure 14-3 LiDAR Data Extents compared to the study area.

Hydrology in this area historically used gauge data and consisted of frequency analysis with basin transfer techniques. A review of the gauge information was completed along with a review of the design of structures in the area and the result was a general relationship between basin size and typical runoff. Although relatively good relationship was established additional detail and more advanced techniques are required for design purposes.

A conceptual model of the study area was then created using all DEM, LiDAR, and hydrology information available. XP-SWMM was used, which consists of two primary components; the hydrologic model which determines the amount of runoff and the resulting hydrograph from each basin, and the hydraulic model which uses the hydrographs as inputs and routs the flows through the drainage network. This effectively brings together hydrology and ditch hydraulics into one system. Drainage network information and model results are shown in the Figure below. Current conditions and predicted future conditions were modeled separately and the results were compared.

The model was calibrated using hydrology and gauge information and overall results fit relatively well with the established hydrology. The following points should be noted with respect to the model:

- Due to complexities and highly variable conditions snowmelt runoff was not directly used. Rainfall simulation was used.
- The model was calibrated using gauge data that include snowmelt events, thus considering snowmelt indirectly.
- The model is a reasonable approximation of drainage patterns; however, there are inherent limitations in the precision of the results which should be understood before utilizing the data.

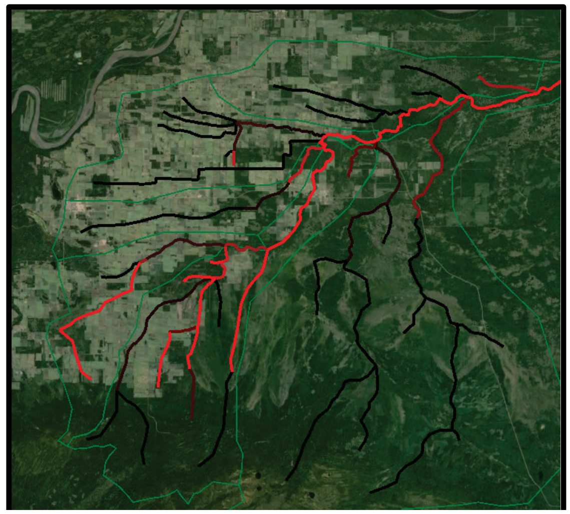


Figure 14-4 Model Results – Increase in flows due to development. See Figure 8-3 for details.

Refer to Section 8 for details of the model including a summary of the input data, assumptions, and limitations. The model results were used for recommendations regardign future development.

Using collected data, GIS information, and the model results, a comprehensive study of drainage throughout the study area was completed. The study area was split into six zones and each was assessed in terms of the identified problem areas and future development areas with conceptual solutions being provided for each area.

A proposed drainage ditch diverting water from the headwaters of Teepee Creek west to Steep Hill Creek was assessed in detail. Several alignments were investigated and costs for two were estimated.

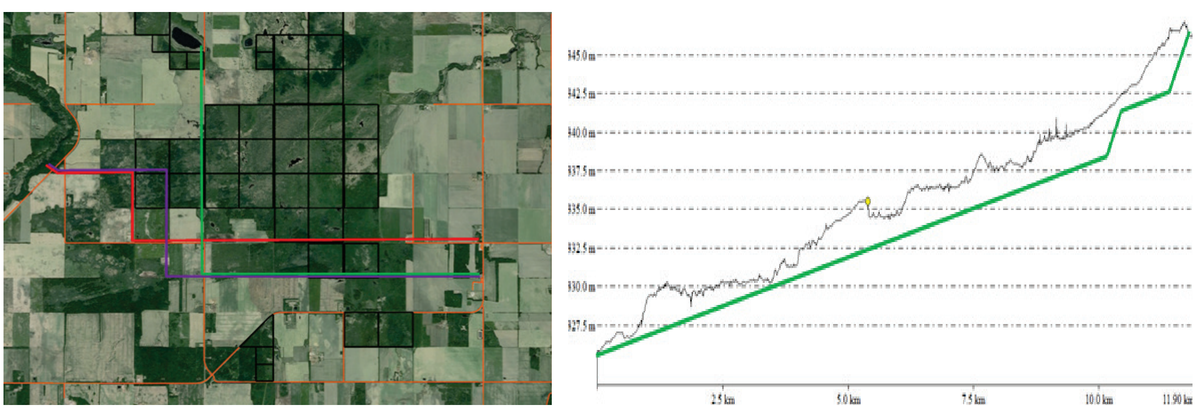


Figure 14-5 Steep Hill Creek Drainage Alignment Options and Profile

The Steep Hill Creek Drainage ditch is expected to benefit at least two existing flood problem areas, and will also assist with local drainage through the development area at that location.

Drainage concepts in other significant development areas throughout the study area were investigated, similar to the analysis for Steep Hill Creek but at a higher conceptual level. Possible future development of AESRD White Zone land parcels was also identified in each area, which could be a factor in the Jackpine Creek area and the Bear River North area.

14.2 RECOMMENDATIONS

Recommended drainage solutions for development areas, including problem areas are summarised in Section 12, Priorities and Costs. In total there are concepts for eight drainage ditches with a total cost of roughly $7.2 M.

Priorities for the ditches are higher for some locations that others. Steep Hill Creek Drainage, TR 1054 overflow drainage, and an assessment of Savage Prairie Drainage is recommended as the highest priorities. The priority for other ditches will depend on the rate of development and amount of planning and drainage already completed. Drainage at TR 1081 may also be a high priority for further assessment and drainage work due to the flat nature of the ground in that location.

This plan makes conceptual recommendations only and further preliminary and detailed design should be completed before construction of any drainage works.

Other recommendations in the report include the following:

- The protection of specific water storage areas, particularly at the end of AJA Friesen Drainage, La Crete (East), and Wilson Prairie Drainage.
- Development of any agricultural land within the study area should be reviewed for drainage concerns prior to approval.
- This plan should be updated if significant development is proposed in the future.
- Environmental regulations for all drainage ditches should be followed.

Prior to clearing land, adding drainage ditches or culverts, altering drainage, or conducting rehabilitation works, Section 10 - “Flood Mitigation Methods” should be reviewed. This section contains suggestions on how to properly design, implement and maintain drainage for this area. Mitigation measures for snow and ice related flooding are also included. This information should also be made available to local landowners for their use.

Maintenance recommendations a maintenance plan which should be implemented based on the recommendations in Section 10.9. This includes inspections, specific ditch and culvert maintenance items as well as spring maintenance suggestions. There is roughly 140 km of ditch within the study area. The County should budget for the regular inspection and maintenance of the drainage system.

15 REFERENCES

Mackenzie County Municipal Development Plan, Bylaw No.735/09, November 2009

Mackenzie County Land Use Bylaw, Bylaw No. 927-13, Revised on December 10, 2013 (ISL Engineering and Land Services Ltd.)

Feasibility Study for La Crete (East) Flood Control Project in Improvement District No. 23, Townships 106 and 107, Range 12, 13, 14, 15, W5, April 1993 (Torchinsky Engineering Ltd.)

La Crete Area Flood Control Proposals (AESRD's Memorandum)

La Crete (South) Flood Control, March 1976 (AESRD)

La Crete (South) Flood Control, Level I, Design Report, September 1975 (AESRD)

Tee Pee Creek Flood Control - Level I, June 1983 (Liland Engineering Ltd.)

Tee Pee Creek Flood Control, As Constructed Report, March 1985 (AESRD)

Buffalo Head Prairie Flood Control Project - As Constructed Report December 1992 (Bekevich Engineering Ltd.)

Bear River North Flood Control Line 4 As Constructed Report, April 1985 (AESRD)

Bear River North Flood Control Line 4 As Constructed Report, 1986 (Keneema Engineering Ltd.)

Wilson Prairie Flood Control, August 1985 (Liland Engineering Ltd.)

Wilson Prairie Flood Control Project (AESRD)

Wilson Prairie Drainage Extension Assessment, June 2003, (WSP, former EXH Engineering Services Ltd.)

AJA Friesen Drainage (Township Road 106-4), 18 Km East of La Crete, Conceptual Drainage Design Report, December 2009

Alberta Transportation – Hydrotechnical Information System (HIS)

Water Survey of Canada (WSC) Gauge Information

Etopo NTS maps (1:250,000 and 1:50,000 scales)

Airborne Imaging LiDAR (1 m resolution)

DEM Data (100 m resolution)

Google Earth (satellite images)

Flash Earth (NASA aqua, NASA daily, ArcGIS, Mapquest)

ESRI maps (streets, imagery, topographic, grey canvas)

Bing maps (road, aerial)

Valtus imagery

Appendix A

SITE PHOTOS

APPENDIX A-1

SITE PHOTOS 2013

01 - Bear River North Drainage Line 4 @ RR 13-1 - Looking East

02 - Bear River North Drainage Line 4 @ RR 13-1 - Culverts Across 13-1

03 - Bear River North Drainage Line 4 @ RR 13-1 - Looking West

04 - Bear River North Drainage Line 4 East of RR 13-1 - Looking West

05 - Bear River North Drainage Line 4 East of RR 13-1 - Looking East

06 - Bear River North Drainage Line 4 @ RR 12-3 - Looking West

07 - Bear River North Drainage Line 4 @ RR 12-3 - Looking East

08 - Bear River North Drainage Line 4 @ RR 12-3 - Looking West

09 - Bear River North Drainage Line 4 @ RR 12-3 - Looking East

10 - Bear River North Drainage Line 4 @ RR 12-1 - Looking West

11 - Bear River North Drainage Line 4 @ RR 12-1 - Looking East

12 - Bear River North Drainage Line 4 @ RR 12-1 - Culverts

13 - Bear River North Drainage Line 1 @ RR 13-1 - Looking East

14 - Bear River North Drainage Line 1 @ TR 107-2 - Twin CSP North Inv (April 2014)

15 - Bear River North Drainage Line 1 @ TR 107-2 - North Ditch Looking East (April 2014)

16 - Bear River North Drainage Line 1 @ TR 107-2 - South Culvert Invert (April 2014)

17 - TR 107-2 and RR 12-4 - Looking East (April 2014)

18 - TR 107-2 and RR 12-4 - Looking West (April 2014)

19 - TR 107-2 east of RR 12-4 - Flooding Near House on North Side (April 2014)

20 - Bear River North Drainage Line 1 @ RR12-2 - Twin 1600 CSP Outlet (April 2014)

21 - Bear River North Drainage Line 1 @ RR12-2 - Twin 1600 CSP Inlet (April 2014)

22 - Bear River North Drainage Line 1 @ RR12-2 - Twin 1600 Low Cover (April 2014)

23 - TR107-2 and RR12-1 - South Ditch Looking West (April 2014)

24 - TR107-2 and Hwy 88 - Looking West (April 2014)

25 - La Crete East Line 1 @ RR 13-1 - Looking West

26 - La Crete East Line 1 @ RR 13-1 - Looing East

27 - La Crete East Line 1 @ RR 13-1 - 1000 CSP Outlet (April 2014)

28 - La Crete East Ditch @ RR 14-0 - Looking West

29 - La Crete East Ditch @ RR 14-0 - Looking South

30 - La Crete East Ditch @ RR 14-0 - Looking East

31 - La Crete East @ RR13-4 - Drop structure (April 2014)

32 - AJA Drainage @ RR 13-4 - Looking West

33 - AJA Drainage @ RR 13-4 - Looking East

34 - AJA Drainage @ RR 13-4 - Looking North

35 - AJA Drainage @ RR 13-4 - Looking South

36 - AJA Drainage @ RR 13-2 - Looking East (April 2014)

37 - AJA Drainage @ RR 13-2 - Looking West (April 2014)

38 - Wilson Prairie Drainage @ RR 14-0 - Looking West

39 - Wilson Prairie Drainage @ RR 14-0 - Looking East

40 - Wilson Prairie Drainage @ RR 14-0 - Looking West (April 2014)

41 - Wilson Prairie Drainage @ RR13-4 - Looking West (April 2014)

42 - Wilson Prairie Drainage @ RR13-4 - Looking East (April 2014)

43 - TR 106-0 west of RR 13-4 - Looking East - Landowners Digging Out Culverts (April 2014)

44 - Teepee Creek Drainage @ RR 14-2 - Looking West

45 - Teepee Creek Drainage @ RR 14-2 - Looking East

46 - Teepee Creek Drainage @ RR 14-2 - BF 81336

47 - Teepee Creek Drainage @ RR 14-0 - Looking West

48 - Teepee Creek Drainage @ RR 14-0 - Looking East

49 - Teepee Creek Drainage @ RR 14-0 - Looking South (April 2014)

50 - Teepee Creek Drainage @ RR 14-0 - Looking West (April 2014)

51 - Teepee Creek Drainage @ RR 14-0 - Looking East (April 2014)

52 - 105-4 west of RR14-0 - Looking North

53 - 105-4 west of RR14-0 - Looking South

54 - TR 105-4 west of RR 14-0 - Looking North (April 2014)

55 - TR 105-4 east of RR 14-0 - Looking West - Undersized CSP (April 2014)

56 - TR 105-4 west of RR 14-0 - Ditch Full (April 2014)

57 - Tributary to Steephill Ck @ RR 16-1 - Looking Upstream

58 - Tributary to Steephill Ck @ RR 16-1 - Culvert

59 - Tributary to Steephill Ck @ RR 16-1A - Upstream (April 2014)

60 - Tributary to Steephill Ck @ RR 16-1A - Culvert

61 - Tributary to Steephill Ck @ RR 16-1A - Looking Downstream

62 - Tributary to Steephill Ck @ RR 16-1A - Outlet to Gully (April 2014)

63 - Tributary to Steephill Ck @ RR 16-1A - Downstream End (April 2014)

64 - Ditch @ TR 104-4 and RR 14-3 - Looking West

65 - Ditch @ TR 104-4 and RR 14-3 - Looking East

66 - Tributary @ TR 105-0 - BF 76506 - Looking North

67 - Tributary @ TR 105-0 - BF 76506 - Looking South

68 - Tributary @ TR 105-2 - Looking North

69 - Tributary @ TR 105-2 - Looking South

70 - Bear River South of TR 104-2 - BF 78318 - Looking North

71 - Bear River South of TR 104-2 - BF 78318 - Looking South

72 - Bear River South of TR 104-2 - BF 78318

73 - Bear River @ TR 104-4 - BF 74852 - Looking South

74 - Bear River @ TR 104-4 - BF 74852 - Looking South (April 2014)

75 - Bear River @ TR 104-4 - BF 74852 - Looking North

76 - Bear River @ TR 104-4 - BF 74852 - Looking North (April 2014)

77 - Bear River South of TR 105-0 - Drop Structure - Looking North

78 - Bear River South of TR 105-0 - Drop Structure - Looking South

79 - Bear River at TR 105-0 - BF 79552 - Looking South (April 2014)

80 - Bear River at TR 105-0 - BF 79552 - Looking North (April 2014)

81 - Bear River at TR 105-0 - BF 79552 - Looking North

82 - Bear River @ TR 105-4 - BF 81737

83 - Bear River @ TR 105-4 - BF 81737 - Looking North (April 2014)

84 - Bear River @ TR 105-4 - BF 81737 - Looking South

85 - Bear River @ TR 105-4 - BF 81737 - Looking North

86 - Bear River @ TR 105-4 - BF 81737 - Looking East

87 - Bear River @ TR 105-4 - BF 81737 - Looking West

88 - Bear River @ TR 106-6 - BF 80939 - Looking South

89 - Bear River @ TR 106-6 - BF 80939 - Looking North

90 - Bear River @ TR 106-6 - BF 80939

91 - Bear River @ Hwy 88 - BF 78914 - Looking West

92 - Bear River @ Hwy 88 - BF 78914 - Looking East

93 - Bear River Tributary - Off Hwy 88 - Large Valley

94 - Jackpine Creek @ Hwy 88 - BF 78195 - Looking West

95 - Jackpine Creek @ Hwy 88 - BF 78195 - Culvert Inlet

96 - Jackpine Creek @ Hwy 88 - BF 78195 - Looking East

97 - Typical Clearing East of Hwy 88

APPENDIX A-2
SITE PHOTOS 2008

Twp106-4 Looking West

Twp 106-4 Looking West

Twp 106-4 Looking West

Twp 106-4 Looking West

Twp 106-4 Looking East

RR 14-0 Looking North

Location: Hwy 697 Correction Line
Inspector: Mark O., Bryan H.
Date: April 28 2008

RR14-0 Looking South

RR14-0 Looking North

RR14-0 Looking North East

RR14-0 Looking North East

EXH Engineering Services
A Member of GENIVAR

Location: Hwy 697 Correction Line
Inspector: Mark O., Bryan H.
Date: April 28 2008

RR14-0 Looking West

RR14-0 Looking South

RR14-0 Looking South West

RR 14-0 Looking North

Location: Hwy 697 Correction Line
Inspector: Mark O., Bryan H.
Date: April 28 2008

Twp 106-4 Looking East

Twp 106-4 Looking East

Location: Hwy 697 Correction Line
Inspector: Mark O., Bryan H.
Date: April 28 2008

Twp 106-4 Looking East

Twp 106-4 Looking South at Farm Entrance

Twp 106-4 Looking West Standing on Farm Entrance

Twp 106-4 Looking South West at Farm Engrance

Twp 107-0 Looking East

Twp 107-0 Looking East

Location: Hwy 697 Correction Line
Inspector: Mark O., Bryan H.
Date: April 28 2008

Twp 107-0 Looking West

Twp 107-0 Looking South East

EXH Engineering Services
A Member of GENIVAR

Location: Hwy 697 Correction Line
Inspector: Mark O., Bryan H.
Date: April 28 2008

Twp 107-0 Looking South East

Twp 107-0 Looking West

Twp 107-0 Looking West

Twp 107-0 Looking West

Twp 107-0 Looking South

Twp 107-0 Looking North

Twp 107-0 Looking North West

Twp 107-0 LookingSouth

Twp 107-0 and RR14-0 Looking South

Twp 107-0 and RR14-1 Looking South

A Member of GENIVAR

Location: Hwy 697 Correction Line
Inspector: Mark O., Bryan H.
Date: April 28 2008

Twp 107-0 Looking South West

Twp 107-0 and RR14-1 Looking South

Appendix B

HYDROLOGY

Annual Maximum and Minimum Instantaneous Discharge Graph for TEEPEE CREEK NEAR LA CRETE (07JD004)

Graph | Table

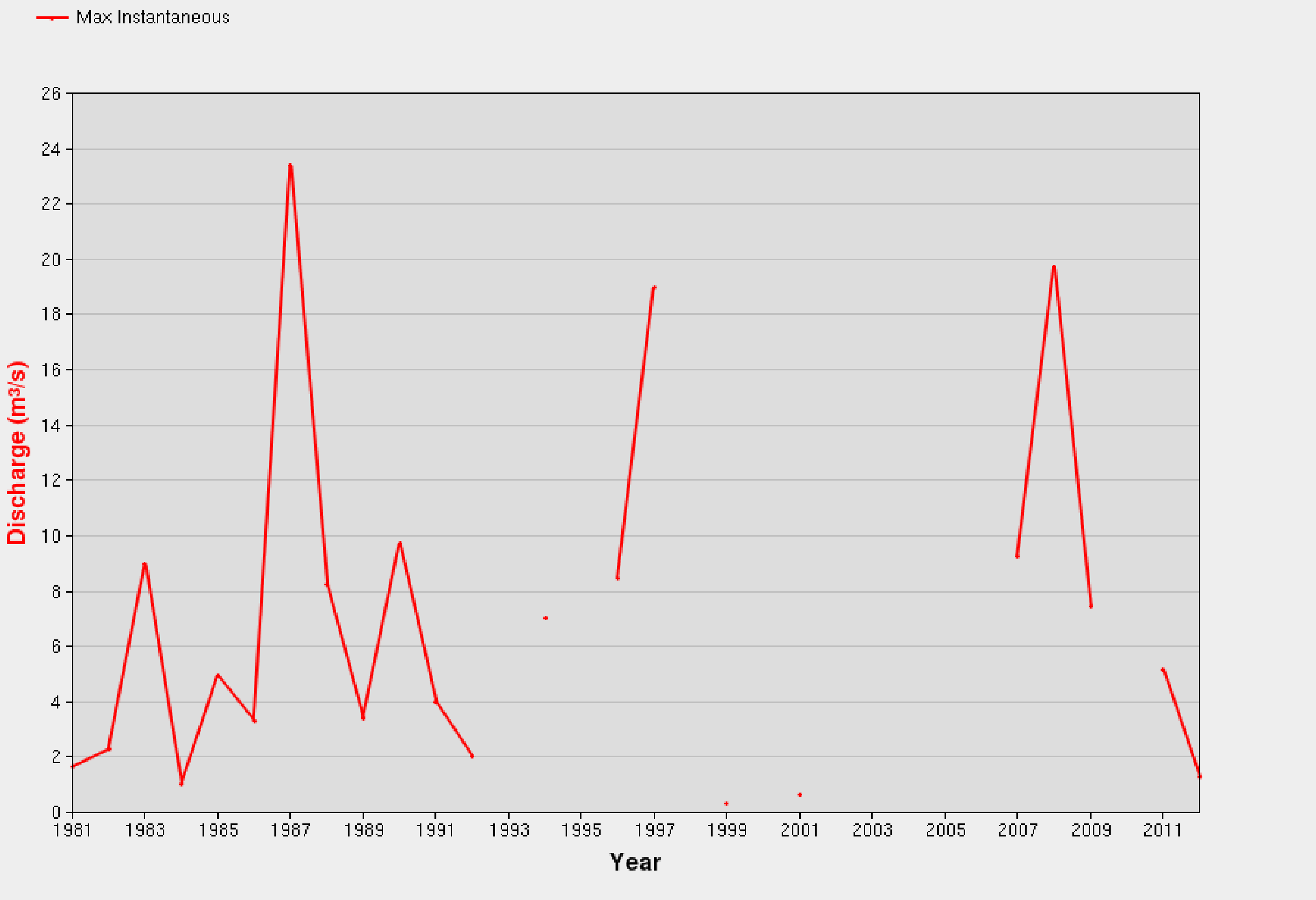
Station: 07JD004

Data Type: Peak

Parameter Type: Flow

for 2012

Download Apply



Modify Settings

Apply Settings

Scale

Log

Normal

*Note: If n<10, percentiles are not calculated. Click here for further information.

Station Information

Active or discontinued:
Active

Province / Territory:
Alberta

Latitude:
58° 08' 14" N

Longitude:
116° 15' 01" W
Gross drainage area:
136 km^2
Effective drainage area:
N/A
Record length:
36 Years
Period of record
1980 - 2015
Regulation type:
Natural
Regulation length:
N/A
Real-time data available:
No
Sediment data available:
No
Type of water body:
River
RHBN:
No
EC Regional Office:
CALGARY
Data contributed by:
N/A
Datum of published data:
ASSUMED DATUM

Data Collection History

This table contains information pertaining to the historical changes of defined elements in the operation of a station.

Period of operation	Type	Operation schedule	Gauge type
2012 - 2015	Flow & Level	Seasonal	Recorder
1980 - 2011	Flow	Seasonal	Recorder

Historical Hydrometric Remarks:
RECORDS PRIOR TO 1984 PUBLISHED AS "TEPEE CREEK NEAR LA CRETE."

Click here for further information on remarks.

Date modified: 2015-03-06

Annual Maximum and Minimum Instantaneous Discharge Data for TEEPEE CREEK NEAR LA CRETE (07JD004)

Graph | Table

Station: 07JD004

Data Type: Peak

Parameter Type: Flow

for 2012

Download Apply

This table provides annual maximum and minimum instantaneous value for a station.

Maximum Instantaneous Discharge			Minimum Instantaneous Discharge		
Date/Time	Timezone	Value (m^3/s)	Date/Time	Timezone	Value (m^3/s)
1981-04-30 10:00	MST	1.63	1981		
1982-04-22 19:00	MST	2.26 A	1982		
1983-04-19 22:00	MST	8.96	1983		
1984-07-07 14:00	MST	1.00	1984		
1985-04-02 18:30	MST	4.94 B	1985		
1986-06-25 7:30	MST	3.31	1986		
1987-04-16 0:30	MST	23.4	1987		
1988-04-17 23:30	MST	8.22 B	1988		
1989-04-13 14:30	MST	3.38 B	1989		
1990-04-19 22:00	MST	9.72	1990		
1991-04-05 17:00	MST	3.99 B	1991		
1992-03-01 17:30	MST	2.01 B	1992		
1993			1993		
1994-03-30 22:30	MST	7.00 B	1994		
1995			1995		
1996-04-17 21:48	MST	8.47	1996		
1997-04-19 17:25	MST	19.0	1997		
1998			1998		
1999-04-13 8:15	MST	0.336	1999-03-01 0:00	MST	B
2000			2000		
2001-04-14 22:30	MST	0.627	2001-03-28 0:00	MST	

2001-04-14 23:30	MST	0.627	2001-02-28 0:00	MST	
2002			2002		
2003			2003-02-28 0:00		
2004			2004-02-25 0:00		
2005			2005		
2006			2006-02-23 0:00		
2007-04-11 1:00	MST	9.26	2007-03-01 0:00	MST	
2008-04-15 16:05	MST	19.7 B	2008-03-01 0:00	MST	B
2009-04-14 23:30	MST	7.44	2009-03-01 0:00	MST	B
2010			2010-03-01 0:00		
2011-04-11 17:15	MST	5.15 B	2011-03-01 0:00	MST	B
2012-03-31 11:00	MST	1.29 B	2012-03-01 0:00	MST	B

Station Information

Active or discontinued:
Active
Province / Territory:
Alberta
Latitude:
58° 08' 14" N
Longitude:
116° 15' 01" W
Gross drainage area:
136 km^2
Effective drainage area:
N/A
Record length:
36 Years
Period of record
1980 - 2015
Regulation type:
Natural
Regulation length:
N/A
Real-time data available:
No
Sediment data available:
No
Type of water body:
River
RHBN:
No
EC Regional Office:
CALGARY
Data contributed by:
N/A
Datum of published data:
ASSUMED DATUM

Data Collection History

This table contains information pertaining to the historical changes of defined elements in the operation of a station.

Period of operation	Type	Operation schedule	Gauge type
2012 - 2015	Flow & Level	Seasonal	Recorder
1980 - 2011	Flow	Seasonal	Recorder

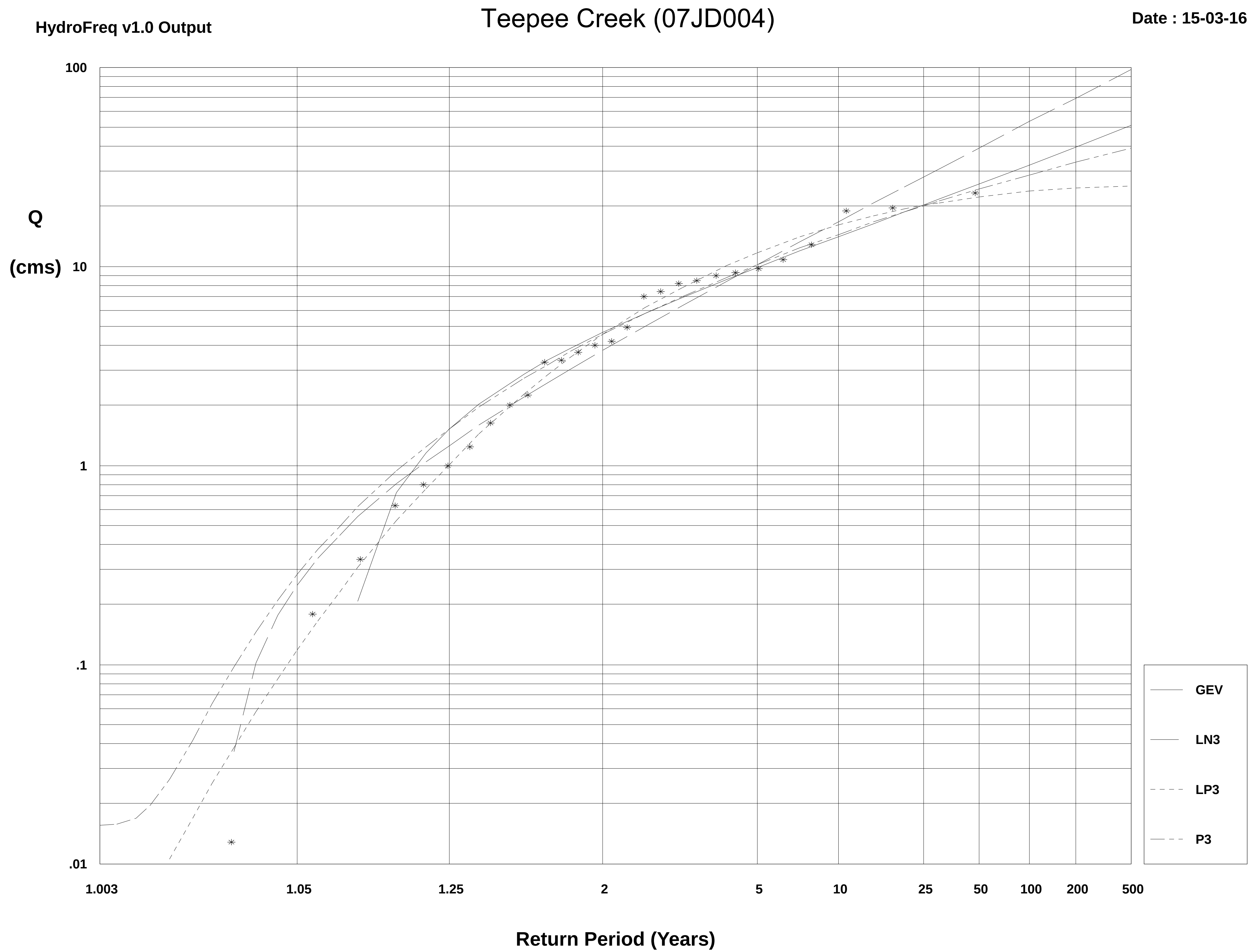
Historical Hydrometric Remarks:
RECORDS PRIOR TO 1984 PUBLISHED AS "TEPEE CREEK NEAR LA CRETE."

Click here for further information on remarks.

Date modified: 2015-03-06

HydroFreq v1.0 Output

Date : 15-03-16



Teepee Creek (07JD004)

HydroFreq v1.0 Output for Project : **Date : 15-03-16**

Statistics Results

	Flows	Log of Flows
Mean	6.37	1.12
St. Dev	6.25	1.63
Skew	1.96	-1.58

Flow Frequency Results

RP	GEV	LN3	LP3	P3
2.00	4.66	3.79	4.55	4.55
5.00	9.87	10.15	11.72	10.17
10.00	14.05	16.68	16.09	14.40
20.00	18.73	25.01	19.38	18.68
25.00	20.36	28.13	20.23	20.07
50.00	25.92	39.33	22.33	24.41
100.00	32.29	53.11	23.76	28.82
200.00	39.64	69.87	24.68	33.29
500.00	51.10	97.37	25.36	39.27

Distribution Parameters Results

RP	GEV	LN3	LP3	P3
	L Moments	Max. Like	Max. Like	Moments
Location	3.23	1.44	3.25	6.37
Scale	3.77	1.09	-1.26	6.25
Shape	-0.21	-0.43	1.68	1.96

HydroFreq v1.0 Output for Project : Teepee Creek (07JD004) Date : 15-03-16

Rank	Flow	Year	R.P.
1	23.4	1987	47.00
2	19.7	2008	17.63
3	19.0	1997	10.85
4	12.8	2005	7.83
5	10.7	2004	6.13
6	9.72	1990	5.04
7	9.26	2007	4.27
8	8.96	1983	3.71
9	8.47	1996	3.28
10	8.22	1988	2.94
11	7.44	2009	2.66
12	7.00	1994	2.43
13	4.94	1985	2.24
14	4.17	1995	2.07
15	3.99	1991	1.93
16	3.68	1998	1.81
17	3.38	1989	1.70
18	3.31	1986	1.60
19	2.26	1982	1.52
20	2.01	1992	1.44
21	1.63	1981	1.37
22	1.23	2000	1.31
23	1.00	1984	1.25
24	0.80	2006	1.19
25	0.63	2001	1.15
26	0.34	1999	1.10
27	0.18	1993	1.06
28	0.01	2002	1.02

Government of Canada | Gouvernement du Canada

Canada

Wateroffice

Home > Historical Data > > Station Search

Annual Maximum and Minimum Instantaneous Discharge Graph for JACKPINE CREEK AT HIGHWAY NO. 88 (07JD003)

Graph | Table

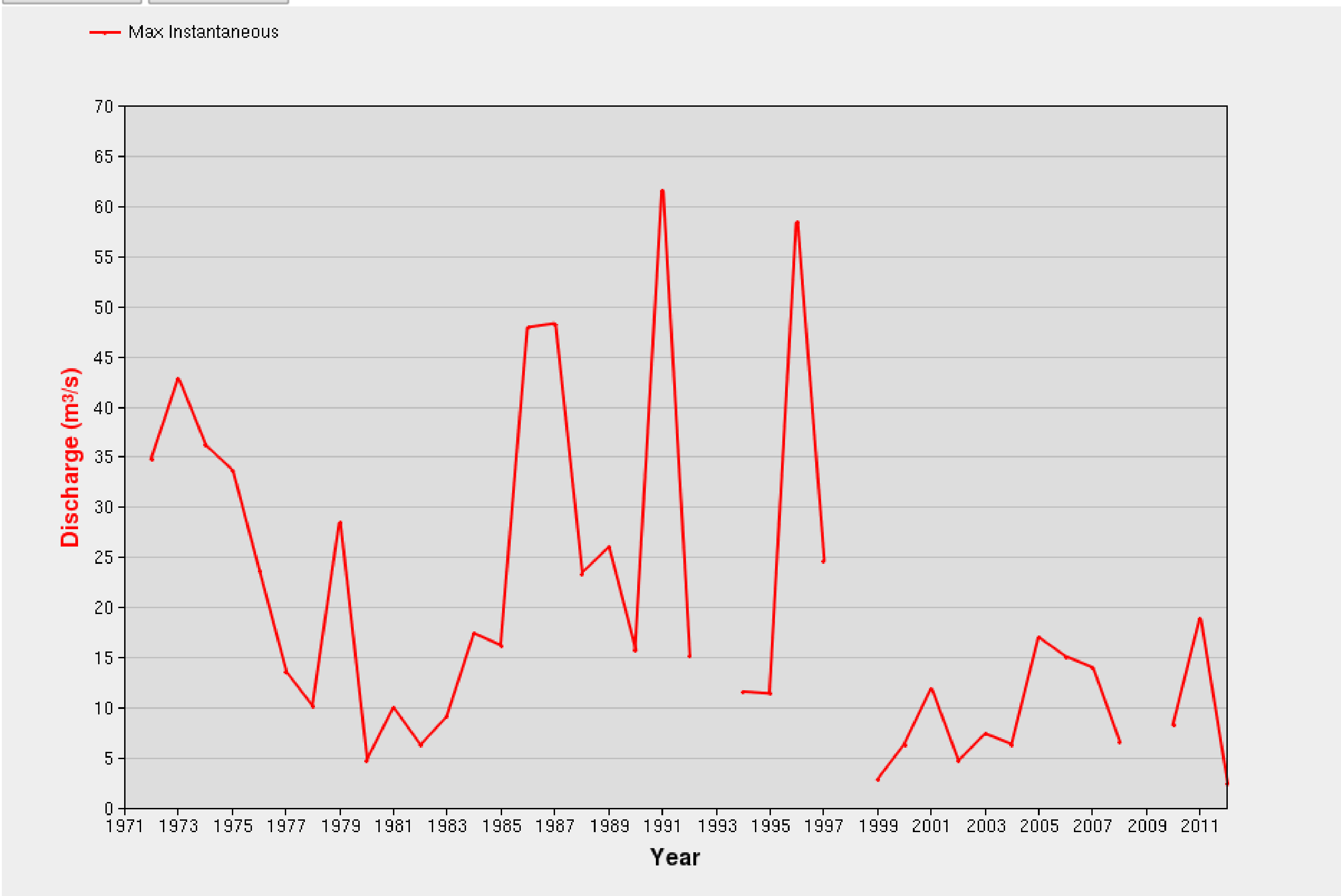
Station: 07JD003

Data Type: Peak

Parameter Type: Flow

for 2012

Download Apply



Modify Settings

Apply Settings

Scale

Log

Normal

*Note: If n<10, percentiles are not calculated. Click here for further information.

Station Information

Active or discontinued:
Active

Province / Territory:
Alberta

Latitude:
58° 11' 34" N

Longitude:
115° 44' 55'' W
Gross drainage area:
582.2 km^2
Effective drainage area:
N/A
Record length:
45 Years
Period of record
1971 - 2015
Regulation type:
Natural
Regulation length:
N/A
Real-time data available:
No
Sediment data available:
No
Type of water body:
River
RHBN:
No
EC Regional Office:
CALGARY
Data contributed by:
N/A
Datum of published data:
ASSUMED DATUM

Data Collection History

This table contains information pertaining to the historical changes of defined elements in the operation of a station.

Period of operation	Type	Operation schedule	Gauge type
2012 - 2015	Flow & Level	Seasonal	Recorder
1971 - 2011	Flow	Seasonal	Recorder

Click here for further information on remarks.

Date modified: 2015-03-06

Annual Maximum and Minimum Instantaneous Discharge Data for JACKPINE CREEK AT HIGHWAY NO. 88 (07JD003)

Graph | Table

Station: 07JD003 ▼

Data Type: Peak ▼

Parameter Type: Flow ▼

for 2000 ▼

Download Apply

This table provides annual maximum and minimum instantaneous value for a station.

Maximum Instantaneous Discharge			Minimum Instantaneous Discharge		
Date/Time	Timezone	Value (m^3/s)	Date/Time	Timezone	Value (m^3/s)
1971					
	MST	34.8	1972		
	MST	42.8	1973		
	MST	36.2	1974		
	MST	33.7	1975		
	MST	23.6	1976		
	MST	13.6	1977		
	MST	10.1	1978		
	MST	28.5 B	1979		
	MST	4.71	1980		
	MST	10.0 B	1981		
	MST	6.27	1982		
	MST	9.17	1983		
	MST	17.4	1984		
	MST	16.2	1985		
	MST	47.9	1986		
	MST	48.3	1987		
		23.4	1988		
	MST	26.0	1989		
	MST	15.7	1990		
	MST	61.5	1991		

	MST	61.5	1991		
	MST	15.2	1992		
1993					
	MST	11.6	1994		
	MST	11.4	1995		
	MST	58.4	1996		
	MST	24.6	1997		
1998					
	MST	2.84		MST	B
2000-09-04 10:00	MST	6.35	2000		
2000-09-04 10:00	MST	11.9	2001		
2000-09-04 10:00	MST	4.68	2002		
2000-09-04 10:00	MST	7.41	2000-09-04 10:00	MST	B
2000-09-04 10:00	MST	6.35	2004		
2000-09-04 10:00	MST	17.0	2005		
2000-09-04 10:00	MST	15.1	2000-09-04 10:00	MST	B
2000-09-04 10:00	MST	14.0	2007		
2000-09-04 10:00	MST	6.56	2000-09-04 10:00	MST	B
2009			2000-09-04 10:00		
2000-09-04 10:00	MST	8.26	2000-09-04 10:00	MST	B
2000-09-04 10:00	MST	18.9	2011		
2000-09-04 10:00	MST	2.45	2012		

Station Information

Active or discontinued:
Active
Province / Territory:
Alberta
Latitude:
58° 11' 34" N
Longitude:
115° 44' 55" W
Gross drainage area:
582.2 km^2
Effective drainage area:
N/A
Record length:
45 Years
Period of record
1971 - 2015
Regulation type:
Natural

Regulation length:
N/A
Real-time data available:
No
Sediment data available:
No
Type of water body:
River
RHBN:
No
EC Regional Office:
CALGARY
Data contributed by:
N/A
Datum of published data:
ASSUMED DATUM

Data Collection History

This table contains information pertaining to the historical changes of defined elements in the operation of a station.

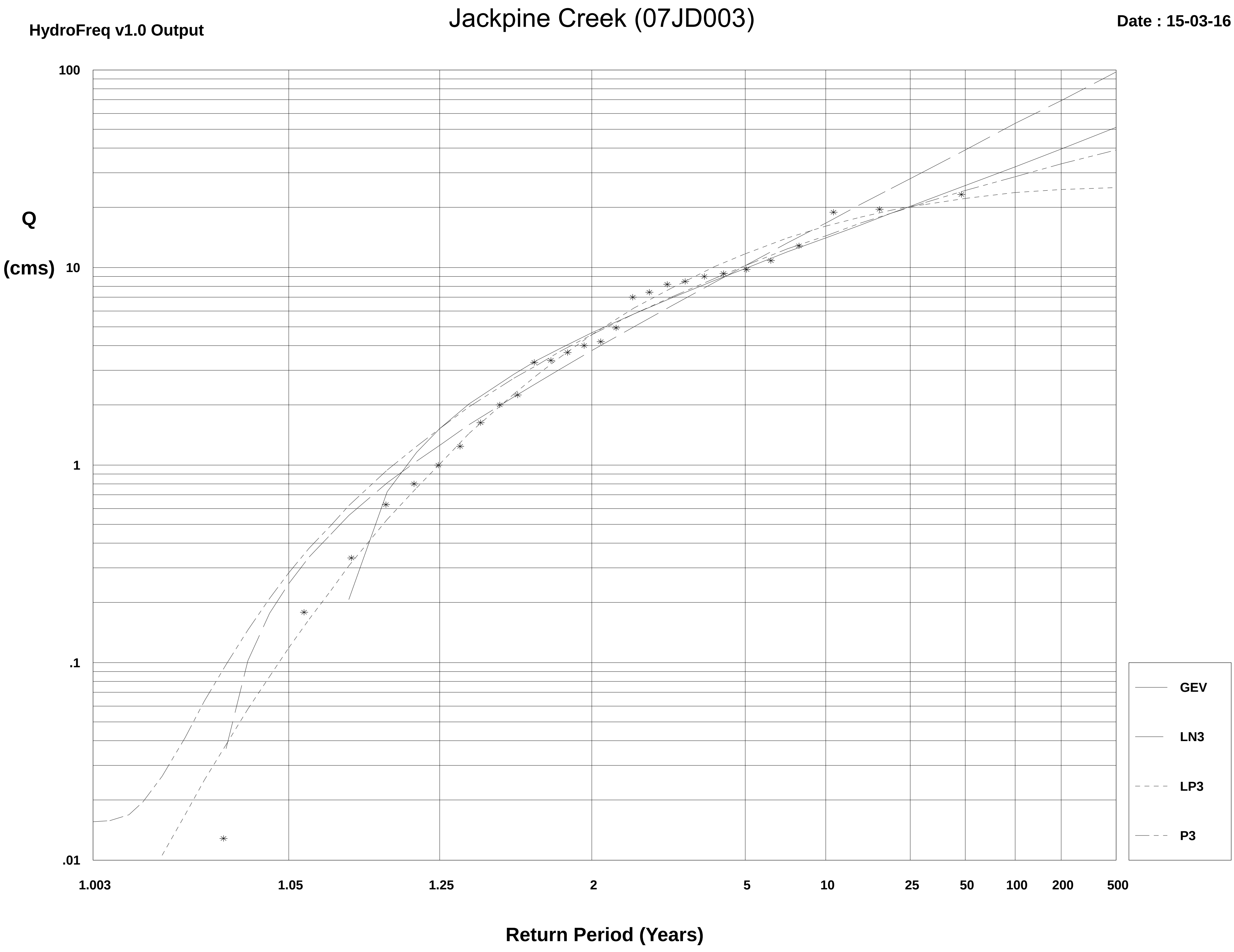
Period of operation	Type	Operation schedule	Gauge type
2012 - 2015	Flow & Level	Seasonal	Recorder
1971 - 2011	Flow	Seasonal	Recorder

Click here for further information on remarks.

Date modified: 2015-03-06

HydroFreq v1.0 Output

Date : 15-03-16



Jackpine Creek (07JD003)

HydroFreq v1.0 Output for Project : **Date : 15-03-16**

Statistics Results

	Flows	Log of Flows
Mean	20.25	2.74
St. Dev	15.37	0.76
Skew	1.52	-0.03

Flow Frequency Results

RP	GEV	LN3	LP3	P3
2.00	15.97	15.15	15.54	16.61
5.00	28.87	29.38	29.14	30.72
10.00	39.29	41.77	40.30	40.54
20.00	50.97	55.95	52.54	50.07
25.00	55.07	60.93	56.74	53.10
50.00	69.01	77.83	70.63	62.45
100.00	85.06	97.06	85.89	71.74
200.00	103.61	118.82	102.62	81.01
500.00	132.68	151.88	127.14	93.22

Distribution Parameters Results

RP	GEV	LN3	LP3	P3
	L Moments	Max. Like	Max. Like	Moments
Location	12.42	2.67	25.32	20.25
Scale	9.31	0.82	-0.03	15.37
Shape	-0.21	0.75	896.96	1.52

HydroFreq v1.0 Output for Project : Jackpine Creek (07JD003) **Date : 15-03-16**

Rank	Flow	Year	R.P.
1	61.5	1991	63.67
2	58.4	1996	23.88
3	48.3	1987	14.69
4	47.9	1986	10.61
5	42.8	1973	8.30
6	36.2	1974	6.82
7	34.8	1972	5.79
8	33.7	1975	5.03
9	28.5	1979	4.44
10	26.9	1993	3.98
11	26.0	1989	3.60
12	24.6	1997	3.29
13	23.6	1976	3.03
14	23.4	1988	2.81
15	17.4	1984	2.62
16	17.0	2005	2.45
17	16.2	1985	2.30
18	15.7	1990	2.17
19	15.2	1992	2.05
20	15.1	2006	1.95
21	14.0	2007	1.85
22	13.6	1977	1.77
23	11.9	2001	1.69
24	11.6	1994	1.62
25	11.4	1995	1.55
26	10.9	1998	1.49
27	10.1	1978	1.44
28	10.00	1981	1.38
29	9.17	1983	1.34
30	8.43	2009	1.29
31	7.41	2003	1.25
32	6.56	2008	1.21
33	6.35	2004	1.17
34	6.35	2000	1.14
35	6.27	1982	1.10
36	4.71	1980	1.07
37	4.68	2002	1.04
38	2.84	1999	1.02

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Wateroffice

Home > Historical Data > > Station Search

Annual Maximum and Minimum Instantaneous Discharge Graph for NORTH STAR DRAINAGE NEAR NORTH STAR (07HC907)

Graph | Table

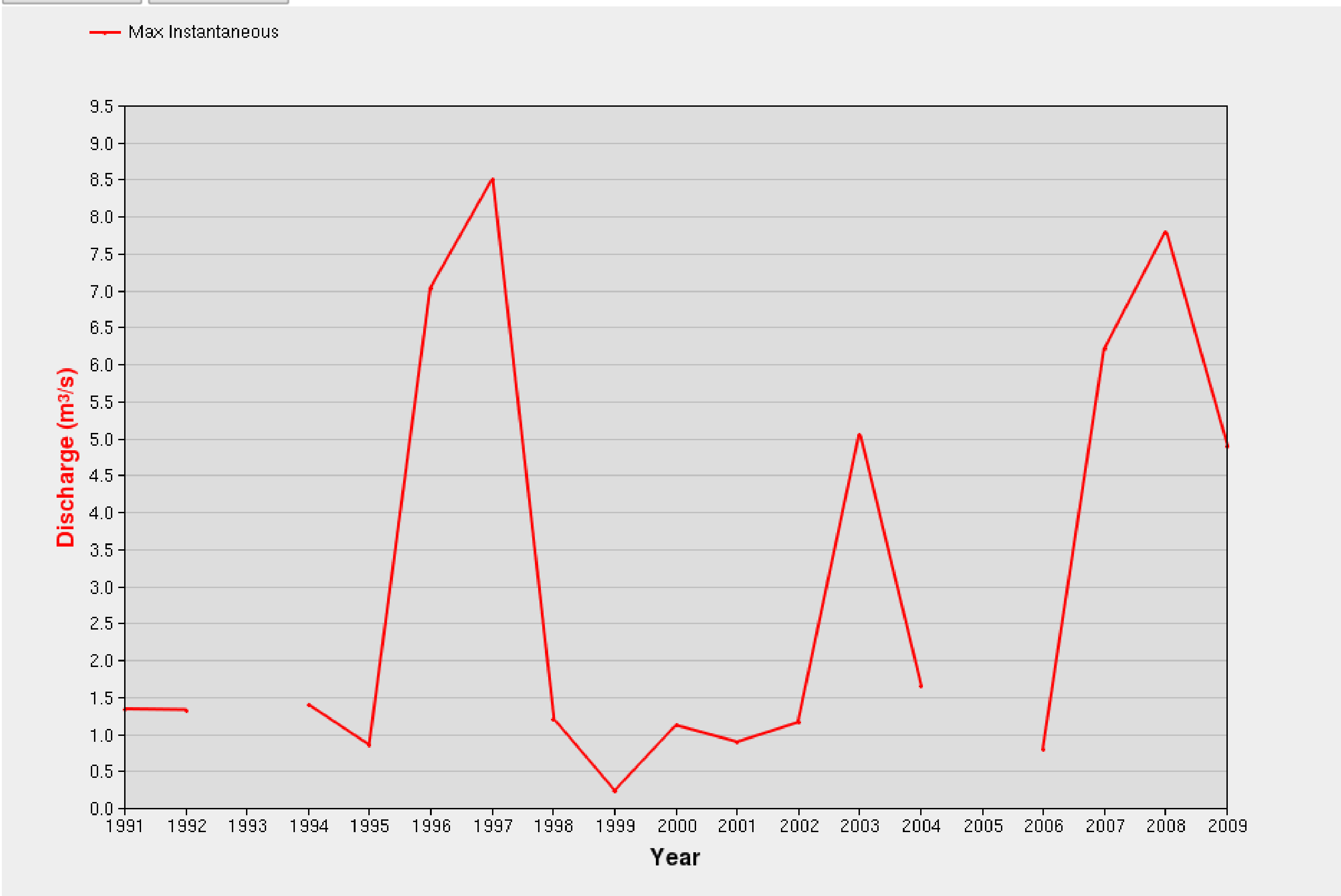
Station: 07HC907

Data Type: Peak

Parameter Type: Flow

for 2009

Download Apply



Modify Settings

Apply Settings

Scale

Log

Normal

*Note: If n<10, percentiles are not calculated. Click here for further information.

Station Information

Active or discontinued:
Active

Province / Territory:
Alberta

Latitude:
56° 49' 43" N

Longitude:
117° 34' 08''
Gross drainage area:
31.4 km^2
Effective drainage area:
N/A
Record length:
24 Years
Period of record
1991 - 2014
Regulation type:
Natural
Regulation length:
N/A
Real-time data available:
No
Sediment data available:
No
Type of water body:
River
RHBN:
No
EC Regional Office:
CALGARY
Data contributed by:
ALBERTA ENVIRONMENTAL PROTECTION
Datum of published data:
ASSUMED DATUM

Data Collection History

This table contains information pertaining to the historical changes of defined elements in the operation of a station.

Period of operation	Type	Operation schedule	Gauge type
1991 - 2014	Flow	Seasonal	Recorder

Annual Hydrometric Remarks:
2009 CONTRIBUTED BY ALBERTA ENVIRONMENT

Historical Hydrometric Remarks:
DATA CONTRIBUTED BY ALBERTA ENVIRONMENT

Click here for further information on remarks.

Date modified: 2015-03-06

Wateroffice

Annual Maximum and Minimum Instantaneous Discharge Data for NORTH STAR DRAINAGE NEAR NORTH STAR (07HC907)

Graph | Table

Station: 07HC907

Data Type: Peak

Parameter Type: Flow

for 2009

Download Apply

This table provides annual maximum and minimum instantaneous value for a station.

Maximum Instantaneous Discharge			Minimum Instantaneous Discharge		
Date/Time	Timezone	Value (m^3/s)	Date/Time	Timezone	Value (m^3/s)
1991-06-16 8:55	MST	1.34	1991		
1992-03-27 16:45	MST	1.33 B	1992		
1993			1993		
1994-03-28 19:30	MST	1.40 B	1994		
1995-04-18 0:35	MST	0.849	1995		
1996-04-06 23:25	MST	7.04 B	1996		
1997-04-17 19:15	MST	8.50 B	1997		
1998-03-26 12:15	MST	1.21 B	1998		
1999-04-12 20:00	MST	0.236 B	1999		
2000-07-10 8:55	MST	1.12	2000		
2001-05-24 15:05	MST	0.893	2001		
2002-05-24 9:15	MST	1.16	2002		
2003-04-17 19:30	MST	5.06 B	2003		
2004-09-21 10:30	MST	1.65	2004		
2005			2005-06-19 0:00	MST	
2006-04-07 10:30	MST	0.800	2006-03-01 0:00	MST	B
2007-04-14 21:00	MST	6.21	2007-03-21 0:00	MST	B
2008-04-13 19:00	MST	7.80	2008-03-01 0:00	MST	B
2009-04-11 18:00	MST	4.90	2009-03-01 0:00	MST	B

Station Information

Active or discontinued:
Active
Province / Territory:
Alberta
Latitude:
56° 49' 43" N
Longitude:
117° 34' 08"
Gross drainage area:
31.4 km^2
Effective drainage area:
N/A
Record length:
24 Years
Period of record
1991 - 2014
Regulation type:
Natural
Regulation length:
N/A
Real-time data available:
No
Sediment data available:
No
Type of water body:
River
RHBN:
No
EC Regional Office:
CALGARY
Data contributed by:
ALBERTA ENVIRONMENTAL PROTECTION
Datum of published data:
ASSUMED DATUM

Data Collection History

This table contains information pertaining to the historical changes of defined elements in the operation of a station.

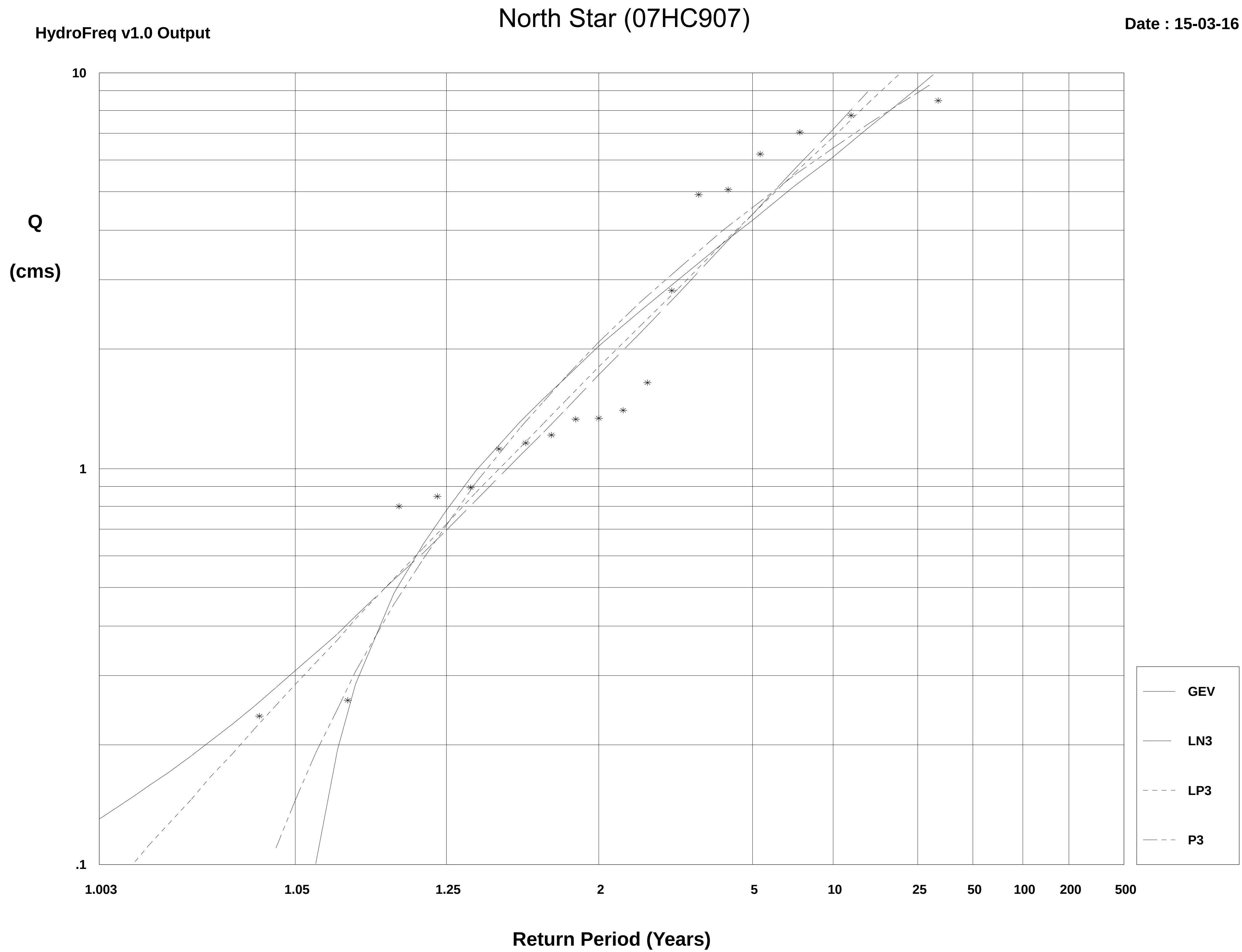
Period of operation	Type	Operation schedule	Gauge type
1991 - 2014	Flow	Seasonal	Recorder

Annual Hydrometric Remarks:
2009 CONTRIBUTED BY ALBERTA ENVIRONMENT

Historical Hydrometric Remarks:
DATA CONTRIBUTED BY ALBERTA ENVIRONMENT

Click here for further information on remarks.

Date modified: 2015-03-06


HydroFreq v1.0 Output
North Star (07HC907)
Date : 15-03-16
Q
(cms)
10
1
.1
1.003
1.05
1.25
2
5
10
25
50
100
200
500
Return Period (Years)
GEV
LN3
LP3
P3

North Star (07HC907)

HydroFreq v1.0 Output for Project : **Date : 15-03-16**

Statistics Results

	Flows	Log of Flows
Mean	2.87	0.57
St. Dev	2.75	1.07
Skew	1.92	-0.12

Flow Frequency Results

RP	GEV	LN3	LP3	P3
2.00	2.03	1.72	1.80	2.08
5.00	4.24	4.37	4.37	4.57
10.00	6.13	7.17	6.85	6.43
20.00	8.34	10.81	9.87	8.29
25.00	9.14	12.19	10.97	8.90
50.00	11.95	17.17	14.81	10.79
100.00	15.32	23.39	19.32	12.70
200.00	19.39	31.03	24.59	14.64
500.00	26.09	43.72	32.81	17.23

Distribution Parameters Results

RP	GEV	LN3	LP3	P3
	L Moments	Max. Like	Moments	Moments
Location	1.45	0.51	18.42	2.87
Scale	1.50	1.14	-0.06	2.75
Shape	-0.27	0.06	278.95	1.92

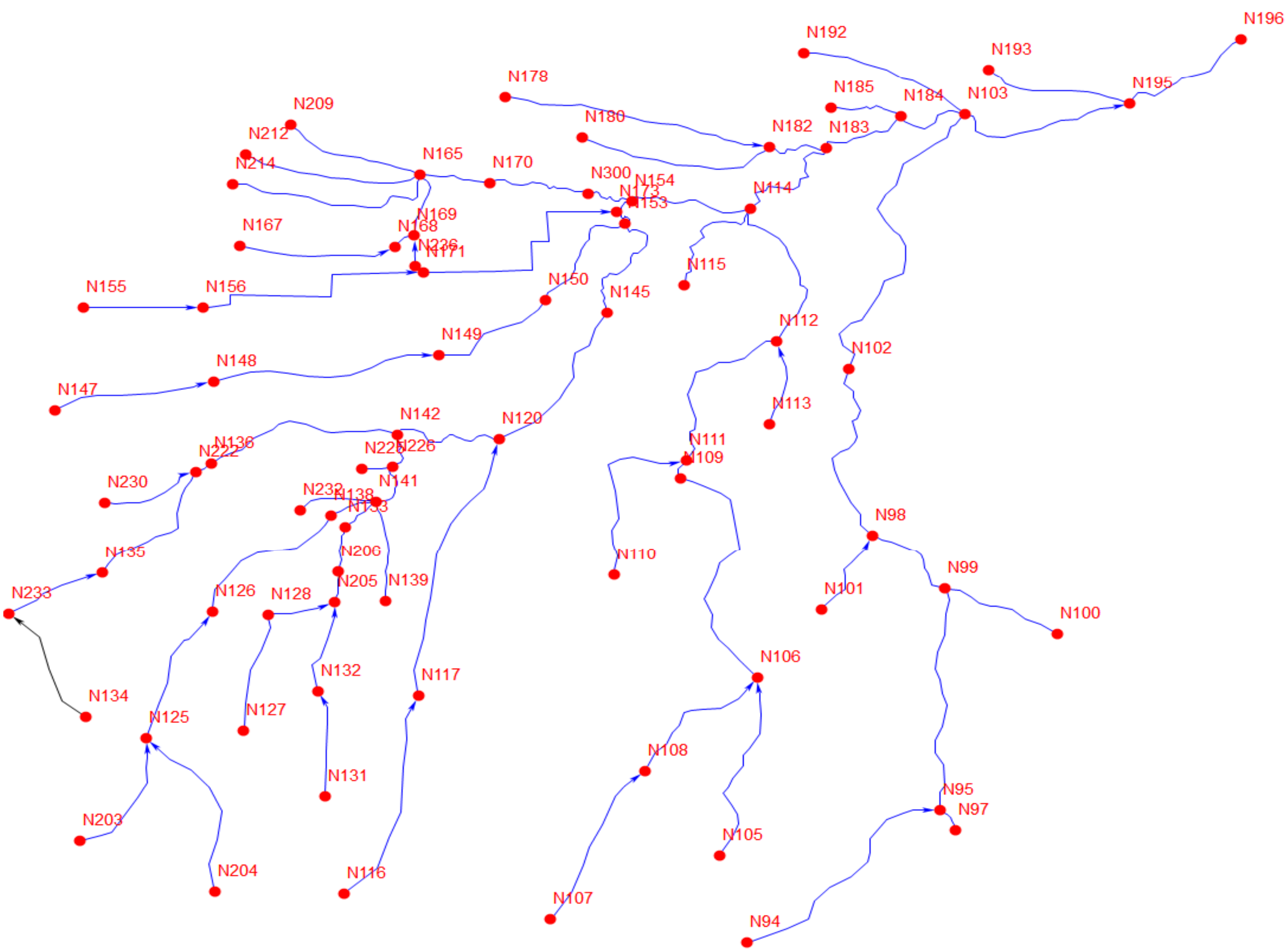
HydroFreq v1.0 Output for Project : North Star (07HC907) **Date : 15-03-16**

Rank	Flow	Year	R.P.
1	8.50	1997	32.00
2	7.80	2008	12.00
3	7.04	1996	7.38
4	6.21	2007	5.33
5	5.06	2003	4.17
6	4.90	2009	3.43
7	2.81	2005	2.91
8	1.65	2004	2.53
9	1.40	1994	2.23
10	1.34	1991	2.00
11	1.33	1992	1.81
12	1.21	1998	1.66
13	1.16	2002	1.52
14	1.12	2000	1.41
15	0.89	2001	1.32
16	0.85	1995	1.23
17	0.80	2006	1.16
18	0.26	1993	1.09
19	0.24	1999	1.03

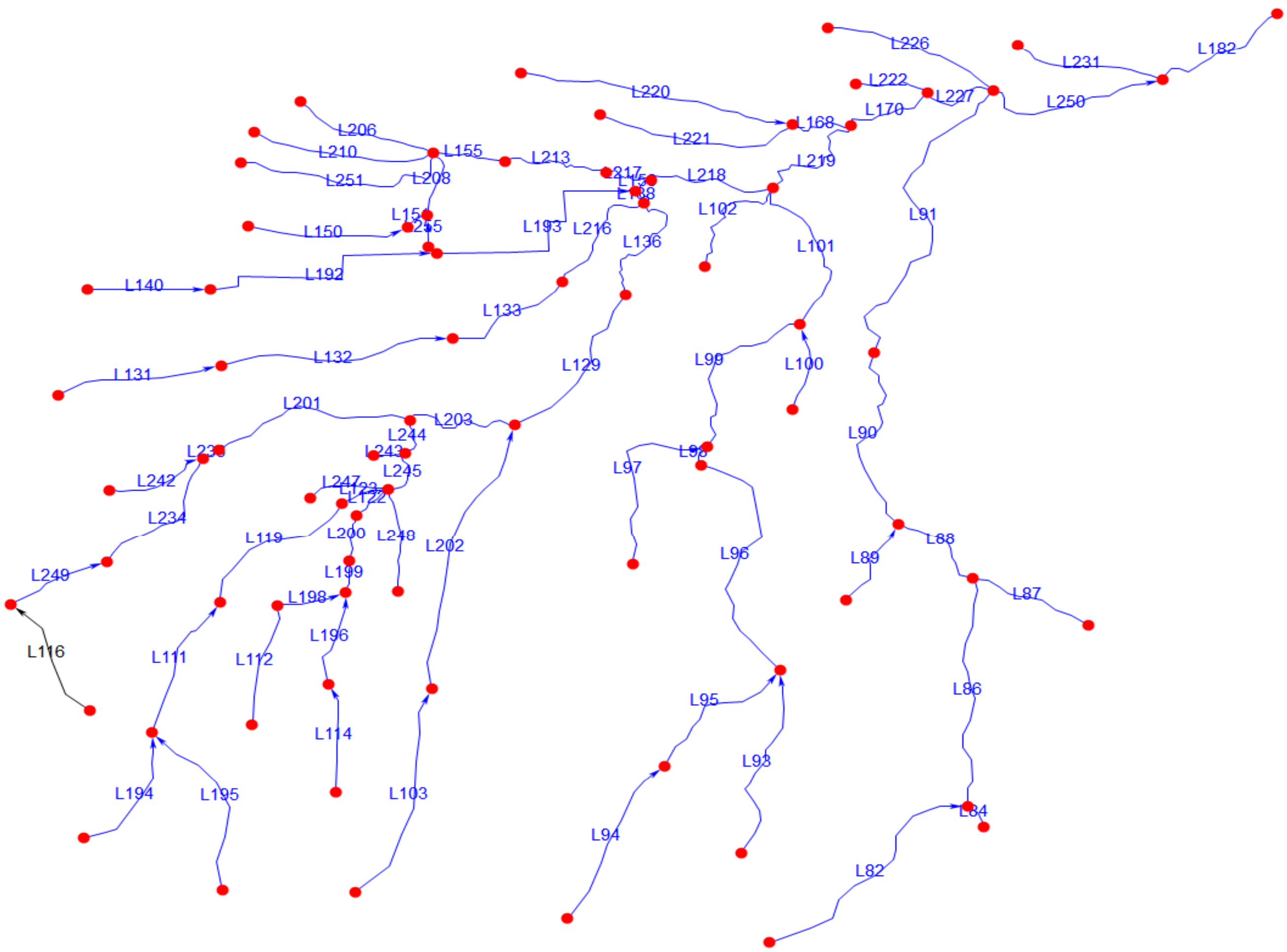
Appendix C

MODEL RESULTS

Mackenzie Drainage Model - Node Network and Labels



Mackenzie Drainage Model - Link / Channel Network and Labels



Mackenzie Drainage Model - Input - Node Data

Name	Infiltration Reference	Ground Elevation (Spill Crest) m	Invert Elevation m	Area ha	Width m	Impervious Percentage %	Slope
N100	H0.0	316.4	296	5833	11600	0	0.01
N101	H0.0	327	306	2200	7100	0	0.005
N102	H0.7	302	278	8200	10000	0	0.005
N103	H0.4	283	257	10408	6000	0.8	0.005
N105	H0.0	371	350	2933.333	6500	0	0.01
N106	H0.0	340	318	7166.667	8000	0	0.005
N107	H0.0	802	780	3566.667	6300	0	0.02
N108	H0.0	392	370	8433.333	6000	0	0.01
N109	H0.0	311.5	289.5	5200	4000	0	0.005
N110	H0.0	361.7	340	6333.333	9600	0	0.005
N111	H0.6	311.5	289	13600	4000	1.5	0.005
N112	H0.0	298.5	276	2866.667	4000	0	0.005
N113	H0.0	312.5	292	966.667	4100	0	0.005
N114	H0.2	289.5	265	6995	4000	0.5	0.005
N115	H0.4	307.9	287.4	1133.333	3800	0.8	0.005
N116	H0.0	737.5	717	1500	4700	0	0.02
N117	H0.0	378.9	358.4	2500	9675.364	0	0.005
N120	H0.6	315.2	292	2715	3698.608	1.6	0.005
N125	H0.0	408.5	386	5165	10360.4	0	0.01
N126	H0.10	362.4	339.9	1770	6799.028	2.5	0.005
N127	H0.10	392.1	371	2315	5600	2.7	0.01
N128	H0.10	352.2	330.6	2315	7104.594	3	0.005
N131	H0.0	602.6	582	4000	3700	0	0.01
N132	H0.6	366.1	342.5	2000	7817.764	1.5	0.005
N133	H0.8	333.1	309.1	905	7219.093	2.3	0.005
N134	H0.4	415.5	394.5	2963.333	5700	0.8	0.01
N135	H0.10	347.8	326.1	5156.667	12091.13	3	0.005
N136	H0.10	331	308.4	2300	52634.59	3	0.005
N138	H0.10	330.8	308.3	1040	3683.541	2.7	0.005
N139	H0.0	345.6	324	895	2200	0	0.005
N141	H0.8	326.7	304.9	1205	4310.599	2.4	0.005
N142	H0.10	318.5	296	2300	4641.308	2.4	0.005
N145	H0.6	305	281.8	2135	2767.312	1.5	0.005
N147	H0.8	341	320	4305	5700	2.1	0.005
N148	H0.10	333	312	5360	13473.54	2.7	0.005
N149	H0.10	313.1	292.1	4050	10795.57	2.5	0.005
N150	H0.8	303.8	282.8	1950	6064.715	1.4	0.005
N153	H0.6	296.4	271.4	1090	1782.133	1.2	0.005
N154	H0.6	292.1	267	868.333	4099.278	1.5	0.005
N155	H0.10	344	323	1730	4000	2.7	0.005
N156	H0.8	324	303	3390	4500	2.3	0.005
N165	H0.10	295.5	274.5	4725	6483.557	2.7	0.005
N167	H0.8	315.35	295	1290	2500	2.4	0.005
N168	H0.10	304.35	284	1685	4384.101	2.7	0.005
N169	H0.10	302.6	281.1	2055	4331.599	2.7	0.005
N170	H0.10	293.2	271.7	778.333	2687.8	2.9	0.005
N171	H0.10	305.3	283.8	1715	3000	2.9	0.005
N173	H0.6	292.2	267.2	1715	4053.744	1.6	0.005

Mackenzie Drainage Model - Input - Node Data

Name	Infiltration Reference	Ground Elevation (Spill Crest) m	Invert Elevation m	Area ha	Width m	Impervious Percentage %	Slope
N178	H0.10	302	281	2295	3000	2.9	0.005
N180	H0.10	293	272	1960	2700	2.9	0.005
N182	H0.6	286	265	4765	10785.37	1.6	0.005
N183	H0.2	288.5	264	510	912.357	0.1	0.005
N184	H0.0	284.2	260	1235	3357.56	0	0.005
N185	H0.4	289	268	725	2000	1.2	0.005
N192	H0.6	285.5	264	4965	4800	1.6	0.005
N193	H0.2	291.5	270	3330	3500	0.5	0.005
N195	H0.0	280	254	3330	4361.303	0	0.005
N196	H0.0	270	245	1470	2530.556	0	0.005
N203	H0.0	750.8	728.5	830	1500	0	0.02
N204	H0.0	602.2	580.2	3605	7800	0	0.02
N205	H0.10	344.4	320.4	595	2320.063	2.5	0.005
N206	H0.8	339.4	315.4	595	6982.953	2.4	0.005
N209	H0.8	312.17	292	1895	6200	2.1	0.005
N212	H0.6	312.17	292	825	1200	1.8	0.005
N214	H0.8	313	292	1610	3100	2.4	0.005
N222	H0.10	333.4	310.8	2193.333	5605.576	2.9	0.005
N225	H0.8	322.7	302	310	1400	2.3	0.005
N226	H0.6	320.5	298	310	1329.968	1.8	0.005
N230	H0.4	343.5	322.7	2193.333	6100	1.2	0.005
N232	H0.10	330.8	309.1	1350	2200	2.7	0.005
N233	H0.8	350.6	330.4	2963.333	3500	2.4	0.005
N236	H0.8	305.6	283.8	450	2700	2.1	0.005
N300	H0.8	289.9	268.4	383.333	884.356	2.4	0.005
N94	H0.0	540.5	500	3333	6000	0	0.02
N95	H0.0	370.5	350	13400	3000	0	0.01
N97	H0.0	390.5	370	2733	7200	0	0.02
N98	H0.0	312	290	10067	5000	0	0.005
N99	H0.0	314.5	294	15600	5000	0	0.005

Mackenzie Drainage Model - Input - Link / Channel Data

Name	Upstream Node Name	Downstream Node Name	Length m	Upstream Invert Elevation	Downstream Invert Elevation	Conduit Slope	Roughness	Shape	Natural Section Shape
L100	N113	N112	5000	292	276	0.22	0.035	Natural	L100
L101	N112	N114	7500	276	265	0.05	0.035	Natural	L101
L102	N115	N114	4000	287.4	265	0.13	0.035	Natural	L102
L103	N116	N117	15000	717	358.4	2	0.035	Natural	L103
L111	N125	N126	7809.94	386	339.9	0.59	0.035	Natural	L111
L112	N127	N128	7300	371	330.6	0.41	0.035	Natural	L112
L114	N131	N132	7300	582	342.5	2.74	0.035	Natural	L114
L116	N134	N233	7300	394.5	330.4	0	0.014	Natural	L116
L119	N126	N138	8470.11	339.9	308.3	0.37	0.035	Natural	L119
L122	N133	N141	3110.73	309.1	304.9	0.14	0.035	Natural	L122
L123	N138	N141	3598.215	308.3	304.9	0.09	0.035	Natural	L123
L129	N120	N145	12000	292	281.8	0.04	0.035	Natural	L129
L131	N147	N148	9500	320	312	0.07	0.035	Natural	L131
L132	N148	N149	11254.62	312	292.1	0.18	0.035	Natural	L132
L133	N149	N150	8500	292.1	282.8	0.1	0.035	Natural	L133
L136	N145	N153	9500	281.8	271.4	0.06	0.035	Natural	L136
L138	N153	N173	3932.5	271.4	267.2	0.11	0.035	Natural	L138
L140	N155	N156	5835.72	323	303	0.34	0.035	Natural	L140
L150	N167	N168	8000	295	284	0.1	0.035	Natural	L150
L151	N168	N169	1837.41	284	281.1	0.16	0.035	Natural	L151
L155	N165	N170	4500	274.5	271.7	0.03	0.035	Natural	L155
L158	N173	N154	2571.425	267.2	267	0.01	0.035	Natural	L158
L168	N182	N183	4000	265	264	0.01	0.035	Natural	L168
L170	N183	N184	6000	264	260	0.04	0.035	Natural	L170
L182	N195	N196	9000	254	245	0.05	0.035	Natural	L182
L192	N156	N171	12340.77	303	283.8	0.16	0.035	Natural	L192
L193	N171	N173	12691.97	283.8	267.2	0.13	0.035	Natural	L193
L194	N203	N125	8500	728.5	386	3.18	0.035	Natural	L194
L195	N204	N125	10000	580.2	386	1.3	0.035	Natural	L195
L196	N132	N205	5500	342.5	320.4	0.29	0.035	Natural	L196
L198	N128	N205	4200	330.6	320.4	0.2	0.035	Natural	L198
L199	N205	N206	2556.225	320.4	315.4	0.2	0.035	Natural	L199
L200	N206	N133	2700	315.4	309.1	0.17	0.035	Natural	L200
L201	N136	N142	11500	308.4	296	0.08	0.035	Natural	L201
L202	N117	N120	16000	358.4	292	0.3	0.035	Natural	L202
L203	N142	N120	8500	296	292	0.03	0.035	Natural	L203
L206	N209	N165	7500	292	274.5	0.1	0.035	Natural	L206
L208	N169	N165	5414.865	281.1	274.5	0.12	0.035	Natural	L208
L210	N212	N165	9500	292	274.5	0.08	0.035	Natural	L210
L213	N170	N300	5500	271.7	268.4	0.03	0.035	Natural	L213
L216	N150	N153	7500	282.8	271.4	0.07	0.035	Natural	L216
L217	N300	N154	2500	268.4	267	0.02	0.035	Natural	L217
L218	N154	N114	7500	267	265	0.02	0.035	Natural	L218
L219	N114	N183	16769.75	265	264	0.01	0.035	Natural	L219
L220	N178	N182	13254.06	281	265	0.12	0.035	Natural	L220

Mackenzie Drainage Model - Input - Link / Channel Data

Name	Upstream Node Name	Downstream Node Name	Length m	Upstream Invert Elevation	Downstream Invert Elevation	Conduit Slope	Roughness	Shape	Natural Section Shape
L221	N180	N182	6000	272	265	0.07	0.035	Natural	L221
L222	N185	N184	5389.2	268	260	0.15	0.035	Natural	L222
L226	N192	N103	10000	264	257	0.05	0.035	Natural	L226
L227	N184	N103	5000	260	257	0.03	0.035	Natural	L227
L231	N193	N195	8500	270	254	0.09	0.035	Natural	L231
L234	N135	N222	8700	326.1	310.8	0.13	0.035	Natural	L234
L236	N222	N136	1310.925	310.8	308.4	0.18	0.035	Natural	L236
L242	N230	N222	5500	322.7	310.8	0.16	0.035	Natural	L242
L243	N225	N226	200	302	298	0.1	0.035	Natural	L243
L244	N226	N142	2500	298	296	0.04	0.035	Natural	L244
L245	N141	N226	4500	304.9	298	0.1	0.035	Natural	L245
L247	N232	N141	5894.52	309.1	304.9	0.07	0.035	Natural	L247
L248	N139	N141	6500	324	304.9	0.23	0.035	Natural	L248
L249	N233	N135	6500	330.4	326.1	0.06	0.035	Natural	L249
L250	N103	N195	9500	257	254	0.01	0.035	Natural	L250
L251	N214	N165	10763.77	292	274.5	0.16	0.035	Natural	L251
L255	N236	N169	1651.2	283.8	281.1	0.16	0.035	Natural	L255
L82	N94	N95	11000	500	350	0.36	0.035	Natural	L82
L84	N97	N95	2085.93	370	350	0.96	0.035	Natural	L84
L86	N95	N99	13000	350	294	0.3	0.035	Natural	L86
L87	N100	N99	7000	296	294	0.02	0.035	Natural	L87
L88	N99	N98	6000	294	290	0.03	0.035	Natural	L88
L89	N101	N98	6500	306	290	0.21	0.035	Natural	L89
L90	N98	N102	8000	290	278	0.04	0.035	Natural	L90
L91	N102	N103	20000	278	257	0.05	0.035	Natural	L91
L93	N105	N106	11000	350	318	0.2	0.035	Natural	L93
L94	N107	N108	9000	780	370	2.89	0.035	Natural	L94
L95	N108	N106	7500	370	318	0.26	0.035	Natural	L95
L96	N106	N109	14000	318	289.5	0.08	0.035	Natural	L96
L97	N110	N111	10000	340	289	0.2	0.035	Natural	L97
L98	N109	N111	2866.15	289.5	289	0.02	0.035	Natural	L98
L99	N111	N112	9500	289	276	0.05	0.035	Natural	L99

Mackenzie Drainage Model - Results - 1:100 Year Storm Event - Pre Development

Name	Storm	Maximum Water Elevation	Maximum Water Elevation	Design Full Flow cms	Max Flow cms	Max Flow/Design Flow	Max Velocity m/s	Max Depth m	Unit Flow (m3/s/km2)	Drainage Area (km2)
L100	HL_100YR_24HR	292.639	278.144	182.1	3.8	0.0	0.5	2.1	2.6	9.7
L101	HL_100YR_24HR	278.144	270.778	390.6	50.0	0.1	1.1	5.8	10.2	510.7
L102	HL_100YR_24HR	288.013	270.778	256.0	4.5	0.0	0.7	5.8	2.5	11.3
L103	HL_100YR_24HR	717.76	359.192	177.2	10.7	0.1	2.6	0.8	2.8	30.6
L111	HL_100YR_24HR	387.799	341.485	583.4	28.7	0.0	1.9	1.8	3.3	96.0
L112	HL_100YR_24HR	372.287	332.389	162.3	17.0	0.1	1.3	1.8	1.4	23.2
L114	HL_100YR_24HR	582.379	343.486	675.4	5.3	0.0	1.4	1.0	3.2	16.9
L116	HL_100YR_24HR	395.177	331.332	455.6	8.8	0.0	0.9	0.9	3.4	29.6
L119	HL_100YR_24HR	341.485	310.685	649.2	34.6	0.1	1.7	2.4	3.3	113.7
L122	HL_100YR_24HR	310.869	307.443	22.3	39.0	1.8	1.3	2.5	2.7	106.9
L123	HL_100YR_24HR	310.685	307.443	225.3	40.2	0.2	0.9	2.5	3.1	124.1
L129	HL_100YR_24HR	295.299	284.833	810.2	75.6	0.1	1.1	3.3	7.8	587.8
L131	HL_100YR_24HR	321.671	314.271	54.8	16.2	0.3	0.5	2.3	2.7	43.1
L132	HL_100YR_24HR	314.271	293.28	63.1	44.7	0.7	0.8	2.3	2.2	96.7
L133	HL_100YR_24HR	293.28	284.953	175.1	62.9	0.4	0.4	2.2	2.2	137.2
L136	HL_100YR_24HR	284.833	274.345	286.1	71.6	0.3	1.2	3.0	8.5	609.1
L138	HL_100YR_24HR	274.345	272.134	1562.2	83.8	0.1	1.1	4.9	9.3	776.7
L140	HL_100YR_24HR	324.346	304.476	119.5	16.3	0.1	1.1	1.5	1.1	17.3
L150	HL_100YR_24HR	295.692	285.212	64.2	6.0	0.1	0.3	1.2	2.2	12.9
L151	HL_100YR_24HR	285.212	282.926	36.9	16.0	0.4	0.4	1.8	1.9	29.8
L155	HL_100YR_24HR	275.915	274.484	120.0	56.6	0.5	0.3	2.8	2.2	124.8
L158	HL_100YR_24HR	272.134	271.985	421.6	82.3	0.2	0.4	5.0	10.5	862.2
L168	HL_100YR_24HR	267.915	267.915	77.2	30.6	0.4	0.2	3.9	2.9	90.2
L170	HL_100YR_24HR	267.915	264.379	639.6	104.0	0.2	1.2	4.4	16.3	1694.5
L182	HL_100YR_24HR	256.965	249	3355.5	109.9	0.0	1.3	4.0	23.7	2605.0
L192	HL_100YR_24HR	304.476	285.603	133.1	22.7	0.2	0.7	1.8	2.3	51.2
L193	HL_100YR_24HR	285.603	272.134	254.8	13.2	0.1	0.8	4.9	5.2	68.4
L194	HL_100YR_24HR	729.013	387.799	3099.7	3.1	0.0	1.6	1.8	2.7	8.3
L195	HL_100YR_24HR	581.086	387.799	1730.3	15.8	0.0	2.4	1.8	2.3	36.1
L196	HL_100YR_24HR	343.486	322.705	249.1	9.2	0.0	0.6	2.3	4.3	39.7
L198	HL_100YR_24HR	332.389	322.705	315.2	35.7	0.1	1.5	2.3	1.3	46.3
L199	HL_100YR_24HR	322.705	317.819	1342.6	34.5	0.0	1.5	2.4	2.7	91.9
L200	HL_100YR_24HR	317.819	310.869	813.9	36.0	0.0	1.5	2.4	2.7	97.9
L201	HL_100YR_24HR	311.106	299.212	249.8	42.4	0.2	0.8	3.2	4.2	177.7
L202	HL_100YR_24HR	359.192	295.299	303.0	19.4	0.1	0.8	3.3	4.6	88.3
L203	HL_100YR_24HR	299.212	295.299	274.3	104.2	0.4	0.6	3.3	4.5	472.4
L206	HL_100YR_24HR	293.178	275.915	24.3	14.3	0.6	0.7	1.4	1.3	19.0
L208	HL_100YR_24HR	282.926	275.915	72.3	25.8	0.4	0.6	1.8	1.3	34.3
L210	HL_100YR_24HR	292.778	275.915	21.6	2.0	0.1	0.5	1.4	4.2	8.3
L213	HL_100YR_24HR	274.484	271.986	116.0	54.8	0.5	0.5	3.6	2.4	132.6
L216	HL_100YR_24HR	284.953	274.345	76.6	54.1	0.7	0.8	2.9	2.9	156.7
L217	HL_100YR_24HR	271.986	271.985	161.8	47.8	0.3	0.4	5.0	2.9	136.4
L218	HL_100YR_24HR	271.985	270.778	215.2	88.2	0.4	0.7	5.8	11.4	1007.3
L219	HL_100YR_24HR	270.778	267.915	207.3	113.4	0.5	0.6	5.8	14.1	1599.2
L220	HL_100YR_24HR	282.302	267.915	117.2	10.4	0.1	0.7	2.9	2.2	23.0
L221	HL_100YR_24HR	273.465	267.915	70.7	12.6	0.2	0.6	2.9	1.6	19.6
L222	HL_100YR_24HR	268.851	264.379	127.1	3.4	0.0	0.7	4.4	2.2	7.3
L226	HL_100YR_24HR	265.801	261.631	247.4	10.2	0.0	0.5	4.6	4.9	49.7
L227	HL_100YR_24HR	264.379	261.631	1101.0	99.8	0.1	1.1	4.6	17.2	1714.1
L231	HL_100YR_24HR	271.484	256.965	156.3	5.5	0.0	1.0	3.0	6.1	33.3
L234	HL_100YR_24HR	327.646	312.98	553.2	26.5	0.0	0.8	2.2	4.2	110.8

Mackenzie Drainage Model - Results - 1:100 Year Storm Event - Pre Development

Name	Storm	Maximum Water Elevation	Maximum Water Elevation	Design Full Flow cms	Max Flow cms	Max Flow/Design Flow	Max Velocity m/s	Max Depth m	Unit Flow (m3/s/km2)	Drainage Area (km2)
L236	HL_100YR_24HR	312.98	311.106	600.9	27.7	0.0	0.9	2.7	5.6	154.7
L242	HL_100YR_24HR	323.508	312.98	150.4	8.8	0.1	0.5	2.2	2.5	21.9
L243	HL_100YR_24HR	302.31	300.599	68.4	1.6	0.0	1.2	2.6	1.9	3.1
L244	HL_100YR_24HR	300.599	299.212	222.3	79.2	0.4	0.5	3.2	3.4	271.7
L245	HL_100YR_24HR	307.443	300.599	274.0	79.3	0.3	1.1	2.6	3.3	265.5
L247	HL_100YR_24HR	309.837	307.443	93.3	4.1	0.0	0.4	2.5	3.3	13.5
L248	HL_100YR_24HR	324.528	307.443	214.5	2.3	0.0	0.5	2.5	3.9	9.0
L249	HL_100YR_24HR	331.332	327.646	59.7	12.0	0.2	0.3	1.5	2.5	29.6
L250	HL_100YR_24HR	261.631	256.965	1606.5	109.7	0.1	1.0	4.6	23.1	2538.4
L251	HL_100YR_24HR	293.287	275.915	76.1	7.7	0.1	0.8	1.4	2.1	16.1
L255	HL_100YR_24HR	284.591	282.926	176.5	4.0	0.0	0.7	1.8	1.1	4.5
L82	HL_100YR_24HR	500.621	351.279	155.3	12.8	0.1	1.5	1.3	2.6	33.3
L84	HL_100YR_24HR	370.699	351.279	214.5	13.7	0.1	0.9	1.3	2.0	27.3
L86	HL_100YR_24HR	351.279	295.56	47.4	32.3	0.7	1.5	1.6	6.0	194.7
L87	HL_100YR_24HR	297.051	295.56	70.2	16.5	0.2	0.2	1.6	3.5	58.3
L88	HL_100YR_24HR	295.56	292.216	33.6	50.9	1.5	0.7	2.2	8.0	409.0
L89	HL_100YR_24HR	306.925	292.216	196.6	8.2	0.0	0.9	2.2	2.7	22.0
L90	HL_100YR_24HR	292.216	280.515	397.1	48.9	0.1	1.3	2.5	10.9	531.7
L91	HL_100YR_24HR	280.515	261.631	2091.6	52.4	0.0	1.2	4.6	11.7	613.7
L93	HL_100YR_24HR	351.245	319.63	107.5	9.3	0.1	0.9	1.6	3.1	29.3
L94	HL_100YR_24HR	780.747	371.583	956.8	13.6	0.0	3.0	1.6	2.6	35.7
L95	HL_100YR_24HR	371.583	319.63	501.4	26.0	0.1	2.1	1.6	4.6	120.0
L96	HL_100YR_24HR	319.63	291.719	310.8	38.3	0.1	1.0	2.2	5.8	221.0
L97	HL_100YR_24HR	340.791	290.701	240.6	12.5	0.1	1.1	1.7	5.1	63.3
L98	HL_100YR_24HR	291.719	290.701	91.0	38.0	0.4	0.4	2.2	7.2	273.0
L99	HL_100YR_24HR	290.701	278.144	1343.2	50.0	0.0	1.0	2.1	9.4	472.3

Mackenzie Drainage Model - Results - 1:100 Year Storm Event - Post Development

Name	Storm	Maximum Water Elevation	Maximum Water Elevation	Design Full Flow cms	Max Flow cms	Max Flow/Design Flow	Max Velocity m/s	Max Depth m	Unit Flow (m3/s/km2)	Drainage Area (km2)
L100	HL_100YR_24HR	292.64	278.23	182.1	3.7	0.0	0.6	2.2	2.6	9.7
L101	HL_100YR_24HR	278.23	271.055	390.6	54.4	0.1	1.1	6.1	9.4	510.7
L102	HL_100YR_24HR	288.026	271.055	256.0	5.2	0.0	0.8	6.1	2.2	11.3
L103	HL_100YR_24HR	717.771	359.19	177.2	10.8	0.1	2.6	0.8	2.8	30.6
L111	HL_100YR_24HR	387.804	341.485	583.4	29.4	0.1	1.8	1.8	3.3	96.0
L112	HL_100YR_24HR	372.393	332.777	162.3	25.1	0.2	1.3	2.2	0.9	23.2
L114	HL_100YR_24HR	582.4	343.75	338.8	5.8	0.0	1.3	1.3	2.9	16.9
L116	HL_100YR_24HR	395.207	331.416	455.6	11.8	0.0	0.9	1.0	2.5	29.6
L119	HL_100YR_24HR	341.485	310.741	649.2	34.5	0.1	1.7	2.4	3.3	113.7
L122	HL_100YR_24HR	310.795	307.577	88.4	52.4	0.6	0.6	2.7	2.0	106.9
L123	HL_100YR_24HR	310.741	307.577	225.3	42.0	0.2	0.8	2.7	3.0	124.1
L129	HL_100YR_24HR	295.504	284.951	810.2	96.1	0.1	1.1	3.5	6.1	587.8
L131	HL_100YR_24HR	321.671	314.273	54.8	16.2	0.3	0.5	2.3	2.7	43.1
L132	HL_100YR_24HR	314.273	293.305	63.1	44.7	0.7	0.8	2.3	2.2	96.7
L133	HL_100YR_24HR	293.305	285.03	175.1	65.9	0.4	0.4	2.2	2.1	137.2
L136	HL_100YR_24HR	284.951	274.697	286.1	89.5	0.3	1.2	3.3	6.8	609.1
L138	HL_100YR_24HR	274.697	272.403	1562.2	98.3	0.1	1.2	5.2	7.9	776.7
L140	HL_100YR_24HR	324.346	304.476	119.5	16.2	0.1	1.1	1.5	1.1	17.3
L150	HL_100YR_24HR	295.693	285.213	64.2	6.0	0.1	0.3	1.2	2.2	12.9
L151	HL_100YR_24HR	285.213	283.05	36.9	16.0	0.4	0.4	2.0	1.9	29.8
L155	HL_100YR_24HR	275.975	274.559	120.0	61.4	0.5	0.3	2.9	2.0	124.8
L158	HL_100YR_24HR	272.403	272.257	421.6	98.6	0.2	0.4	5.3	8.7	862.2
L168	HL_100YR_24HR	268.298	268.297	77.2	30.2	0.4	0.2	4.3	3.0	90.2
L170	HL_100YR_24HR	268.297	264.735	639.6	112.9	0.2	1.3	4.7	15.0	1694.5
L182	HL_100YR_24HR	257.072	249	3355.5	118.3	0.0	1.3	4.0	22.0	2605.0
L192	HL_100YR_24HR	304.476	285.604	133.1	22.7	0.2	0.7	1.8	2.3	51.2
L193	HL_100YR_24HR	285.604	272.403	254.8	13.2	0.1	0.8	5.2	5.2	68.4
L194	HL_100YR_24HR	729.015	387.804	3099.7	3.1	0.0	1.6	1.8	2.7	8.3
L195	HL_100YR_24HR	581.086	387.804	1730.3	15.8	0.0	2.5	1.8	2.3	36.1
L196	HL_100YR_24HR	343.75	322.965	862.0	17.1	0.0	1.1	2.6	2.3	39.7
L198	HL_100YR_24HR	332.777	322.965	315.2	37.7	0.1	1.3	2.6	1.2	46.3
L199	HL_100YR_24HR	322.965	318.143	1342.6	44.0	0.0	1.6	2.7	2.1	91.9
L200	HL_100YR_24HR	318.143	310.795	813.9	46.1	0.1	1.6	2.7	2.1	97.9
L201	HL_100YR_24HR	311.112	299.424	249.8	39.3	0.2	0.9	3.4	4.5	177.7
L202	HL_100YR_24HR	359.19	295.504	303.0	19.1	0.1	0.7	3.5	4.6	88.3
L203	HL_100YR_24HR	299.424	295.504	274.3	127.0	0.5	0.7	3.5	3.7	472.4
L206	HL_100YR_24HR	293.167	275.975	24.3	14.3	0.6	0.7	1.5	1.3	19.0
L208	HL_100YR_24HR	283.05	275.975	72.3	31.1	0.4	0.6	2.0	1.1	34.3
L210	HL_100YR_24HR	292.779	275.975	21.6	2.0	0.1	0.5	1.5	4.2	8.3
L213	HL_100YR_24HR	274.559	272.258	116.0	59.8	0.5	0.6	3.9	2.2	132.6
L216	HL_100YR_24HR	285.03	274.697	76.6	60.0	0.8	0.8	3.3	2.6	156.7
L217	HL_100YR_24HR	272.258	272.257	161.8	52.1	0.3	0.4	5.3	2.6	136.4
L218	HL_100YR_24HR	272.257	271.055	215.2	104.7	0.5	0.7	6.1	9.6	1007.3
L219	HL_100YR_24HR	271.055	268.297	207.3	129.8	0.6	0.6	6.1	12.3	1599.2
L220	HL_100YR_24HR	282.302	268.298	117.2	10.4	0.1	0.7	3.3	2.2	23.0
L221	HL_100YR_24HR	273.465	268.298	70.7	12.6	0.2	0.6	3.3	1.6	19.6
L222	HL_100YR_24HR	268.85	264.735	127.1	3.4	0.0	0.7	4.7	2.2	7.3
L226	HL_100YR_24HR	265.801	261.782	247.4	9.9	0.0	0.5	4.8	5.0	49.7

Mackenzie Drainage Model - Results - 1:100 Year Storm Event - Post Development

Name	Storm	Maximum Water Elevation	Maximum Water Elevation	Design Full Flow cms	Max Flow cms	Max Flow/Design Flow	Max Velocity m/s	Max Depth m	Unit Flow (m3/s/km2)	Drainage Area (km2)
L227	HL_100YR_24HR	264.735	261.782	1101.0	107.7	0.1	1.1	4.8	15.9	1714.1
L231	HL_100YR_24HR	271.655	257.072	156.3	5.8	0.0	0.8	3.1	5.7	33.3
L234	HL_100YR_24HR	327.741	313.15	553.2	35.2	0.1	0.9	2.4	3.1	110.8
L236	HL_100YR_24HR	313.15	311.112	600.9	39.8	0.1	0.9	2.7	3.9	154.7
L242	HL_100YR_24HR	323.508	313.15	150.4	8.8	0.1	0.5	2.4	2.5	21.9
L243	HL_100YR_24HR	302.422	301.251	68.4	3.0	0.0	1.6	3.3	1.0	3.1
L244	HL_100YR_24HR	301.251	299.424	625.1	91.7	0.1	0.8	3.4	3.0	271.7
L245	HL_100YR_24HR	307.577	301.251	274.0	90.6	0.3	1.1	3.3	2.9	265.5
L247	HL_100YR_24HR	309.951	307.577	93.3	7.8	0.1	0.4	2.7	1.7	13.5
L248	HL_100YR_24HR	324.531	307.577	214.5	2.1	0.0	0.5	2.7	4.2	9.0
L249	HL_100YR_24HR	331.416	327.741	59.7	16.4	0.3	0.3	1.6	1.8	29.6
L250	HL_100YR_24HR	261.782	257.072	1606.5	118.0	0.1	1.1	4.8	21.5	2538.4
L251	HL_100YR_24HR	293.282	275.975	76.1	7.4	0.1	0.8	1.5	2.2	16.1
L255	HL_100YR_24HR	284.714	283.05	176.5	5.1	0.0	0.8	2.0	0.9	4.5
L82	HL_100YR_24HR	500.621	351.277	155.3	12.8	0.1	1.5	1.3	2.6	33.3
L84	HL_100YR_24HR	370.699	351.277	214.5	13.7	0.1	0.9	1.3	2.0	27.3
L86	HL_100YR_24HR	351.277	295.559	47.4	32.2	0.7	1.5	1.6	6.0	194.7
L87	HL_100YR_24HR	297.051	295.559	70.2	16.5	0.2	0.2	1.6	3.5	58.3
L88	HL_100YR_24HR	295.559	292.209	33.6	50.6	1.5	0.7	2.2	8.1	409.0
L89	HL_100YR_24HR	306.924	292.209	196.6	8.2	0.0	0.9	2.2	2.7	22.0
L90	HL_100YR_24HR	292.209	280.516	397.1	48.8	0.1	1.3	2.5	10.9	531.7
L91	HL_100YR_24HR	280.516	261.782	2091.6	52.1	0.0	1.2	4.8	11.8	613.7
L93	HL_100YR_24HR	351.245	319.63	107.5	9.3	0.1	0.9	1.6	3.1	29.3
L94	HL_100YR_24HR	780.747	371.583	956.8	13.6	0.0	3.0	1.6	2.6	35.7
L95	HL_100YR_24HR	371.583	319.63	501.4	26.0	0.1	2.1	1.6	4.6	120.0
L96	HL_100YR_24HR	319.63	291.729	310.8	38.3	0.1	1.0	2.2	5.8	221.0
L97	HL_100YR_24HR	340.802	290.765	240.6	12.0	0.1	0.9	1.8	5.3	63.3
L98	HL_100YR_24HR	291.729	290.765	91.0	38.2	0.4	0.4	2.2	7.2	273.0
L99	HL_100YR_24HR	290.765	278.23	1343.2	54.7	0.0	1.0	2.2	8.6	472.3

Mackenzie Drainage Model - Results - 1:10 Year Storm Event - Pre Development

Name	Storm	Maximum Water Elevation	Maximum Water Elevation	Design Full Flow cms	Max Flow cms	Max Flow/Design Flow	Max Velocity m/s	Max Depth m	Unit Flow (m3/s/km2)	Drainage Area (km2)
L100	1in10 - 24 HR	292.405	276.923	182.1	1.2	0.0	0.6	0.9	8.3	9.7
L101	1in10 - 24 HR	276.923	268.228	390.6	8.9	0.0	0.7	3.2	57.6	510.7
L102	1in10 - 24 HR	287.735	268.228	256.0	1.2	0.0	0.7	3.2	9.4	11.3
L103	1in10 - 24 HR	717.376	358.937	177.2	2.6	0.0	1.7	0.5	11.9	30.6
L111	1in10 - 24 HR	386.88	340.789	583.4	8.6	0.0	1.5	0.9	11.2	96.0
L112	1in10 - 24 HR	371.727	331.643	162.3	5.0	0.0	1.1	1.0	4.6	23.2
L114	1in10 - 24 HR	582.178	342.995	675.4	1.4	0.0	1.0	0.5	11.8	16.9
L116	1in10 - 24 HR	395.059	331.052	455.6	1.5	0.0	0.8	0.7	19.5	29.6
L119	1in10 - 24 HR	340.789	309.615	649.2	11.6	0.0	1.3	1.3	9.8	113.7
L122	1in10 - 24 HR	310.578	306.361	22.3	14.7	0.7	0.9	1.5	7.3	106.9
L123	1in10 - 24 HR	309.615	306.361	225.3	13.2	0.1	0.8	1.5	9.4	124.1
L129	1in10 - 24 HR	293.678	283.23	810.2	18.6	0.0	0.8	1.7	31.6	587.8
L131	1in10 - 24 HR	321.216	313.505	54.8	3.7	0.1	0.5	1.5	11.5	43.1
L132	1in10 - 24 HR	313.505	292.821	63.1	12.9	0.2	0.8	1.5	7.5	96.7
L133	1in10 - 24 HR	292.821	284.008	175.1	18.5	0.1	0.3	1.2	7.4	137.2
L136	1in10 - 24 HR	283.23	273.019	286.1	18.3	0.1	0.9	1.6	33.2	609.1
L138	1in10 - 24 HR	273.019	269.881	1562.2	22.1	0.0	0.8	2.7	35.2	776.7
L140	1in10 - 24 HR	323.728	304.151	119.5	4.5	0.0	1.0	1.2	3.8	17.3
L150	1in10 - 24 HR	295.48	284.758	64.2	1.4	0.0	0.3	0.8	9.2	12.9
L151	1in10 - 24 HR	284.758	282.24	36.9	3.1	0.1	0.4	1.1	9.7	29.8
L155	1in10 - 24 HR	275.316	273.423	120.0	17.0	0.1	0.2	1.7	7.3	124.8
L158	1in10 - 24 HR	269.881	269.643	421.6	21.4	0.1	0.4	2.7	40.4	862.2
L168	1in10 - 24 HR	266.051	266.005	77.2	10.7	0.1	0.2	2.0	8.4	90.2
L170	1in10 - 24 HR	266.005	262.058	639.6	24.0	0.0	0.9	2.1	70.5	1694.5
L182	1in10 - 24 HR	255.386	249	3355.5	23.9	0.0	0.7	4.0	108.9	2605.0
L192	1in10 - 24 HR	304.151	284.842	133.1	5.3	0.0	0.8	1.2	9.6	51.2
L193	1in10 - 24 HR	284.842	269.881	254.8	6.1	0.0	0.8	2.7	11.3	68.4
L194	1in10 - 24 HR	728.735	386.88	3099.7	0.8	0.0	1.1	0.9	10.4	8.3
L195	1in10 - 24 HR	580.646	386.88	1730.3	4.0	0.0	1.6	0.9	9.0	36.1
L196	1in10 - 24 HR	342.995	321.831	249.1	3.2	0.0	0.4	1.4	12.3	39.7
L198	1in10 - 24 HR	331.643	321.831	315.2	11.6	0.0	1.1	1.4	4.0	46.3
L199	1in10 - 24 HR	321.831	316.817	1342.6	12.0	0.0	1.1	1.4	7.7	91.9
L200	1in10 - 24 HR	316.817	310.578	813.9	12.8	0.0	1.2	1.5	7.6	97.9
L201	1in10 - 24 HR	310.448	298.215	249.8	17.5	0.1	1.0	2.2	10.2	177.7
L202	1in10 - 24 HR	358.937	293.678	303.0	2.9	0.0	0.7	1.7	30.6	88.3
L203	1in10 - 24 HR	298.215	293.678	274.3	30.6	0.1	0.6	2.2	15.5	472.4
L206	1in10 - 24 HR	292.871	275.316	24.3	3.4	0.1	0.8	0.9	5.6	19.0
L208	1in10 - 24 HR	282.24	275.316	72.3	5.6	0.1	0.6	1.1	6.2	34.3
L210	1in10 - 24 HR	292.367	275.316	21.6	0.7	0.0	0.4	0.8	12.2	8.3
L213	1in10 - 24 HR	273.423	269.769	116.0	10.8	0.1	0.6	1.7	12.3	132.6
L216	1in10 - 24 HR	284.008	273.019	76.6	5.7	0.1	0.8	1.6	27.7	156.7
L217	1in10 - 24 HR	269.769	269.643	161.8	9.9	0.1	0.4	2.6	13.8	136.4
L218	1in10 - 24 HR	269.643	268.228	215.2	24.6	0.1	0.5	3.2	40.9	1007.3
L219	1in10 - 24 HR	268.228	266.005	207.3	25.6	0.1	0.4	3.2	62.5	1599.2

Mackenzie Drainage Model - Results - 1:10 Year Storm Event - Pre Development

Name	Storm	Maximum Water Elevation	Maximum Water Elevation	Design Full Flow cms	Max Flow cms	Max Flow/Design Flow	Max Velocity m/s	Max Depth m	Unit Flow (m3/s/km2)	Drainage Area (km2)
L220	1in10 - 24 HR	281.878	266.051	117.2	3.8	0.0	0.7	1.1	6.0	23.0
L221	1in10 - 24 HR	272.866	266.051	70.7	3.7	0.1	0.7	1.1	5.3	19.6
L222	1in10 - 24 HR	268.39	262.058	127.1	0.8	0.0	0.5	2.1	9.1	7.3
L226	1in10 - 24 HR	265.166	259.3	247.4	3.4	0.0	0.6	2.3	14.8	49.7
L227	1in10 - 24 HR	262.058	259.3	1101.0	23.8	0.0	0.8	2.3	72.0	1714.1
L231	1in10 - 24 HR	270.773	255.386	156.3	1.2	0.0	0.7	1.4	28.6	33.3
L234	1in10 - 24 HR	326.934	311.936	553.2	6.2	0.0	0.7	1.1	17.9	110.8
L236	1in10 - 24 HR	311.936	310.448	600.9	9.0	0.0	0.9	2.0	17.1	154.7
L242	1in10 - 24 HR	323.332	311.936	150.4	2.0	0.0	0.6	1.1	10.8	21.9
L243	1in10 - 24 HR	302.152	299.64	68.4	0.4	0.0	0.7	1.6	7.5	3.1
L244	1in10 - 24 HR	299.64	298.215	222.3	22.0	0.1	0.6	2.2	12.3	271.7
L245	1in10 - 24 HR	306.361	299.64	274.0	22.7	0.1	1.1	1.6	11.7	265.5
L247	1in10 - 24 HR	309.576	306.361	93.3	0.9	0.0	0.3	1.5	15.7	13.5
L248	1in10 - 24 HR	324.207	306.361	214.5	0.6	0.0	0.3	1.5	14.7	9.0
L249	1in10 - 24 HR	331.052	326.934	59.7	1.8	0.0	0.3	0.8	16.3	29.6
L250	1in10 - 24 HR	259.3	255.386	1606.5	24.0	0.0	0.7	2.3	105.9	2538.4
L251	1in10 - 24 HR	292.763	275.316	76.1	2.3	0.0	0.7	0.8	7.0	16.1
L255	1in10 - 24 HR	284.191	282.24	176.5	1.1	0.0	0.4	1.1	4.2	4.5
L82	1in10 - 24 HR	500.336	350.678	155.3	3.2	0.0	1.0	0.7	10.6	33.3
L84	1in10 - 24 HR	370.388	350.678	214.5	3.5	0.0	1.0	0.7	7.7	27.3
L86	1in10 - 24 HR	350.678	294.785	47.4	7.6	0.2	1.0	0.8	25.8	194.7
L87	1in10 - 24 HR	296.7	294.785	70.2	3.5	0.1	0.2	0.8	16.6	58.3
L88	1in10 - 24 HR	294.785	290.918	33.6	7.0	0.2	0.4	0.9	58.4	409.0
L89	1in10 - 24 HR	306.496	290.918	196.6	2.1	0.0	0.6	0.9	10.6	22.0
L90	1in10 - 24 HR	290.918	279.007	397.1	7.9	0.0	0.8	1.0	66.9	531.7
L91	1in10 - 24 HR	279.007	259.3	2091.6	8.3	0.0	0.7	2.3	73.6	613.7
L93	1in10 - 24 HR	350.644	318.875	107.5	2.5	0.0	0.8	0.9	11.8	29.3
L94	1in10 - 24 HR	780.38	370.813	956.8	3.4	0.0	2.1	0.8	10.6	35.7
L95	1in10 - 24 HR	370.813	318.875	501.4	6.2	0.0	1.5	0.9	19.2	120.0
L96	1in10 - 24 HR	318.875	290.794	310.8	10.3	0.0	0.8	1.3	21.4	221.0
L97	1in10 - 24 HR	340.403	289.911	240.6	2.9	0.0	0.8	0.9	21.9	63.3
L98	1in10 - 24 HR	290.794	289.911	91.0	8.5	0.1	0.3	1.3	32.1	273.0
L99	1in10 - 24 HR	289.911	276.923	1343.2	10.5	0.0	0.7	0.9	44.8	472.3

Mackenzie Drainage Model - Results - 1:10 Year Storm Event - Post Development

Name	Storm	Maximum Water Elevation (US) m	Maximum Water Elevation (DS) m	Design Full Flow cms	Max Flow cms	Max Flow/Design Flow (fraction)	Max Velocity m/s	Max Depth m	Unit Flow (m3/s/km2)	Drainage Area (km2)	%Change Existing to Future
L100	1in10 - 24 HR	292.394	276.994	182.1	1.0	0.0	0.5	1.0	0.2	0.2	-0.1
L101	1in10 - 24 HR	276.994	268.818	390.6	10.2	0.0	0.7	3.8	0.0	0.2	0.1
L102	1in10 - 24 HR	287.775	268.818	256.0	1.4	0.0	0.6	3.8	0.1	0.2	0.1
L103	1in10 - 24 HR	717.348	358.961	177.2	2.2	0.0	1.6	0.6	0.1	0.2	-0.2
L111	1in10 - 24 HR	386.879	340.817	583.4	8.6	0.0	1.5	0.9	0.0	0.2	0.0
L112	1in10 - 24 HR	371.933	331.724	162.3	7.7	0.0	1.3	1.1	0.0	0.3	0.3
L114	1in10 - 24 HR	582.213	343.194	338.8	1.6	0.0	1.0	0.7	0.2	0.3	0.1
L116	1in10 - 24 HR	395.092	331.092	455.6	2.5	0.0	0.8	0.7	0.1	0.3	0.4
L119	1in10 - 24 HR	340.817	309.686	649.2	12.3	0.0	1.3	1.4	0.0	0.3	0.1
L122	1in10 - 24 HR	310.809	306.862	22.3	22.6	1.0	1.1	2.0	0.0	0.3	0.4
L123	1in10 - 24 HR	309.686	306.862	225.3	14.3	0.1	0.8	2.0	0.0	0.3	0.1
L129	1in10 - 24 HR	294.318	283.781	810.2	36.7	0.0	1.0	2.3	0.0	0.2	0.5
L131	1in10 - 24 HR	321.216	313.502	54.8	3.7	0.1	0.5	1.5	0.1	0.4	0.0
L132	1in10 - 24 HR	313.502	292.837	63.1	12.8	0.2	0.8	1.5	0.0	0.4	0.0
L133	1in10 - 24 HR	292.837	284.081	175.1	19.5	0.1	0.3	1.3	0.0	0.4	0.1
L136	1in10 - 24 HR	283.781	273.538	286.1	36.4	0.1	1.1	2.1	0.0	0.4	0.5
L138	1in10 - 24 HR	273.538	270.474	1562.2	42.5	0.0	1.0	3.3	0.0	0.4	0.5
L140	1in10 - 24 HR	323.728	304.152	119.5	4.5	0.0	1.0	1.2	0.1	0.5	0.0
L150	1in10 - 24 HR	295.48	284.768	64.2	1.4	0.0	0.3	0.8	0.3	0.5	0.0
L151	1in10 - 24 HR	284.768	282.325	36.9	3.1	0.1	0.4	1.2	0.2	0.5	0.0
L155	1in10 - 24 HR	275.353	273.49	120.0	19.1	0.2	0.2	1.8	0.0	0.5	0.1
L158	1in10 - 24 HR	270.474	270.238	421.6	37.6	0.1	0.4	3.3	0.0	0.5	0.4
L168	1in10 - 24 HR	266.389	266.389	77.2	10.9	0.1	0.2	2.4	0.1	0.6	0.0
L170	1in10 - 24 HR	266.389	262.444	639.6	35.1	0.1	0.9	2.4	0.0	0.6	0.3
L182	1in10 - 24 HR	255.662	249	3355.5	33.9	0.0	0.8	4.0	0.0	0.6	0.3
L192	1in10 - 24 HR	304.152	284.84	133.1	5.0	0.0	0.8	1.2	0.1	0.5	-0.1
L193	1in10 - 24 HR	284.84	270.474	254.8	6.0	0.0	0.8	3.3	0.1	0.5	0.0
L194	1in10 - 24 HR	728.735	386.879	3099.7	0.8	0.0	1.1	0.9	0.8	0.6	0.0
L195	1in10 - 24 HR	580.646	386.879	1730.3	4.0	0.0	1.6	0.9	0.2	0.6	0.0
L196	1in10 - 24 HR	343.194	322.171	862.0	4.8	0.0	0.8	1.8	0.1	0.3	0.3
L198	1in10 - 24 HR	331.724	322.171	315.2	13.6	0.0	1.1	1.8	0.0	0.3	0.1
L199	1in10 - 24 HR	322.171	317.176	1342.6	19.1	0.0	1.3	1.8	0.0	0.7	0.4
L200	1in10 - 24 HR	317.176	310.809	813.9	20.4	0.0	1.4	1.8	0.0	0.7	0.4
L201	1in10 - 24 HR	310.426	298.331	249.8	18.3	0.1	1.0	2.3	0.0	0.3	0.0
L202	1in10 - 24 HR	358.961	294.318	28.2	4.1	0.1	0.8	2.3	0.1	0.2	0.3
L203	1in10 - 24 HR	298.331	294.318	274.3	38.3	0.1	0.6	2.3	0.0	0.4	0.2
L206	1in10 - 24 HR	292.872	275.353	24.3	3.3	0.1	0.8	0.9	0.2	0.7	0.0
L208	1in10 - 24 HR	282.325	275.353	72.3	7.5	0.1	0.6	1.2	0.1	0.5	0.3
L210	1in10 - 24 HR	292.366	275.353	21.6	0.7	0.0	0.4	0.9	1.0	0.7	0.0
L213	1in10 - 24 HR	273.49	270.305	116.0	12.4	0.1	0.5	1.9	0.0	0.5	0.1
L216	1in10 - 24 HR	284.081	273.538	76.6	7.3	0.1	0.8	2.1	0.1	0.4	0.2
L217	1in10 - 24 HR	270.305	270.238	161.8	10.2	0.1	0.4	3.2	0.1	0.7	0.0
L218	1in10 - 24 HR	270.238	268.818	215.2	39.7	0.2	0.6	3.8	0.0	0.4	0.4
L219	1in10 - 24 HR	268.818	266.389	207.3	40.0	0.2	0.5	3.8	0.0	0.2	0.4
L220	1in10 - 24 HR	281.88	266.389	117.2	3.8	0.0	0.7	1.4	0.1	0.5	0.0
L221	1in10 - 24 HR	272.865	266.389	70.7	3.7	0.1	0.7	1.4	0.1	0.6	0.0
L222	1in10 - 24 HR	268.39	262.444	127.1	0.8	0.0	0.5	2.4	0.7	0.6	0.0
L226	1in10 - 24 HR	265.128	259.721	247.4	3.4	0.0	0.6	2.7	0.2	0.6	0.0
L227	1in10 - 24 HR	262.444	259.721	1101.0	34.4	0.0	0.9	2.7	0.0	0.6	0.3
L231	1in10 - 24 HR	270.843	255.662	156.3	1.4	0.0	0.7	1.7	0.4	0.6	0.2
L234	1in10 - 24 HR	327.071	312.046	553.2	8.9	0.0	0.8	1.2	0.0	0.3	0.3
L236	1in10 - 24 HR	312.046	310.426	600.9	11.3	0.0	0.9	2.0	0.1	0.7	0.2
L242	1in10 - 24 HR	323.332	312.046	150.4	2.0	0.0	0.6	1.2	0.4	0.7	0.0
L243	1in10 - 24 HR	302.22	300.011	68.4	0.8	0.0	1.1	2.0	0.9	0.7	0.5
L244	1in10 - 24 HR	300.011	298.331	222.3	29.3	0.1	0.6	2.3	0.0	0.7	0.2
L245	1in10 - 24 HR	306.862	300.011	274.0	30.1	0.1	1.1	2.0	0.0	0.4	0.2
L247	1in10 - 24 HR	309.885	306.862	63.3	2.6	0.0	0.4	2.0	0.3	0.8	0.7
L248	1in10 - 24 HR	324.21	306.862	96.3	0.6	0.0	0.2	2.0	0.6	0.4	0.0

Mackenzie Drainage Model - Results - 1:10 Year Storm Event - Post Development

Name	Storm	Maximum Water Elevation (US) m	Maximum Water Elevation (DS) m	Design Full Flow cms	Max Flow cms	Max Flow/Design Flow (fraction)	Max Velocity m/s	Max Depth m	Unit Flow (m3/s/km2)	Drainage Area (km2)	%Change Existing to Future
L249	1in10 - 24 HR	331.092	327.071	59.7	2.8	0.0	0.3	1.0	0.3	0.8	0.4
L250	1in10 - 24 HR	259.721	255.662	1606.5	34.0	0.0	0.7	2.7	0.0	0.1	0.3
L251	1in10 - 24 HR	292.761	275.353	76.1	2.3	0.0	0.7	0.9	0.3	0.7	0.0
L255	1in10 - 24 HR	284.253	282.325	176.5	1.4	0.0	0.5	1.2	0.5	0.8	0.2
L82	1in10 - 24 HR	500.336	350.678	155.3	3.2	0.0	1.0	0.7	0.0	0.0	0.0
L84	1in10 - 24 HR	370.388	350.678	214.5	3.5	0.0	1.0	0.7	0.0	0.0	0.0
L86	1in10 - 24 HR	350.678	294.785	47.4	7.6	0.2	1.0	0.8	0.0	0.0	0.0
L87	1in10 - 24 HR	296.7	294.785	70.2	3.5	0.1	0.2	0.8	0.0	0.1	0.0
L88	1in10 - 24 HR	294.785	290.917	33.6	7.0	0.2	0.4	0.9	0.0	0.1	0.0
L89	1in10 - 24 HR	306.495	290.917	196.6	2.1	0.0	0.6	0.9	0.0	0.1	0.0
L90	1in10 - 24 HR	290.917	279.107	397.1	7.9	0.0	0.8	1.1	0.0	0.0	0.0
L91	1in10 - 24 HR	279.107	259.721	2091.6	10.0	0.0	0.7	2.7	0.0	0.1	0.2
L93	1in10 - 24 HR	350.644	318.876	107.5	2.5	0.0	0.8	0.9	0.0	0.1	0.0
L94	1in10 - 24 HR	780.38	370.811	956.8	3.4	0.0	2.1	0.8	0.0	0.1	0.0
L95	1in10 - 24 HR	370.811	318.876	501.4	6.2	0.0	1.5	0.9	0.0	0.1	0.0
L96	1in10 - 24 HR	318.876	290.793	310.8	10.3	0.0	0.8	1.3	0.0	0.1	0.0
L97	1in10 - 24 HR	340.4	289.939	240.6	2.8	0.0	0.7	0.9	0.1	0.2	0.0
L98	1in10 - 24 HR	290.793	289.939	91.0	8.5	0.1	0.3	1.3	0.0	0.1	0.0
L99	1in10 - 24 HR	289.939	276.994	1343.2	11.7	0.0	0.7	1.0	0.0	0.2	0.1