2022-07-07

Public

Kiley Marchuk
Planning & Development Services
Strathcona County
2001 Sherwood Drive
Sherwood Park, AB T8A 3W7

Dear Ms. Marchuk,

Please find enclosed the unsigned final submission of the Astotin Creek Resiliency Study: Drainage Master Plan. As per discussions between Strathcona County and WSP, in addition to the previously provided signed and sealed report, we are also providing this document as an unsigned final version to enable the County to reduce the file size to meet requirements for sharing this report on the County's website.

As this file is not a locked document, WSP cannot guarantee that this report has not been modified and as such should not be relied upon for engineering purposes. When referencing this report for any purpose related to future planning or design, only the full signed and sealed document should be used. When sharing these reports on the County's website, WSP requests that a statement, or this cover letter, is included directing users to contact the County for the full final report as required.

Yours sincerely,

Joshua Maxwell, M.Sc., P.Eng. PMP.
Team Lead, Water Resources,
Municipal Engineering

Encl. Astotin Creek Resiliency Study: Drainage Master Plan

10909 Jasper Avenue, Suite 1200
Edmonton, Alberta
T6B 2R1

T: +1 780-466-6555

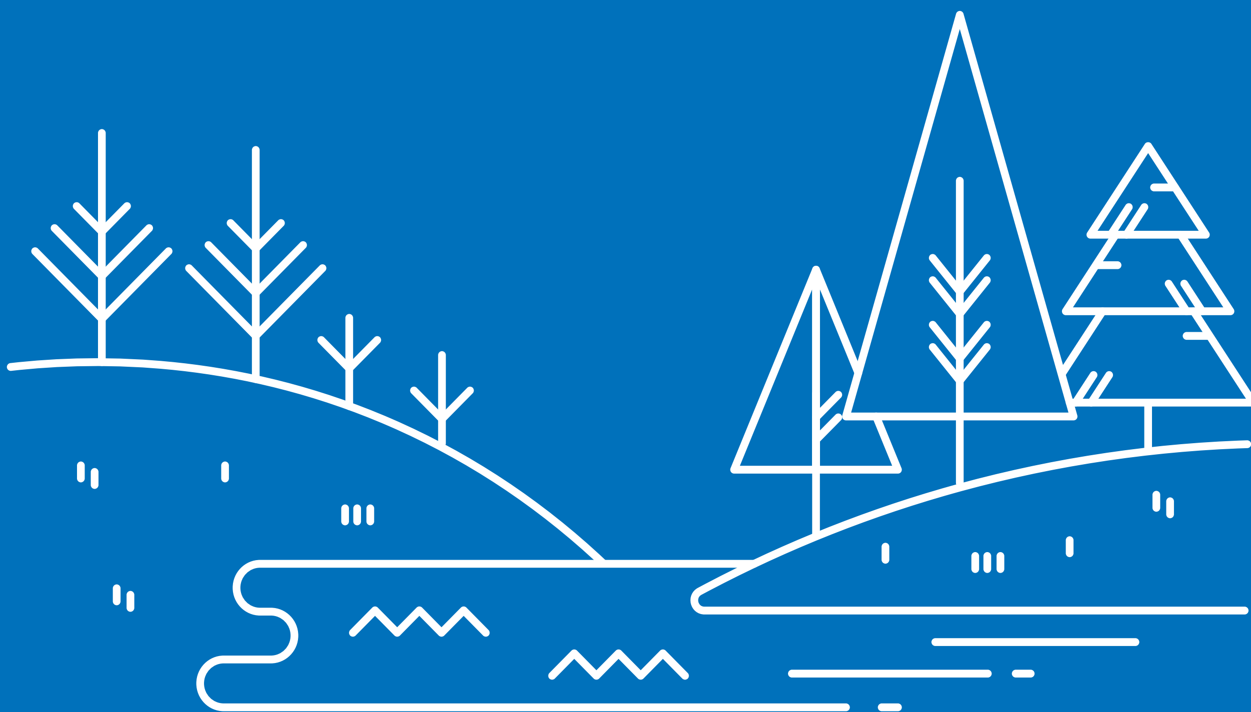
wsp.com

ASTOTIN CREEK

RESILIENCY STUDY

Drainage Master Plan

June 2022



STRATHCONA COUNTY

wsp

Territorial Acknowledgment

Strathcona County honours the past, present and future First Peoples of this land. We acknowledge that this land has embraced and nourished the Cree, Métis, Blackfoot, amongst many others, for generations. We recognize Strathcona County is within Treaty Six Territory and the homeland of the Métis Nation of Alberta, Region Two and Four.

Strathcona County has an inherent responsibility to foster healthier relationships with Indigenous Partners. We will strive to respond to the Calls to Action as outlined by the Truth and Reconciliation Commission.

Strathcona County is close in proximity to Enoch Cree Nation (maskêkosihk), Ermineskin Cree Nation (neyaskweyahk), Louis Bull Tribe (kisipatinahk), Michel First Nation, Montana First Nation (akamihk), Papaschase First Nation, Samson Cree Nation (nipisikopahk), and Saddle Lake Cree Nation (onihcikiskwapiwinihk).

Furthermore, the geographic boundaries of Strathcona County includes parts of Regions Two and Four of the Métis Nation of Alberta, and are near the Elizabeth Métis Settlement, Fishing Lake Métis Settlement, Buffalo Lake Métis Settlement, and Kikino Métis Settlement.

We recognize the importance of allying with First Peoples and taking steps to foster a healthier relationship. As such, we will demonstate ***manacitôwin****, the Cree word meaning respect for each other.*

Signatures

Drainage Plan
Prepared by

Juan Upegui, M.Eng., P.Eng.
Water Resources Engineer, Infrastructure

Watershed Hydrology and Creek Hydraulics
Prepared by

Ana Hosseinpour, Ph.D., P.Eng.
Water Resource Engineer, ERI

Reviewed by

Vincent Cormier M.Sc., P.Eng.
Hydrotechnical Engineering Lead, ERI

Permit to practice

Disclaimer

WSP prepared this report solely for the use of the intended recipient, Strathcona County, in accordance with the professional services agreement. The intended recipient is solely responsible for the disclosure of any information contained in this report. The content and opinions contained in the present report are based on the observations and/or information available to WSP at the time of preparation. If a third party makes use of, relies on, or makes decisions in accordance with this report, said third party is solely responsible for such use, reliance or decisions. WSP does not accept responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken by said third party based on this report. This limitations statement is considered an integral part of this report.

The original of this digital file will be conserved by WSP for a period of not less than 10 years. As the digital file transmitted to the intended recipient is no longer under the control of WSP, its integrity cannot be assured. As such, WSP does not guarantee any modifications made to this digital file subsequent to its transmission to the intended recipient.

Table of Contents

FIGURES

TABLES

APPENDICES

Appendix A – Land Cover Maps

Appendix B – Municipal Development Plan Maps

Appendix C – Stormwater Infrastructure Drawing Set Table

Appendix D – Flood Inundation Maps

Appendix E – Flood-Prone Areas

Appendix F – Flood-Prone Areas Details

Appendix G – Hydraulic Model Results & 2018 Flood Comparison

Appendix H – 100-Year Flood Hazard Maps

Appendix I –100-Year Flood Inundation Map (Climate Change Included)

INTRODUCTION

1

1 Introduction

1.1 Astotin Creek Resiliency Study

Strathcona County (the County) engaged WSP Canada Inc. (WSP) to undertake a detailed study of the Astotin Creek watershed within the County's jurisdiction. The Astotin Creek watershed has experienced various flooding events in recent years, which have resulted in flooding of farmlands and County roads and threatened private residences. Historically, the watershed has experienced significant beaver activity and anthropogenic changes, including creek alterations, vegetation removal, and land development. The Astotin Creek Resiliency Study was initiated to understand historical changes in the watershed and current conditions to manage current and future water quantity and quality implications.

The scope of work for the Astotin Creek Resiliency Study included the following components:

- State of the Watershed Report;
- Drainage Master Plan;
- What We Heard and What We Did Engagement Summary;
- Resiliency Action Plan.

1.2 Scope of this report

The main objective of the Drainage Master Plan (DMP) is to assess the existing conditions in Astotin Creek and its watershed and develop a conceptual plan that addresses current and future drainage needs. The scope of work for the DMP included the following tasks:

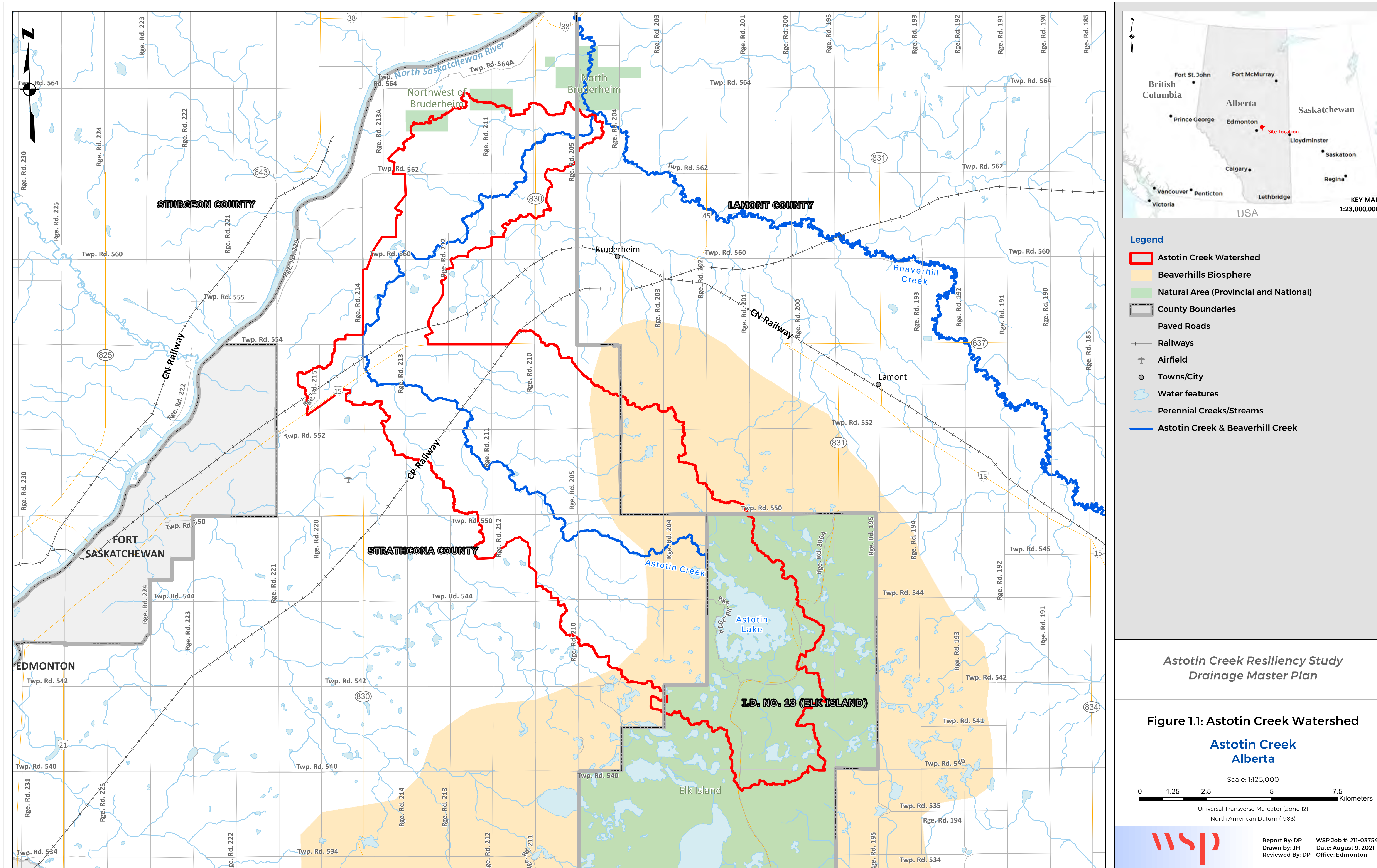
- Reviewing background information;
- Defining the watershed boundary and principal sub-watersheds;
- Characterizing the watershed, including hydrologic analyses;
- Determining the 100-year pre-development unit area release rate for the watershed;
- Determining the existing hydraulic conditions in the creek;
- Developing flood inundation maps for the 20-year, 50-year, 100-year floods and 100-year flood with climate change consideration;
- Identifying flood hazard areas, floodway, and flood fringes for the 100-year flood;
- Assessing the impact of climate change on flood events;
- Identifying issues and constraints in the existing drainage system and creek;
- Developing a future drainage servicing concept for the watershed;
- Outlining stormwater management design parameters and criteria for future developments.

1.3 Study Area

The Astotin Creek watershed is located approximately 30 km northeast of Sherwood Park, Alberta. The watershed includes 184.3 km^2 (18,430 ha) of land from Strathcona County, Lamont County, and Improvement District No. 13 (Elk Island National Park), as shown in Figure 1.1.

The breakdown of the watershed by municipality is as follows: 135.5 km^2 (73.5%) within Strathcona County, 36.0 km^2 (19.5%) within Elk Island National Park, and 12.8 km^2 (7.0%) within Lamont County. The Astotin Creek watershed is part of the Beaverhill system, one of the twelve North Saskatchewan River sub-watersheds (North Saskatchewan Watershed Alliance, n.d.).

Astotin Creek is the principal watercourse draining the watershed. The creek originates in Astotin Lake, within Elk Island National Park, and flows in a northerly direction toward the North Saskatchewan River. Astotin Creek has a reach approximately 50 km long that meanders in an arc fashion to the north, joining Beaverhill Creek east of Range Road (RR) 205, about 2.5 km north of Township Road (TR) 562. From the confluence of the creeks, water flows to the north for about 5 km, where it discharges to the North Saskatchewan River.



Astotin Creek Resiliency Study
Drainage Master Plan

Figure 1.1: Astotin Creek Watershed

Astotin Creek
Alberta

Scale: 1:125,000

0 1.25 2.5 5 7.5 Kilometers

Universal Transverse Mercator (Zone 12)
North American Datum (1983)

WSP

Report By: DP
Drawn by: JH
Reviewed By: DP

WSP Job #: 211-03754-00
Date: August 9, 2021
Office: Edmonton

Notes: Data provided by Altalis; Natural Resource Canada; ESRI

1.3.1 Existing Land Uses

Predominant land cover types in the watershed consist of agricultural and forested lands, with pockets of open water and urbanized lands. Figure 1.2 illustrates the land cover type in the watershed within Strathcona County. More detailed land cover type figures are provided in Appendix A. Table 1-1 provides a land cover breakdown based on the Government of Canada (2021).

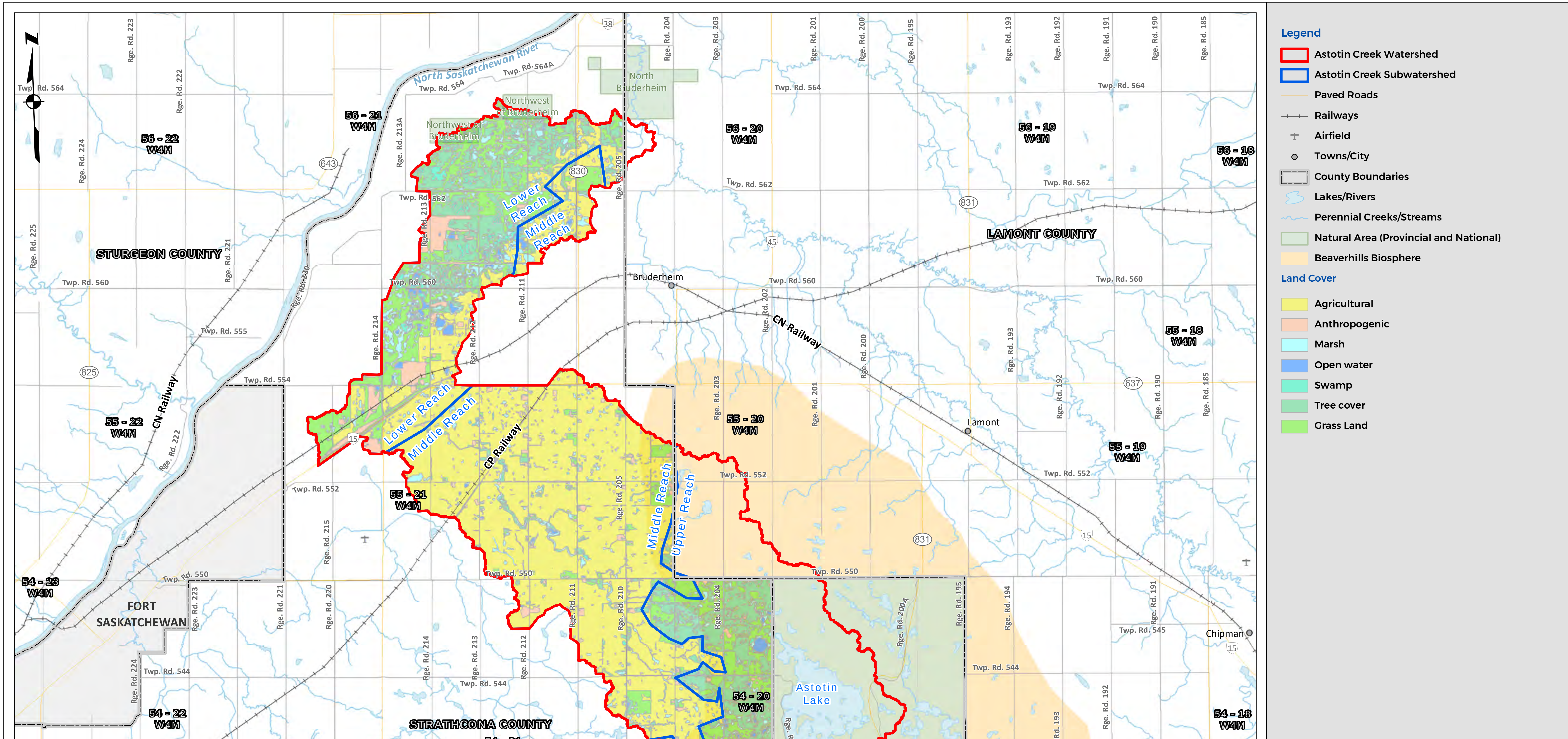
Table 1-1: Land cover breakdown in the Astotin Creek watershed

Land Cover Type	Coverage	Area (km^2)
Agricultural	60%	110.6
Forested	30%	55.3
Open water	5%	9.2
Urbanized (Industrialized)	5%	9.2

Figure 1.3 illustrates the current land use plan in the watershed within Strathcona County (Strathcona County, 2021a). The portion of the watershed south of Highway 15 consists almost entirely of Agriculture: General (AG) land uses. North of Highway 15, the watershed includes Heavy Industrial (Heartland) (IHH) land uses, as well as some Agriculture: General (AG) and Medium Industrial (Heartland) (IMH) land uses. Along the north end of the watershed boundary, there are four quarter sections of land which are part of the Northwest of Bruderheim Natural Area. Existing industrial developments in Alberta's Industrial Heartland (AIH) portion of the watershed (IHH and IMH land uses) encompass approximately 7 km^2 of land. For perspective, the total AIH area within the County's portion of the watershed comprises roughly 54 km^2.

The watershed is in Strathcona County's Rural Service Area (Map 2 in Appendix B) and includes portions of the Heartland Policy Area, Agriculture Large Holdings Policy Area, and the Beaver Hills Policy Area (Strathcona County, 2020). The Heartland Policy Area is the County's portion of the AIH and is intended to accommodate industrial developments (heavy/medium/light industrial, transitional, and agri-industrial land uses) and conserve the North Saskatchewan River Valley. Some development has occurred within the Heartland Policy Area over the past five to ten years, though significant development is anticipated in the future. The Agriculture Large Holdings Policy Area includes large agricultural operations with limited commercial and residential land uses (primarily to support agricultural operations). Most of the Agriculture Large Holdings Policy Area in the watershed appears to be already developed. The main purpose of the Beaver Hills Policy Area is to conserve the Beaver Hills Moraine and support agricultural operations, recreation, tourism, and limited rural residential land use. Very limited future development is expected in the Beaver Hills Policy Area.

The Beaver Hills Biosphere was created in recognition of its abundant forests, wetland, and lake habitats, which support high boreal biodiversity within and outside protected areas. As a UNESCO Biosphere Reserve, it aims to demonstrate how sustainable development can be achieved in a conserved and lived-in landscape through regional cooperation on land management, education, and research. Elk Island National Park and the Beaver Hills Biosphere play an important role in sustaining the ecological function and benefit of the Upper Reach of the Astotin Creek Watershed and through the creek's hydrogeological and habitat connections its downstream reaches as well.



Astotin Creek Resiliency Study
Drainage Master Plan

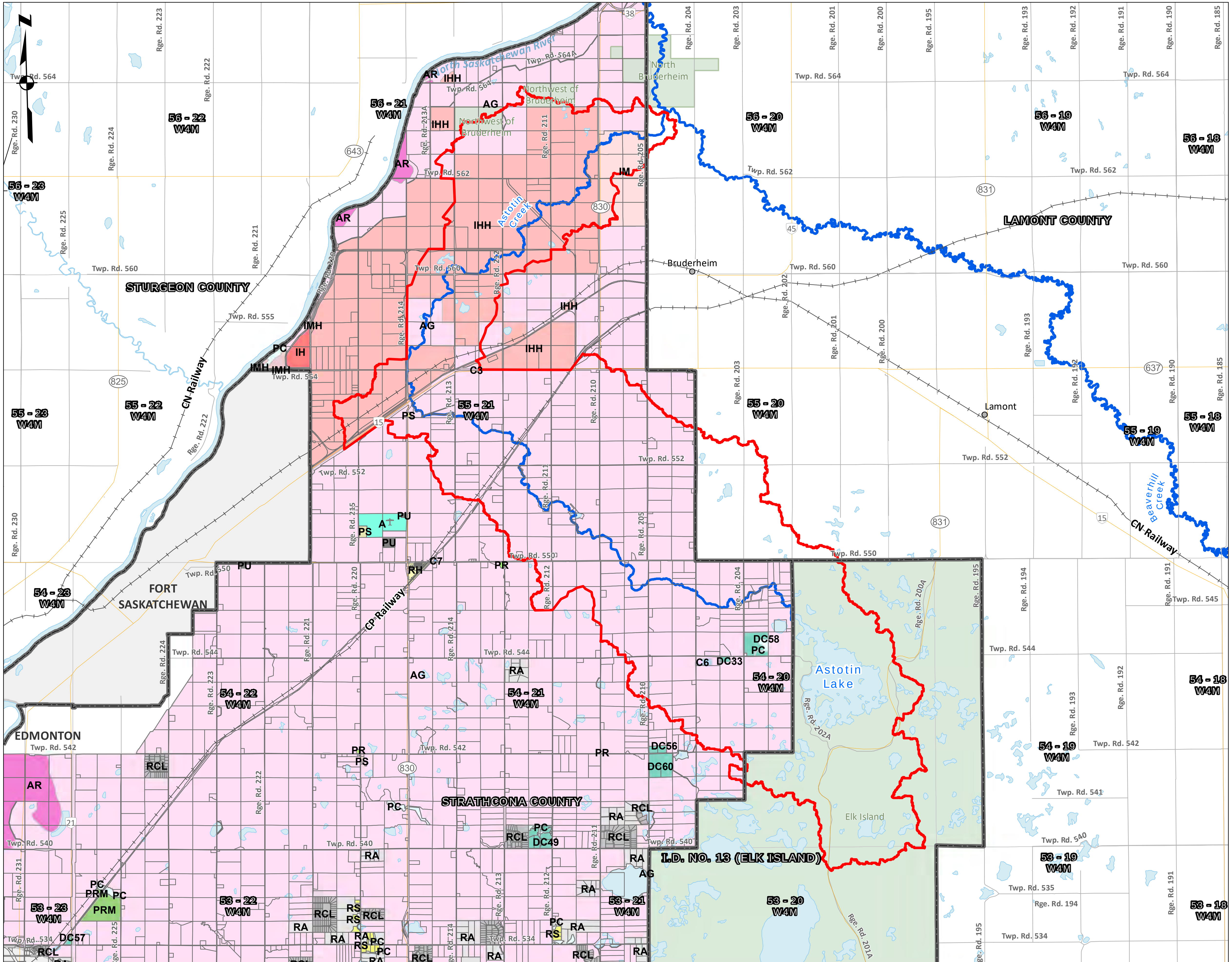
Figure 1.2: Land Cover

Astotin Creek
Alberta

Report By: JU
Drawn by: JH
Reviewed By: DP

WSP Job #: 211-03754-00
Date: August 9, 2021
Office: Edmonton

Notes:Data provided by Altalis;Natural Resource Canada; ESRI



Legend

- Astotin Creek Watershed
- Legal Boundaries
- Paved Roads
- Railways
- Airfield
- Towns/City
- County Boundaries
- Lakes/Rivers
- Astotin Creek & Beaverhill Creek
- Natural Area (Provincial and National)

Existing Land Use Bylaw

- A - Airport
- AD - Agriculture: Future Development
- AG - Agriculture: General
- AR - Agriculture: River Valley
- C3 - Highway Commercial
- C6 - Recreation Commercial
- C7 - Local Commercial
- DC - Direct Control
- IH - Heavy Industrial
- IHH - Heavy Industrial (Heartland)
- IM - Medium Industrial
- IMH - Medium Industrial (Heartland)
- PC - Conservation
- PR - Recreation
- PRM - Public Recreation Major
- PS - Public Services
- PU - Public Utilities
- RA - Rural Residential/Agriculture
- RCL - Low Density Country Residential
- RH - Hamlet
- RS - Small Holdings

Astotin Creek Resiliency Study
Drainage Master Plan

Figure 1.3: Existing Land Use Bylaw

Astotin Creek
Alberta

Scale: 1:125,000

0 0.5 1 2 3 4 5 Kilometers

Universal Transverse Mercator (Zone 12)
North American Datum (1983)

Report By: JU
Drawn by: JH
Reviewed By: JU

WSP Job #: 211-03754-00
Date: August 9, 2021
Office: Edmonton

Notes: Data provided by Altalis; Natural Resource Canada; ESRI

1.3.2 Topography and Drainage Patterns

Figure 1.4 illustrates the ground topography in the watershed. Ground elevations in the watershed range between 738 m near Astotin Lake and 600 m at the confluence of Astotin Creek and Beaverhill Creek. Much of the ground elevation variation occurs southeast of the Canadian Pacific (CP) Railway tracks located south of Highway 15. Ground elevations vary between 738 m and 648 m, generally south of Highway 15. North of Highway 15, the topography of the watershed is generally flat, with ground elevations varying between 648 m and 600 m.

Drainage patterns throughout the watershed generally follow pre-development or natural patterns, except as modified due to the transportation network, AIH and agricultural developments. North of Highway 15, the watershed is generally poorly drained, as evidenced by many wetlands and the lack of well-defined drainage paths. The watershed displays well-defined drainage paths with few wetlands or depressions south of the CP Railway tracks. The watershed section between Highway 15 and the CP Railway tracks is poorly drained (various wetlands and depressions) as there is little variation in ground elevations.

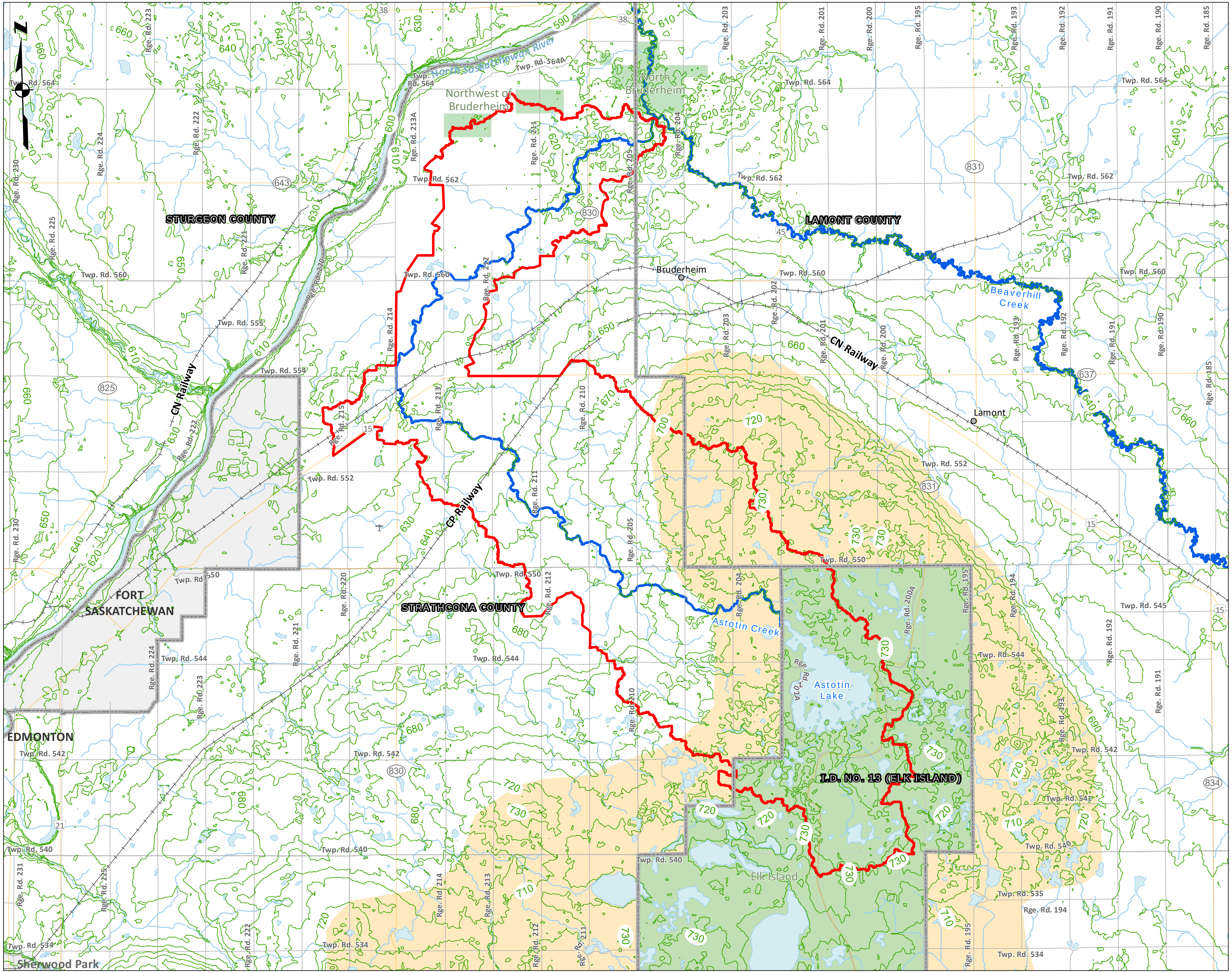
1.3.3 Existing Drainage System

The existing drainage system in the watershed consists primarily of drainageways, roadside ditches, culvert crossings, wet pond stormwater management facilities (SWMF), wetlands, dugouts, and depressions. Figure 1.5 displays some of the drainage infrastructure in the watershed. The location of some culvert crossings and wet pond SWMFs were inferred from background information (i.e., survey data, aerial imagery, drawings, etc.).

Strathcona County owns and maintains most hydraulic structures in the watershed, except those located within highway right-of-way (Alberta Transportation) and private crossings. The wet pond SWMFs in the AIH are privately owned and operated. Most of the drainageways in the watershed are located within private property and may include private bridges or culvert crossings. In other instances, sections of drainageways are located within road right-of-way after being altered due to the development of the transportation network.

The number of culvert crossings (excluding private access road crossings) in the watershed is estimated to be over 100. Survey data collected by the County was available for about 20 crossings, including some located along the creek channel. As part of the project, 12 culvert crossings were surveyed along the creek channel. The survey data indicated that culvert crossing pipe diameters ranged between 400 mm and 5,000 mm, including infrastructure along the creek alignment. Outside of the creek channel, there are two bridge-size structures (culvert diameters greater than 1500 mm).

The watershed currently includes 11 wet pond SWMFs. These are located within lands owned by CN Railway, TC Energy, ATCO Energy Solutions, Enbridge, Wolf Midstream, and InterPipeline Ltd. All these facilities are regulated by Alberta Environment and/or Alberta Energy Regulator (AER). Facilities regulated by AER are recommended to release collected runoff back to the environment but only after successful water quality testing. AER regulated facilities can discharge collected runoff to a watercourse if permitted by AEP (Environmental and Protection Enhancement Act approval) or may hold runoff for use as process water (i.e., water is not returned to the creek system). Reuse of runoff as process water requires proper water diversion licensing. SWMFs in the AIH were sized to store the 100-year, 24-hour rainfall with stormwater release to Astotin Creek or drainageways only after successful water quality testing, as required by AER. All AIH SWMFs within the Astotin Creek watershed include either control structures, valves, or pump stations designed to restrict discharges to 4.1 l/s/ha, which is the current allowable unit area release rate for the 100-year event. The 4.1 l/s/ha value was adopted in place of a watershed-specific unit area release rate and was based on studies for watersheds similar to the Astotin Creek watershed. While all AIH SWMFs include a release mechanism, collected runoff may be retained for industrial processes in some instances.



Legend

- Astotin Creek Watershed
- 10m Elevation Contour (masl)
- Beaverhills Biosphere
- Natural Area (Provincial and National)
- County Boundaries
- Paved Roads
- Railways
- Airfield
- Towns/City
- Water features
- Perennial Creeks/Streams
- Astotin Creek & Beaverhill Creek

Astotin Creek Resiliency Study
Drainage Master Plan

Figure 1.4: Elevation Contours

Astotin Creek
Alberta

Scale: 1:125,000

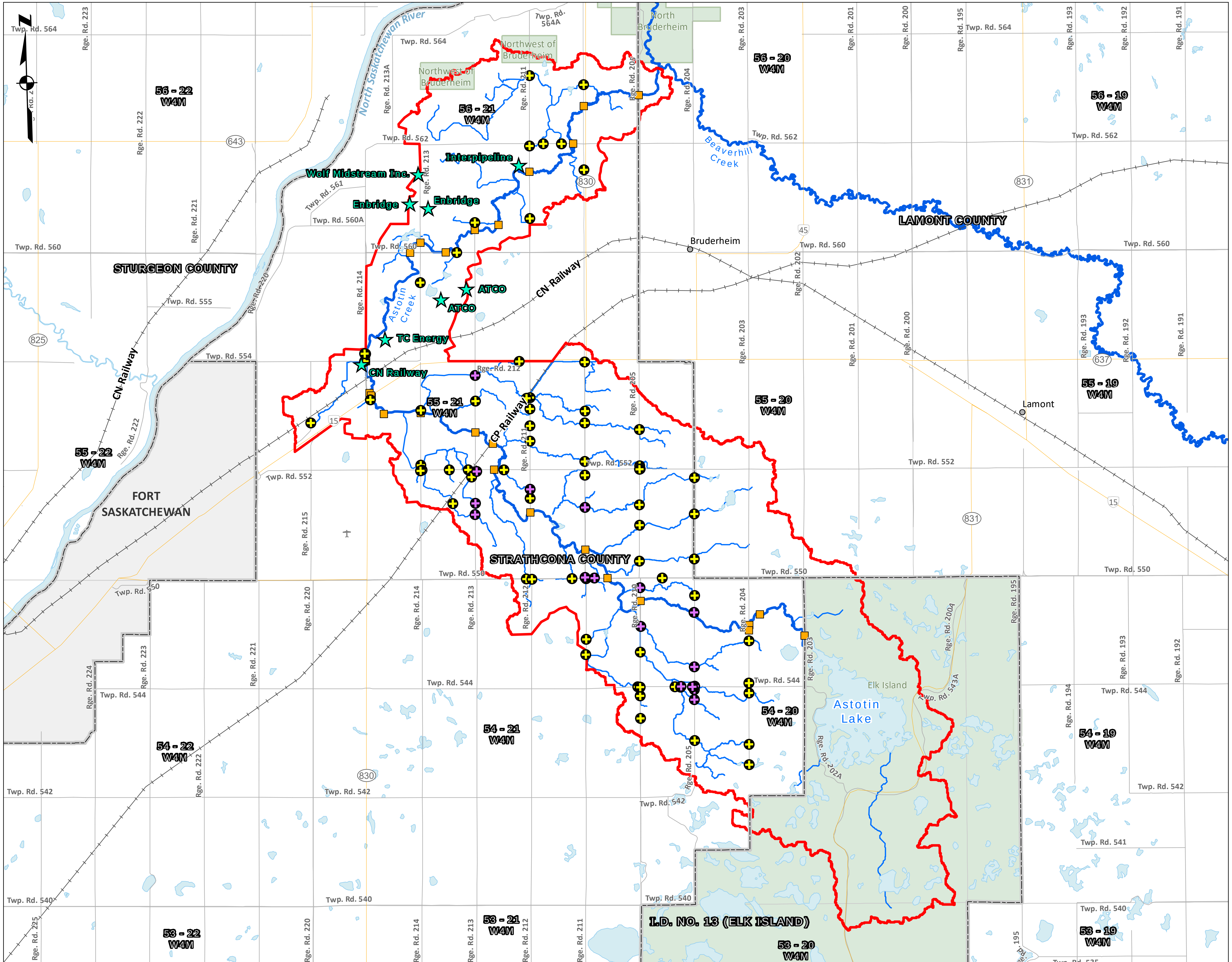
0 1.25 2.5 5 7.5 Kilometers

Universal Transverse Mercator (Zone 12)
North American Datum (1983)

Report By: JU
Drawn by: JH
Reviewed By: DP

WSP Job #: 211-03754-00
Date: November 1, 2021
Office: Edmonton

Notes: Data provided by Altalis; Natural Resource Canada; ESRI



Legend

- Surveyed Culvert Crossing
- Potential Culvert Crossing
- Structures
- Stormwater Management Facilities
- Astotin Creek Watershed
- Paved Roads
- Railways
- Airfield
- Towns/City
- County Boundaries
- Lakes/Rivers
- Astotin Creek and Beaverhill Creek
- Drainage Ways
- Natural Area (Provincial and National)

Astotin Creek Resiliency Study
Drainage Master Plan

Figure 1.5: Existing Drainage Infrastructure

Astotin Creek
Alberta

Scale: 1:110,000

0 0.5 1 2 3 4 5 Kilometers

Universal Transverse Mercator (Zone 12)
North American Datum (1983)

wsp

Report By: JU
Drawn By: JH
Reviewed By: JU

WSP Job #: 211-03754-00
Date: August 9, 2021
Office: Edmonton

Notes: Data provided by Altalis; Natural Resource Canada; ESRI

1.4 Background Review

1.4.1 Historical Flooding

As described previously, the Astotin Creek watershed experienced several flooding and drainage issues in the past decades, leading to the temporary closure of some roads. The flooding history in the Astotin Creek watershed is illustrated in Figure 1.6, and the general location of documented flooding is discussed in Section 3 of this report.

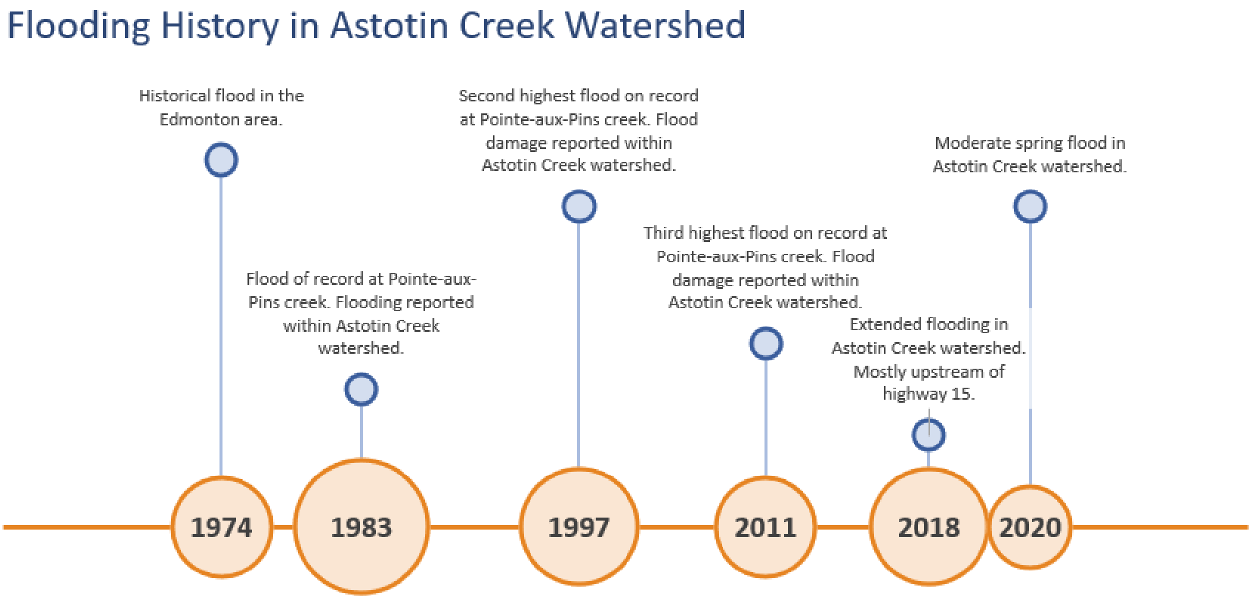


Figure 1.6: Flooding history in the Astotin Creek watershed

Most flooding issues were documented south of Highway 15, generally in proximity to the Astotin Creek channel. Drainage issues were also observed in some drainageways and areas outside the creek channel. Issues outside of the creek channel may have been driven by flooding at the creek (backwater effect), culvert icing or blockages.

For example, RR 205 was overtopped about 1.5 km north of TR 542 (Photo 1). At another location along RR 210, about 1.5 km south of TR 550, a culvert crossing was observed to be flowing near full capacity resulting in flooding of agricultural lands located upstream and downstream of the crossing (Photo 2).

Photo 1: Range Road 205 overtopped during the 2018 flood (Strathcona County, 2020)

Photo 2: Range Road 210 culvert crossing during the 2018 flood (Strathcona County, 2020)

1.4.2 Studies and Planning Documents

Various existing reports address creek and overall drainage work in the watershed. Next, reports and documents relevant to the study are presented, including a brief description of relevant information. Documents are presented from the oldest to the most recent.

1.4.2.1 Alberta's Industrial Heartland Stormwater Drainage Study (Stantec Consulting Ltd., 2016)

The County engaged Stantec Consulting Ltd. (Stantec) to prepare a stormwater drainage study for the Strathcona County AIH Area Structure Plan (ASP). The AIH includes 582 km^2 of land within the City of Edmonton, the City of Fort Saskatchewan, Strathcona County, Sturgeon County, and Lamont County. The County's AIH portion includes 134.57 km^2 (23% of the overall AIH area), some of which is within the Astotin Creek watershed. The drainage study presented a high-level stormwater servicing concept for the County's AIH lands and recommended a pre-development discharge rate for the area. The existing land uses include primarily agricultural land uses with portions of rural residences (southwest), natural areas (Bruderheim and Astotin Natural Areas in the north), and some industrial developments (west). The proposed land uses include primarily industrial land uses (heavy industrial, transitional, and agri-industrial land uses) with environmental reserve areas adjacent to the North Saskatchewan River. The estimated peak runoff rate for the existing conditions under the 100-year, 24-hour design storm (County intensity-duration-frequency curve data) was 4.77 l/s/ha. However, Stantec recommended that the County continue to use the currently adopted value of 4 l/s/ha. The proposed stormwater management system included a dual-drainage system with regional detention facilities at each Astotin Creek sub-watershed (16 detention facilities). The County determined that regional detention facilities were not suitable or practical for implementation in the AIH due to AER requirements for storages. The minor and major systems should be designed for the 5- and the 100-year return periods, respectively.

1.4.2.2 Strathcona County Best Management Practices for Stormwater Management Facilities (Strathcona County, 2016)

In this document, the County sets out guidelines and best management practices (BMPs) to protect the North Saskatchewan River watershed by managing the quantity and quality of stormwater discharging to receiving watercourses. The County currently uses source control, lot-level, conveyance, pre-treatment, and treatment BMPs and envisions incorporating new approaches such as low impact development (LID).

1.4.2.3 Strathcona County Functional Planning Study – Highway 15:06 from Range Road 220 To Highway 830 (CIMA+, 2016)

The County engaged CIMA+ to complete a functional planning study of Highway 15 from RR 220 to Highway 830 north. The functional plan identified interim and long-term requirements to accommodate future traffic in the general area for a 20- and 50-year design horizon. Existing drainage infrastructure along the highway consists of ditches (poorly graded) and culverts. Stormwater management work related to the highway twinning is expected to include repairing or replacing existing damaged or undersized culverts and improving the grade of the roadside ditches to reduce ponding. The future interchange at RR 214 is expected to require the realignment of Astotin Creek.

1.4.2.4 Alberta's Industrial Heartland Transportation Study Update 2017 (Stantec Consulting Ltd., 2017)

The County engaged Stantec to update the 2007 Strathcona Industrial Heartland Area Transportation Study due to changes in land use and development patterns. The study provided guiding principles for transportation network planning in the AIH and a conceptual plan of the major internal road network, including construction costs. The recommended roadway network accommodates peak hour demands based on industry requirements, stakeholder input, and future railways.

1.4.2.5 Heartland Industrial Area Structure Plan – Bylaw 21-2018 (Strathcona County, 2018)

The County prepared an Area Structure Plan (ASP) for the AIH lands within its jurisdiction. The document outlined the proposed land use plan for the Heartland Industrial Area and identified general infrastructure and services requirements and the natural landscape and environmentally significant areas to be protected. The document recognizes that the County's AIH lands are within the Beaverhill watershed, draining to Astotin Creek. Stormwater within the ASP boundary is to be managed by individual developments and continue to drain to Astotin Creek. The document outlines stormwater management requirements for developments, including (1) the need for stormwater management plans for each sub-watershed to ensure effective stormwater management and infrastructure coordination and (2) design criteria for stormwater systems in the County's AIH lands (100-year rainfall event).

1.4.2.6 Strathcona County Municipal Development Plan – Bylaw 20-2017 (Strathcona County, 2020)

The County's Municipal Development Plan (MDP) is a statutory, high-level, long-term planning and policy document. The MDP provides guidelines for orderly growth and development within the County over the next 20 years and beyond through land-use decisions, development management, and infrastructure investment. Utility system policies in the MDP outline that the County will require master drainage plans and master utility plans for watersheds experiencing active development, such as the Heartland Policy Area. The County also encourages (1) a regional approach to water demand management, (2) improving water quality within stormwater management facilities, (3) opportunities for non-potable water irrigation, and (4) implementing stormwater best management practices and low-impact development. Relevant maps from the MDP document are provided in Appendix A.

1.4.2.7 Strathcona County Land Use Bylaw 6-2015 (Strathcona County, 2021a)

The County's land use bylaw (LUB) regulates the use and development of land and buildings. The County is a specialized municipality that includes a Rural Service Area (hamlets, country residential development, and industrial and agricultural lands) and Urban Service Areas (Sherwood Park and Bremner). The LUB divides the County into Zoning Districts such as the Urban Service Area Zoning Districts, the Rural Service Area Zoning Districts and Other Zoning Districts. The Astotin Creek watershed is part of the Rural Area Zoning Districts and primarily consists of Agriculture: General (AG), Heavy Industrial (Heartland) (IHH), Medium Industrial (Heartland) (IMH) and Medium Industrial (IM) land uses.

1.4.2.8 Strathcona County Design and Construction Standards (Strathcona County, 2021b)

The County's design and construction standards (the Standards) provide information regarding the design, preparation, and submission of plans, including specifications for the construction of roadways; water, wastewater, and stormwater systems; open spaces; trails; and landscaping. As in other planning documents, the Standards provide specific criteria for the rural and urban areas. The Standards outline rural transportation (roadside drainage) and rural stormwater management requirements. In general, the County requires that drainage systems in the Rural Service Area (1) eliminate or mitigate property damage and flooding, (2) maintain pre-development runoff release rates or as required to protect the receiving watercourse, (3) control erosion and sedimentation in creeks, drainageways and ditches, and (4) protect significant wetlands.

1.4.2.9 Strathcona County Environmental Framework (Strathcona County, 2021c)

The County's environmental framework sets out environmental priorities informed by public and stakeholder engagement, research and review of trends and policies and guides the assessment of factors and impacts. Topic areas include Air, Water, Land, Biological Diversity, Waste and Energy. The document provides specific outcomes and various objectives under each topic.

1.4.3 Datasets

Datasets collected and reviewed in the study are listed below. A brief description of each dataset is also provided.

- Topographic LiDAR DEM data (Airborne Imaging, 2018). The dataset includes 0.5-m bare earth gridded data collected in the spring of 2018.
- National Hydrographic Network (NHN) (Government of Canada, 2020). The dataset contains geospatial information of Canada's inland surface waters, including lakes, reservoirs and watercourses, canals, islands, linear drainage networks, names, etc.
- 25 m Alberta Provincial Digital Elevation Model (Alberta Environment and Parks, 2017). The dataset represents the Province of Alberta land surface generated from contour and hydrography data from Natural Resources Canada.
- Historical aerial imagery for several years between 1996 and 2019 within the County's municipal boundary.
- Culvert and water level survey provided by Strathcona County.
- 2015 Land Cover of Canada dataset (Government of Canada, 2021). The dataset contains a 30-m resolution land cover raster of the entire country.
- Strathcona County 2018 and 2020 Floods GIS Data (Strathcona County, 2020). The webpage includes georeferenced photos and field observations.
- Alberta Transportation Hydrotechnical Information System (Alberta Transportation, 2019). The database provides infrastructure and some design and flood information regarding bridge and bridge-sized culverts owned by Alberta Transportation.

1.4.4 Drawings

The County provided design drawings of private stormwater management facilities and related infrastructure within the Astotin Creek watershed. The drawing sets are listed below:

- PX6-Polaris Christina Lake Extension;
- Canadian Diluent Hub 3;
- S.W. Quarter Laydown Area;
- Stonefell (AB) Terminal – East;
- Stonefell (AB) Terminal – West;
- TC Terminals/Grand Rapids;
- TC Terminals;
- Grand Rapids Heartland Terminal;

- Sedimentation Pond and Pumphouse;
- Proposed Laydown Area, Phase 1;
- Strathcona Sulphur Facility.

More information about these drawing sets is summarized in Appendix C.

HYDROLOGICAL ANALYSIS

2

2 Hydrological Analysis

Determination of flood quantiles, which correspond to peak flows for various return periods, is required to develop flood inundation and flood hazard maps. Flood quantiles are also used to determine the allowable release rate for future development within the watershed. To determine flood quantiles for Astotin Creek, WSP implemented the two following methods:

- Flood Frequency Analysis on streamflow data recorded at a proxy site;
- Development of a deterministic run-off model of Astotin Creek watershed.

This section summarises the methodology and results of these two methods. It also provides the recommended unit allowable release rate and a climate change assessment.

2.1 Watershed

The following geospatial data was used to delineate the Astotin Creek watershed and determine its drainage characteristics:

- National Hydrographic Network (NHN) (Government of Canada, 2020);
- 25 m Alberta Provincial Digital Elevation Model (Alberta Environment and Parks, 2017); and
- 0.5 m resolution LiDAR (Airborne Imaging, 2018).

The watershed delineation resulted in a total drainage area of 184 km2. Figure 1.1 showed the delineated Astotin Creek watershed, and Table 2-1 summarizes its key drainage characteristics.

Table 2-1: Astotin Creek watershed physical characteristics

Characteristics	Astotin Creek
Area (km^2)	184.3
Longest flow path (km)	48.5
Average slope (%)	2.8
Minimum elevation (m)	611.7
Average elevation (m)	675.7
Maximum elevation (m)	742.6

2.2 Flood Frequency Analysis

Streamflow data are collected, analyzed, and published by Water Survey Canada (WSC) at specific locations across Canada and Alberta. However, there are no active or discontinued hydrometric stations measuring streamflow data on Astotin Creek. There used to be a hydrometric station on Beaverhill Creek, downstream of the confluence with Astotin Creek (Beaverhill Creek near the mouth [05EB015]). However, the station was discontinued in 1986 and included a short record of only 13 years (1974 to 1986), which is not suitable for estimating higher return period floods. Moreover, Beaverhill Creek is less reactive to storm events and displays a much lower unit discharge rate than a smaller creek due to its larger watershed area. For example, the June 1983 storm, which corresponds to the Beaverhill Creek flood of record (between 1974 to 1986), generated a peak unit discharge of 0.3 l/s/ha at the Beaverhill Creek hydrometric station[1] versus 1.5 l/s/ha at the Pointe-aux-Pins Creek station[2] (ID 05EB902). Hence, the Beaverhill Creek station was not retained for the Flood Frequency Analysis, despite Astotin Creek being one of its tributaries.

Astotin Creek's flow data must therefore be derived from other stations located on neighbouring streams. It was shown in WSP's 2021 *State of The Watershed* report that Pointe-aux-Pins Creek and Astotin Creek share similar watershed characteristics. Thirteen hydrometric stations were screened, and the Pointe-aux-Pins Creek watershed was found to be the closest and most similar to the Astotin Creek watershed. Moreover, the historical floods recorded at the Pointe-aux-Pins Creek station correspond to the historical floods experienced at Astotin Creek. The WSC hydrometric station 05EB902 on Pointe-aux-Pins Creek (Pointe-aux-Pins Creek near Ardrossan) was therefore used as a proxy in the hydrological assessment of Astotin Creek.

To determine the flood quantiles for the Astotin Creek watershed, a single-station flood frequency analysis on Pointe-aux-Pins Creek annual peak flow data was completed and transferred to the Astotin Creek watershed. This is an appropriate approach given the proximity between the two creeks and the similarity of their watersheds and climates. It should be noted that the Pointe-aux-Pins Creek watershed is smaller than the Astotin Creek watershed (106 km^2 vs 184 km^2), meaning that the Pointe-aux-Pins Creek watershed should theoretically be more reactive to intense precipitation events than the Astotin Creek watershed, leading to a potentially more conservative flood quantile estimate.

The frequency analysis was performed on the annual peak flows using HYFRAN software. The annual peak flows were extracted from the Pointe-aux-Pins Creek hydrometric station as listed in Table 2-2 and illustrated in Figure 2.1. Although the yearly peak flow can occur in spring following snowmelt events and in summer due to storm events, the peak flow dataset was treated as a single population. The flood frequency analysis was conducted on the dataset listed in Table 2-2.

Table 2-2: Yearly peak flow recorded at Pointe-aux-Pins Creek hydrometric station (05EB902)

Year	Peak Flow (m^3/s)	Year	Peak Flow (m^3/s)	Year	Peak Flow (m^3/s)
1979	4.13	1994	2.57	2008	0.115
1980	5.03	1995	1.98	2009	0.992
1982	6.52	1996	2.85	2010	0.924
1983	16.2	1997	7.34	2011	6.98
1984	1.59	1998	5.28	2012	0.443
1985	5.09	1999	4.97	2013	2.59
1986	2.54	2000	0.925	2014	2.94
1987	3.49	2001	1.47	2015	2.01
1988	4.06	2002	1.89	2016	1.91
1989	2.53	2003	3.78	2017	2.96
1990	4.43	2004	2.14	2018	5.1
1991	5.02	2005	2.95	2019	2.12
1992	0.618	2006	2.1		
1993	1.20	2007	5.92		

[1] Peak flow of 78.7 m^3/s recorded on June 26, 1983 at Station 05EB015, for a gross watershed area of 2930 km^2.
[2] Peak flow of 16.2 m^3/s recorded on June 25, 1983 at Station 05EB902, for a gross watershed area of 106 km^2.

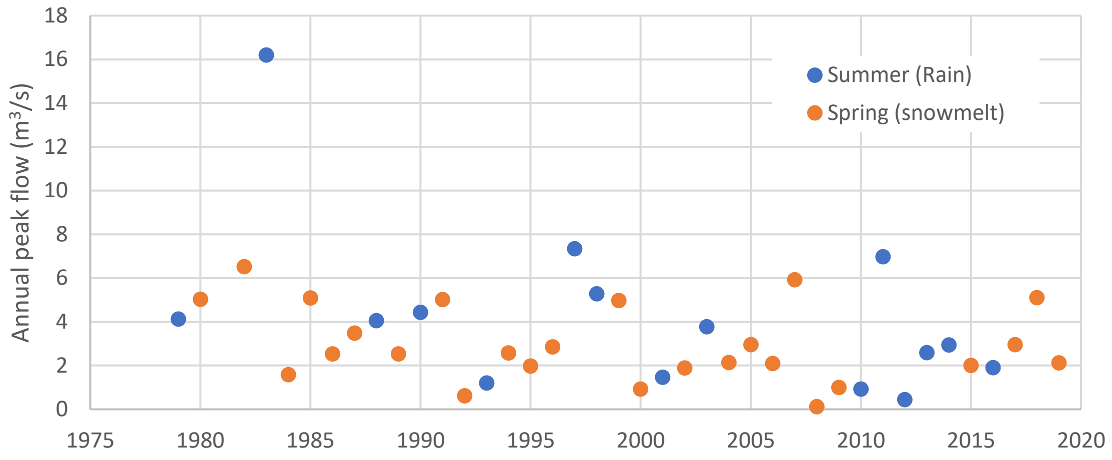


Figure 2.1: Historical peak flows recorded at the Pointe-aux-Pins Creek near Ardrossan station (05EB902)

HYFRAN is a software package developed for statistical analysis of extreme events. The analysis involves the application of different statistical distributions. The best-fit distribution law was selected considering statistical criteria including Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) and visual fit and sample statistics. AIC and BIC are indices estimating the risk of overfitting or underfitting the selected distribution law. The Bayesian methodology selects the model which most closely represents the observed data by calculating a posterior probability. The distribution fit with the lowest AIC and BIC and the highest posterior probability was selected when comparing different distributions. The best numerical fit distribution was also verified by inspecting the visual adjustment of the sample data and model results. A goodness-of-fit test was also carried out. Before fitting a sample using a statistical distribution, hypothesis tests were performed to check the assumptions of independence, stationarity, and data homogeneity. These adequacy tests check if the data set is appropriate for frequency analysis. The annual maximum instantaneous flows of the Pointe-aux-Pins station passed the adequacy tests, and the Lognormal distribution was selected as the best fit for this data. Figure 2.2 shows this adjustment on the sample data.

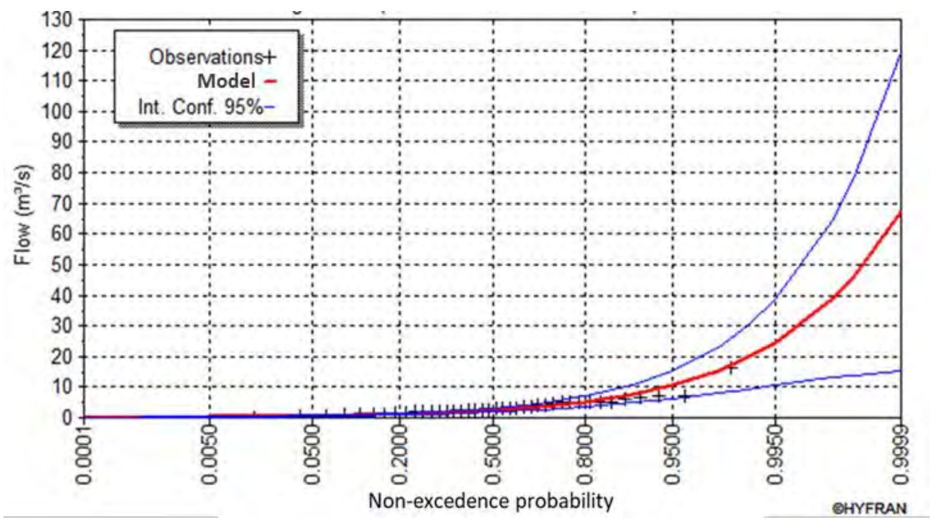


Figure 2.2: Lognormal distribution fit results

The calculated peak flow for Pointe-aux-Pins Creek was then transposed to the Astotin Creek watershed. The estimation of peak streamflow at the ungauged station is expressed by eq 2.1 (CEHQ, 2019):

$$Q_U = \left(\frac{A_U}{A_G}\right)^n x\, Q_G \qquad (eq\ 2.1)$$

Where:

Q_U : Streamflow at the ungauged station (m^3/s)

Q_G : Streamflow at the gauged station (m^3/s)

A_U : Area of the ungauged station watershed (km^2)

A_G : Area of the gauged station watershed (km^2)

n : Regional exponent

The "n" exponent generally ranges between 0.6 and 1 (Anctil et al. 2008). The regional exponent is assumed to be 1.0 for this project. The Pointe-aux-Pins flood quantiles and the Astotin Creek flood quantiles calculated using eq 2.1 are listed in Table 2-3.

Table 2-3: Flood frequency analysis results

Return Period (years)	Peak Flow Pointe-aux-Pins (m^3/s)	Peak Flow Astotin Creek (m^3/s)	Unit Discharge Astotin Creek (l/s/ha)
100	19.7	34.3	1.9
50	15.5	27.0	1.5
20	10.8	18.8	1.0
10	7.9	13.7	0.7
5	5.3	9.3	0.5
3	3.7	6.4	0.4
2	2.5	4.4	0.2

2.2.1 Comparison with Previous Studies

The calculated flood quantiles calculated in this study were compared with other hydrological assessments completed in the region for creeks of similar watershed sizes. The following studies were reviewed:

- Northwest Hydraulic Consultants, 2014 Nisku Flood Hazard Study – Blackmud Creek;
- Stanley Associates Engineering Ltd., 1998 Lamont Flood Risk Mapping Study;
- Total E&P Canada Ltd., 2007 Environmental Impact Assessment for the TOTAL Upgrader Project;
- Stantec Consulting Ltd., 2019 Bremner and LEA utilities Master Plan.

The various flood quantiles calculated in these studies were compared using their calculated unit discharge, which is equal to the peak flow divided by the watershed area. This allows comparing flood quantiles for watersheds of various sizes. Table 2-4 summarises the calculated unit discharge for each study.

Table 2-4: Summary of unit flood quantiles calculated in the region

Study	Studied Creek	Watershed area (km^2)	Unit Discharge (l/s/ha) for Various Return Periods					
			2-yr	5-yr	10-yr	20-yr	50-yr	100-yr
Stanley Associates Engineering Ltd. 1998	Lamont Creek	61.6	0.4	0.9	1.3	1.7	2.2	2.7
Northwest Hydraulic Consultants, 2014	Blackmud Creek	643 .0	0.2	0.4	0.6	0.8	1.1	1.2
Total E&P Canada, 2007	Astotin Creek	270.0	0.1		0.4			1.0
	Beaverhill Creek	2930.0	0.04		0.2			0.5
Stantec, 2019	Pointe-aux-Pins	63.5		0.91				1.6
	Oldman Creek	135.0		0.76				1.4
WSP, 2021 (Current Study)	**Astotin Creek**	**184.3**	**0.2**	**0.5**	**0.7**	**1.0**	**1.5**	**1.9**

These results indicate that the calculated unit discharge for Astotin Creek in this study is within the range of calculated unit discharges in the region, ranging between 0.5 l/s/ha and 2.7 l/s/ha. The 2007 Environmental Impact Assessment for the TOTAL Upgrader Project is the only recent study that developed flood quantiles for the Astotin Creek. As shown in Table 2-4, the unit discharges calculated in the 2007 EIA for the Total Upgrader Project are lower than WSP's estimate. This is due to the inclusion of larger watersheds in the 2007 regional flood frequency analysis, which generally display lower unit discharge than smaller creeks like Astotin Creek and can potentially underestimate peak flow at smaller creeks. Therefore, the flood quantiles calculated in the current study are considered more representative of the Astotin Creek flood regime.

2.3 Hydrological Modelling

To validate the Flood Frequency Analysis results presented in the previous section, a hydrological model of Astotin Creek was also prepared to simulate the total runoff over the Astotin Creek watershed for a summer 100-year precipitation event. The objective of the hydrological model is to confirm that a 100-year storm event would generate a peak flow of similar magnitude to the 100-year peak flow obtained in the Flood Frequency Analysis. Given the lack of historical streamflow data on Astotin Creek, a hydrological model of Pointe-aux-Pins Creek was first prepared and calibrated to develop representative infiltration parameters of the watershed. These parameters were then transferred to the Astotin Creek hydrological model, assuming that both watersheds have similar infiltration characteristics. Both hydrological models were developed using PCSWMM, a dynamic rainfall-runoff simulation model that can be used for a single event or long-term (continuous) simulation of runoff.

To calibrate the model, the following climatological inputs were used:

- Daily precipitation data at Elk Island National Park Weather Station (Station ID 3012275);
- Monthly mean evaporation from shallow water evaporation data available for Edmonton Int Airport station (Alberta Government, 2013).

Three calibration events were selected based on historical storm events. The 1983, 1997, and 2011 flood events were retained since they correspond to the three largest floods on record at Pointe-aux-Pins Creek. These three events also correspond to summer storm events with no snowmelt contribution. The three calibration events were modelled on a daily timestep since the Pointe-aux-Pins streamflow data, and Elk Island precipitation data are only available on a daily timestep. Figure 2.4 shows the simulated flow versus measured flow for the 1983 flood event.

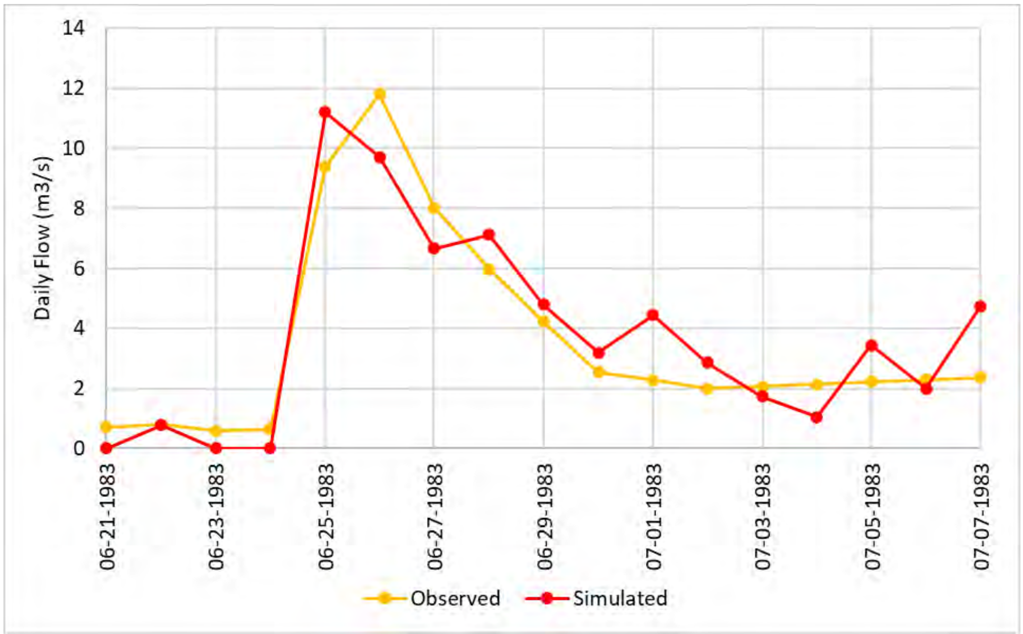


Figure 2.3: Simulated Flow Versus Observed (Measured) Flow at Point-Aux-Pins, 1983

Table 2-5 shows the calibrated parameters for Pointe-aux-Pins Creek. In this table, the "urban and built-up (%)" parameter for 2011 is calculated based on the 2015 Canada Land Cover database (Government of Canada, 2021). It is assumed that the percentage of this land use has increased from 1% in 1983 to 3% in 1997 and 7.16% in 2011, and the impervious ratio of that has increased from 20% in 1983 to 40% in 1997 and 75% in 2011. The depression storage and Manning roughness for each year were calculated based on a weighted average of the values assigned to each land use in the watershed. Then, the infiltration parameters were adjusted to calibrate the peak runoff to the Pointe-aux-Pins Creek peak flow. The calibrated parameters were then transferred to the Astotin Creek watershed, as shown in Table 2-5. The developed model for the Astotin Creek watershed was used to simulate 100-year flow and quantify the impact of climate change on precipitation and runoff.

The PCSWMM simulation was performed for a five-day precipitation event with maximum daily precipitation of 73 mm, equal to the 100-year, 12-hour precipitation. The four-day antecedent precipitation was set to 55 mm, similar to the four-day antecedent precipitation of the 1997 flood. The 12-hour AES distribution was used to create the hourly hydrograph of the peak precipitation. According to Watt (1989), the AES 70 percentile is appropriate for the area of study. Based on the results, the 100-year flow for the Astotin Creek watershed is 31 m^3/s, as shown in Figure 2.4.

Table 2-5: PCSWMM watershed parameters

Parameter	Pointe-aux-Pins Watershed at the Downstream End of the Creek			Astotin Watershed
	1983	1997	2011	Current
Urban and built-up (%)	1	3	7.16	4.77
Imperviousness of urban and built-up (%)	20	40	75	75
Total imperviousness (%)	2.95	3.95	8.12	8.66
Depression storage on impervious area (mm)	1.6	1.6	1.6	1.8
Depression storage on pervious area (mm)	4.7	4.8	5	5.1
Manning's n for impervious area	0.011	0.012	0.015	0.013
Manning's n for pervious area	0.55	0.55	0.548	0.551

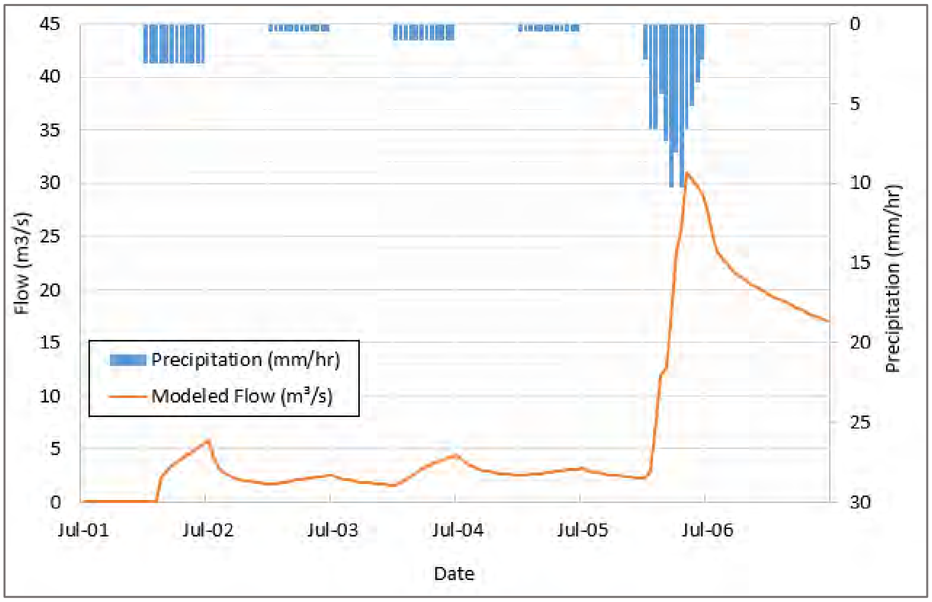


Figure 2.4: Simulated Flow Hydrograph Using PCSWMM

The 100-year peak flow obtained in the Flood Frequency Analysis presented in Section 2.2 equals 34 m^3/s, which is about 10% higher than the 100-year peak flow obtained in PCSWMM. Therefore, these two methods yield similar results, increasing the confidence in the Flood Frequency Analysis results.

2.4 Unit Allowable Release Rate (UARR)

Allowable release rates are usually based on pre-development flow rates for a 100-year storm event, obtained through hydrological modelling or statistical analysis. The flood quantiles obtained through the Flood Frequency Analysis, presented in Section 2.2, should be used to define the UARR within the Astotin Creek watershed. Hence, based on the results provided in Table 2-3, the recommended UARR for the Astotin Creek watershed is 1.9 L/s/ha.

A hydrological analysis completed in Stantec Consulting Ltd. (2016) which yielded a weighted average pre-development rate of 4.77 L/s/ha. This was determined by hydrological modelling of small sub-watersheds within the industrial heartland. The analysis was completed using SWMHYMO and the Soil Conservation Service (SCS) method for a 100-year, 24-hour storm event. The study recommends using a UARR of 4 l/s/ha, given that it is the currently accepted value by the County. These results suggest that the predevelopment rate is about two times higher than the rate developed in the current study. To explain this difference, the following comments are offered with respect to the above:

- A cursory review of Stantec Consulting Ltd. (2016) revealed that the hydrological model developed was not calibrated. Therefore, the runoff parameters (Curve Number value and Time of concentration) are not necessarily representative of the Astotin Creek watershed. A Curve Number (CN) value of 85 was used for all the modelled watersheds. This is considered conservative for the Astotin Creek watershed, which is characterized by medium-textured soil (Alberta Soil Information Viewer) and relatively low gradient slopes. Moreover, the SCS method was developed for small urban and rural watersheds in the United States, and runoff Curve Numbers applicable to Canadian watersheds are poorly documented. Hydrological parameters should therefore be calibrated when modelling extreme storm events in Canada. The Flood Frequency Analysis provided in the current study was complemented by a calibrated hydrological model, which yielded a pre-development 100-year peak flow similar to the flood frequency analysis results. Therefore, the approach implemented in the current study is considered more robust and reliable than the Stantec Consulting Ltd. (2016).
- The pre-development flow rate developed in Stantec Consulting Ltd. (2016) is significantly higher than other studies conducted on neighbouring watersheds, as shown in Table 2-4. This reinforces the argument that the 100-year pre-development rate developed in Stantec Consulting Ltd. (2016) is likely over estimated. These previous studies are based on statistical streamflow analysis and are therefore based on historical streamflow recorded in the region. This is considered more adequate for determining the pre-development discharge rate than implementing an uncalibrated hydrological model.

Further guidance regarding the UARR is provided in section 4.2 of this study.

2.5 Climate Change Assessment

WSP's 2021 *State of the Watershed* report presented a qualitative climate change impact within the Astotin Creek watershed. The analysis revealed that increased temperature and precipitation could be expected, leading to more frequent and intense spring and summer floods. To quantify the impact of climate change on pluvial flooding, the IDF_CC tool (www.idf-cc-uwo.ca), developed by Western University, was implemented. This tool provides historical Intensity-Duration-Frequency (IDF) curves at gauged and ungauged locations across Canada. The tool also provides projected rainfall intensity for future time intervals based on four emissions pathways – low, medium (two individual scenarios), and high. Results from the IDF_CC tools should not be used as discrete design values but can inform the variability of future rain events. While there is an improving understanding regarding the development and use of future IDF statistics that consider climate change, there is also a lack of consensus on the most appropriate methods. This is due to the wide array of distribution functions, climate model projections, downscaling methods used in creating future IDF statistics. Climate models represent rain events on a large geographic and temporal scale rather than localised convection-induced (i.e., summer heavy precipitation) events, principally as these are often driven by local conditions, such as topography.

Moreover, climate models provide daily outputs, whereas IDF curves are derived from hourly to sub-hourly datasets to properly approximate extreme events. Therefore, there are high uncertainties regarding the outputs of the IDF_CC tool, especially in relation to high intensity, short-duration rain events. Nonetheless, assessing the increase in IDF curves with the help of the IDF_CC tool and the scientific literature is the best way to assess the likelihood of heavy rain events in Canada easily. The projections indicate a projected change in intensity for extreme precipitation events ranging from 11.2% to 29.4% for 100-year precipitation events with a duration of 1 hour or more.

As there is considerable uncertainty surrounding the projections of precipitation as a result of climate change, it is beneficial to consider other sources of projection data. The CSA PLUS 4013:19 standard[3] on the development, interpretation and use of rainfall IDF information states that a 7% increase can be expected for every degree of warming. This has been applied to the historical data from the Elk Island National Park weather station (ID# 3012275) and the increase in mean annual temperature to provide an alternative set of projections for extreme precipitation. However, the projections are the same for each precipitation duration as it is based on the same temperature change. The precipitation increase returned by the CSA PLUS method, provided in Table 2-6, are larger than for the IDF_CC tool. When carrying out flooding modelling or planning exercises, it is recommended to use the most conservative projections data to ensure a worst-case scenario is considered. The below percentages from calculations using CSA's proxy should therefore be used.

Table 2-6: Historical and projected values and trends of indicators for the years 2021-2050 and 2051-2080 for RCP4.5 and RCP8.5 (Western University, 2018; CSA, 2019)

<table>
<tr><th rowspan="2">Climate Indicator</th><th rowspan="2">Historic Mean (1985-2017) [Range]</th><th colspan="2">Near Future (2021-2050) [Range]</th><th colspan="2">Far future (2051-2080) [Range]</th><th rowspan="2">Trend</th></tr>
<tr><th>RCP4.5</th><th>RCP8.5</th><th>RCP4.5</th><th>RCP8.5</th></tr>
<tr><td>15-min 100-year maximum precipitation (mm)</td><td>22.1</td><td rowspan="4">13.7%
[0.7% – 27.6%]</td><td rowspan="4">15.3%
[2.7% – 29.3%]</td><td rowspan="4">22.5%
[9.2% – 39.3%]</td><td rowspan="4">33.8%
[16.0% – 53.2%]</td><td>↑</td></tr>
<tr><td>1-hour 100-year maximum precipitation (mm)</td><td>29.7</td><td>↑</td></tr>
<tr><td>12-hour 100-year maximum precipitation</td><td>73</td><td>↑</td></tr>
<tr><td>24-hour 100-year maximum precipitation (mm)</td><td>90.8</td><td>↑</td></tr>
</table>

These projected precipitations, for the far future scenario (2051-2080), were incorporated into the PCSWMM model to calculate the corresponding runoffs. The antecedent precipitations were kept the same as in the scenario described in Section 2.3. The peak flows for each climate projection scenario are summarised in Table 2-7. Figure 2.5 shows the flood hydrographs for the present-day scenario and the RCP 8.5 far future climate scenario.

[3] https://webstore.ansi.org/standards/csa/csaplus40132019

Table 2-7: Climate change impact on precipitation and peak flows

Climate Scenario	Present-Day Conditions	RCP 4.5		RCP 8.5	
		Value Under RCP 2.6	Increase (%)	Value Under RCP 8.5	Increase (%)
12-hour 100-year precipitation (mm)	73	89	22.5	98	33.8
Peak flow (m^3/s)	31	39	25	44	40

According to these results, the 100-year flood with climate change is expected to be between 39 m^3/s and 44 m^3/s for the RCP 4.5 and RCP 8.5 respectively. This 44 m^3/s flow, which is the most conservative prediction, is 40% higher than the calculated flow for a 100-year, 12-hour precipitation event in current conditions, which is 31 m^3/s. Applying a magnification factor of 40% on the 100-year peak flood obtained in the Flood Frequency Analysis and listed in Table 2-3 yields a 100-year flood of 48 m^3/s for the far future under an RCP 8.5 scenario.

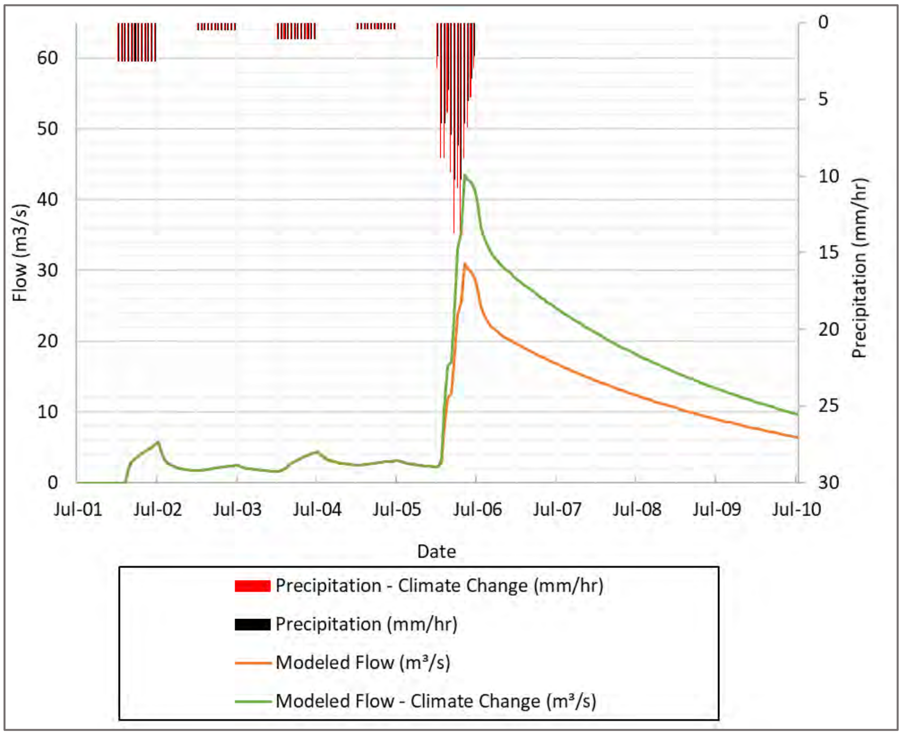


Figure 2.5: 100-year flood hydrograph in present-day and climate change scenarios (RCP 8.5).

HYDRAULIC ANALYSIS

3

3 Hydraulic Analysis

To determine the water levels and water velocities along the study reach, a hydraulic model of Astotin Creek was developed. The model was used to simulate the peak flows presented in Section 2 and develop flood inundation maps and flood hazard maps along Astotin Creek. This section describes the hydraulic model that was developed and summarises the main results of this analysis.

3.1 Model Development

A two-dimensional (2D) hydrodynamic model was created using HEC-RAS version 6.0 software developed by the US Army Corps of Engineers to assess numerical hydraulic simulations of the flood for almost 45.5 km of Astotin Creek and its floodway.

The objective of the modelling exercise was to:

- Extract the inundation maps for various flood scenarios;
- Define the floodway and flood fringe of the creek;
- Define the flood-prone areas;
- Detect the main causes of flooding in the flood-prone areas and provide potential flood hazard mitigation recommendations for these areas.

To decrease the size of the model, the study reach was split into two sections. One model was developed for the upstream part of the creek between Astotin Lake and Highway 15, and another model for the lower part of the creek downstream of Highway 15.

The calculation mesh of the two 2D models together comprises more than 72,500 computational cells. Most of the cells are square-shaped, with an average size of 50 m x 50 m. Several break lines were used to refine the mesh (at roads, ridges and sharp topography) to add more detail (i.e., mesh size of 2 m x 2 m) and align the mesh with the riverbanks and flow direction. Figure 3.1 provides the overall extent of the 2D domain for the project site.

Hydraulic structures such as the surveyed bridges, culverts, and beaver dams were integrated directly into the 2D model mesh.

The Full Momentum equation set was implemented, as recommended by the US Army Corps of Engineers, for flatter rivers, where gravity and friction may not be the dominant forces acting on a body of water because "the forces associated with changes in velocity with respect to time and distance, will play a much more significant role in how a flood wave moves and changes shape in a flat system" (USACE, 2021).

3.1.1 Digital Elevation Model

The 2D model was developed using the available LiDAR data gathered by Airborne Imaging in 2018. It should be noted that LiDAR technology has no penetration in water and the LiDAR data, therefore, returns the surface of water elevation on the survey's day. However, the bathymetric data collected along the creek (where possible) by WSP's survey team was incorporated into the model's terrain. The Digital Elevation Model (DEM) was also manually deepened in ponding areas, such as upstream of beaver dams and wetland areas. The resulting DEM is shown in Figure 3.1.

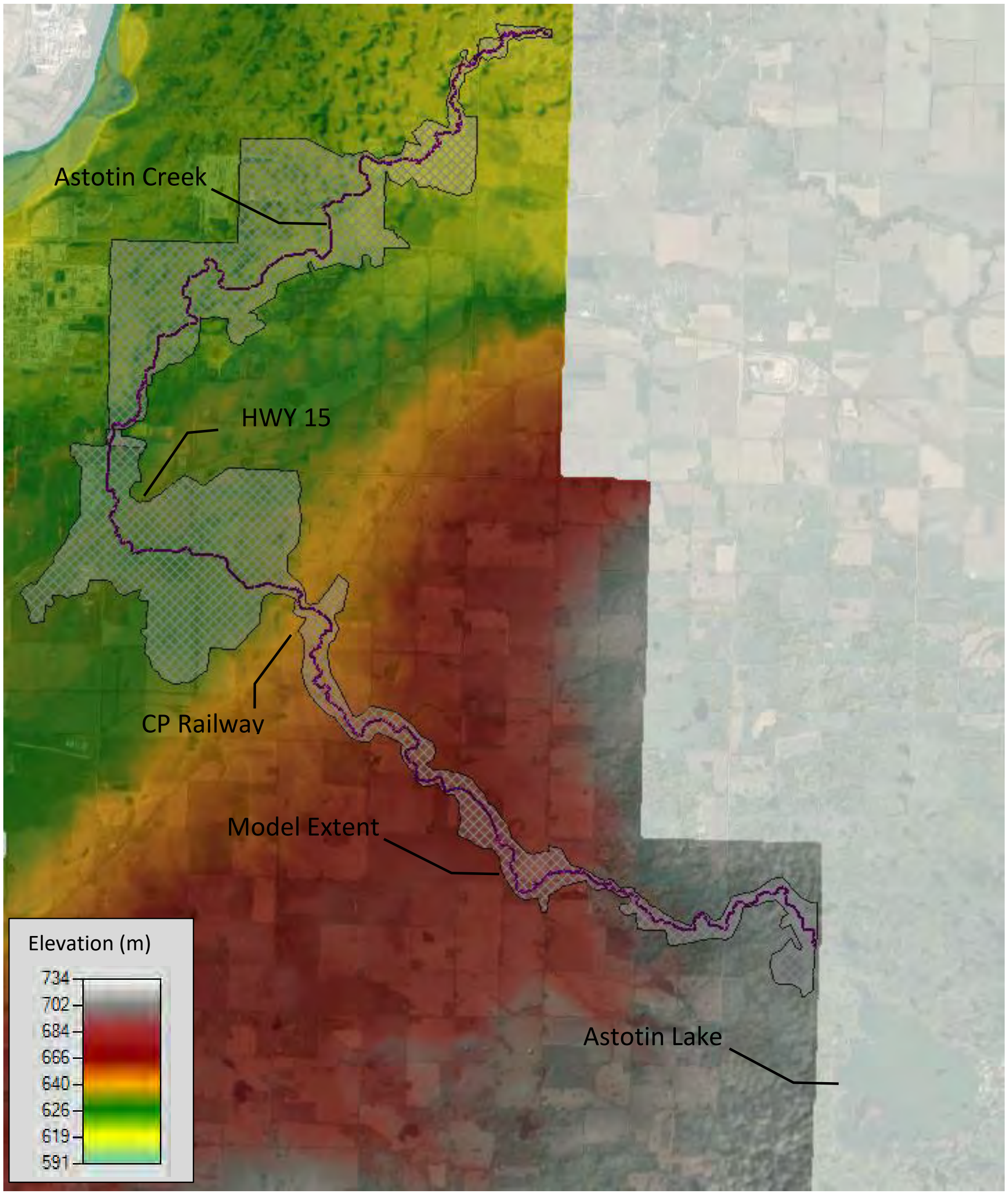


Figure 3.1: 2D Model Extent

3.1.2 Hydraulic Structures

All major hydraulic structures identified along the creek were also included in the model. Table 3-1 lists all the crossings (bridges and culverts) included in the model. Most of these were surveyed by WSP in June 2021. However, some structures on private lands could not be inspected and surveyed. Their characteristics (hydraulic opening, height, elevation) had to be approximated based on LiDAR data and aerial photography. Twenty-four beaver dams were also modelled as inline structures in the hydraulic model. Their length, width, and top elevation were extracted from the DEM.

Table 3-1: Crossings along Astotin Creek

Structure ID	Location*	Distance (km)	Type	Number of Culverts/Bridge Spans	Culvert Diameter (mm)/ Approximate Bridge Span – Height (m)
1	54511 RR 204	2.48	Culvert	1	1120
2	54511 RR 204	3.05	Culvert	1	1060
3	RR 204	3.28	Culvert	1	1200
4	RR 205	5.73	Culvert	1	1200
5	RR 210	7.89	Bridge	1	9.4-2.2
6	Private Crossing	8.31	Unknown, assumed to be a culvert	Unknown, assumed to be 1	Unknown, assumed to be 900
7	Private Crossing	8.48	Unknown, assumed to be a culvert	Unknown, assumed to be 1	Unknown, assumed to be 900
8	Private Crossing	8.65	Unknown, assumed to be a culvert	Unknown, assumed to be 2	Unknown, assumed to be 500, 500
9	TR 550	10.22	Bridge	1	5.4-2.4
10	Private Crossing	11.20	Unknown, assumed to be a culvert	Unknown, assumed to be 2	Unknown, assumed to be 200, 200
11	RR 210	11.37	Bridge	1	5.5-2.1
12	RR 211	14.55	Bridge	1	7.5-2.6
13	TR 552	17.92	Bridge	1	5.5-2.1
14	CP Railroad	19.23	Culvert	2	Unknown, assumed to be 2200, 2200
15	RR 212	20.20	Culvert	1	3180
16	RR 213	22.17	Bridge	1	7.4-2.1
17	TR 553	23.36	Bridge	1	7.5-1.8
18	HWY 15	24.21	Culvert	1	5000
19	HWY 15	24.26	Bridge	2	5.6-2.8
20	CN Railroad	24.34	Bridge	5	18.6-4.1
21	TR 554	25.64	Bridge	1	7.4-2.5
22	TR 560	30.82	Culvert	1	2670
23	RR 213	31.33	Bridge	1	8-1.7
24	Local Road on TR 560	32.86	Culvert	3	1100, 1200, 1200
25	RR 212	34.01	Culvert	3	920, 1200, 780
26	Railroad	34.96	Culvert	2	1000, 1000
27	RR 211	37.89	Bridge	1	9.4-1.8
28	TR 562	40.83	Bridge	1	5.5-2.4
29	RR 210	42.92	Bridge	3	25.5-3.6
30	Private Crossing	43.88	Unknown, assumed to be a culvert	Unknown, assumed to be 1	Unknown, assumed to be 1500

*RR = Range Road, TR = Township Road

3.1.3 Manning's Roughness

Representative Manning's n values were used to simulate the frictional resistance to flow along the riverbed and banks. Using the 2015 Canadian Land Cover Inventory, seven types of landcover were determined in the area of the 2D model. The land cover maps are presented in Appendix A and the adopted Manning's n values are summarised in Table 3-2. These values were assigned based on site conditions, available aerial imagery and the US Army Corps of Engineers guidance documentation regarding Manning's n values selection (USACE, 2021).

Table 3-2: Adopted Manning's Roughness Values

ID	Land Cover	Manning's n Value
1	Swamp	0.08
2	Tree	0.1
3	Agricultural	0.05
4	Anthropogenic	0.05
5	Grassland	0.04
6	Marsh	0.08
7	Open water	0.045

Also, Manning's n values are assumed to be 0.024 for the corrugated steel pipes (CSP) and 0.03 at the bridge cross-sections.

3.1.4 Boundary Conditions

The upstream 2D hydraulic model includes five boundary conditions: one upstream flow hydrograph on Astotin Creek, three internal flow hydrographs to represent the intermediate surface runoff, and one downstream normal depth condition.

The downstream 2D hydraulic model includes three boundary conditions: one upstream flow hydrograph on Astotin Creek, one internal flow hydrograph representing the intermediate surface runoff, and one downstream normal depth condition. In both models, the downstream boundary condition is the only modelled outflow location, meaning that the entire flow is conveyed through Astotin Creek, and no outflow was allowed in flat sections of the floodplain where watershed flow transfer is possible. This is a conservative assumption as it can potentially lead to higher water levels in certain model areas. However, the level of conservativism associated with this assumption is uncertain, given that the outflow magnitude has never been measured or documented. The hydraulic model would need to be extended outside of Astotin Creek watershed to accurately model these potential outflows, where no survey data is currently available. The crossings along the outflow paths would need to be surveyed to model the amount of flow exiting Astotin Creek accurately. Flow separation between Astotin Creek and these outflow locations should also be calibrated based on field measurements. But it should be noted that several factors such as culvert or bridge blockage, anthropogenic blockage and road raising could also limit the outflow magnitude. Therefore, it is more prudent to neglect the flow potentially exiting Astotin Creek for flood mapping purposes. But it should be recognized that these outflow locations potentially act as relief points, reducing Astotin Creek flow and downstream flood risk.

The upstream and intermediate flow values for each boundary condition are calculated based on area ratio techniques at each sub-watershed of the Astotin Creek watershed using the flood quantiles calculated in Section 2. Table 3-3 summarises the modelled flow at various locations along Astotin Creek.

Table 3-3: Modeled peak flows at various locations along Astotin Creek

Location	Modelled peak flow (m^3/s)			
	20-year flood	50-year flood	100-year flood	100-year flood with climate change
Range Road 203, downstream of Astotin lake	4.9	7.0	8.9	12.5
CP Railway (SW 14-55-21-4)	17.1	24.5	31.1	43.8
Downstream limit of the model	18.8	27.0	34.3	48.2

3.1.5 Calibration

The model was calibrated for low-flow conditions, corresponding to the observed conditions during WSP's 2021 site visit. Low-flow calibration is useful for adjusting the DEM and ensuring that all the flow control structures are included in the model. The only historical flood documented was the 2018 flood event, during which several aerial photographs were taken. However, no corresponding flow measurements were available on Astotin Creek, and the model could not be accurately calibrated based on this event. The peak flow recorded on Pointe-aux-Pins Creek on April 21st, 2018, was 5.1 m^3/s, which would correspond to a 5-year flood event if Astotin Creek experienced a spring freshet similar in magnitude. However, this could not be confirmed from the available information. Nonetheless, the 2018 flood event was used as a validation scenario to ensure that the model returned comparable flood extents for large flood events.

3.1.6 Simulation Scenarios

The 2D simulation was completed for the following scenarios:

- Scenario 1: 20-year flood event;
- Scenario 2: 50-year flood event;
- Scenario 3: 100-year flood event;
- Scenario 4: 100-year flood event under climate change.

3.1.7 Assumptions and Limitations

The list of assumptions and limitations of the model are as follows:

- The size of the two culverts at the CP Railway crossing between Township Road (TR)-552 and Range Road (RR)-212 was not available, and it was assumed that their diameter is 2.2 m, based on LiDAR data and aerial photographs;
- The culverts and bridges were assumed to be free of debris;
- The location of some beaver dams was derived from the 2018 LiDAR data. The locations and conditions of these beaver dams have potentially changed since 2018;

- The weir coefficient of overtopped structures (roads, bridges, and beaver dams) was assumed to be 1.55;
- There was no information available of the private (farm) crossings. The size of the culverts at these crossings was estimated based on the ground height observed in the LiDAR database;
- Where the invert elevation of culverts was missing on one side, the culvert slope was assumed to be 1%;
- The exit loss coefficient of the culverts was assumed to be 0.5;
- The entrance loss coefficient of culverts was assumed to be 0.9 for regular culverts, 0.7 for culverts with wing walls, and 1 for deformed culverts or culverts with trash racks;
- Potential outflow from Astotin Creek towards the adjacent watersheds was not allowed in the model, meaning that the entire modelled peak flow is conveyed in Astotin Creek.

3.2 Modelling Results

The hydraulic simulation results were used to produce flood inundation maps for the 100-year, 50-year, and 20-year flood events. Flood hazard maps were also produced for the 100-year flood scenario, as discussed in the following section. A 1:10,000 scale was used for all the maps, and a 1:350,000 scale index map is also provided on each map. The flood inundation maps are provided in Appendix D, and the flood-prone areas are shown in Appendices E and F of this report. A description of the 100-year flood event along the study reach is provided below.

The flood inundation maps show that Astotin Creek is generally well contained between Astotin Lake and RR 210, which is located about 7.8 km downstream of Astotin Lake. Along that reach, the riverbed is about 5 m wide, the flood plain about 25 m wide and the riverbanks are up to 7 m high. However, overtopping of 54511 RR 204 is expected due to undersized culverts at the crossing, as shown in Figure F-1 of Appendix F. Overtopping of RR 204 and RR 205 is also expected during the 100-year flood, as shown in Figures F-2 and F-3 respectively.

At RR 210, the floodplain sits lower than the creek's elevation and some overland flooding is observed on the right overbank, as shown in Figures F-4 and F-5. Three farm crossings located just downstream of the overland flooding location act as hydraulic controls, increasing the water level upstream and contributing to the overland flooding. Upstream of TR 550, flooding is expected at the left overbank, where TR 550 is overtopped. Further downstream, between TR 550 and RR210, significant overland flooding is noted on the left overbank, where a residence is located within the flood extent, as shown in Figure F-7. The bridge at RR 210 appears to increase upstream water levels due to a potentially undersized hydraulic opening. The riverbed deepens again downstream up to RR 211 and TR 550, upstream of which minor overland flooding can be observed, as shown in Figures F-8 and F-9, respectively. The CP railway is located about 1,000 m downstream of TR 550 but has a limited impact on overland flooding since it is located about 3-4 m lower than TR 550.

About 1.2 km downstream of the CP Railway, Astotin Creek's riparian buffer decreases sharply. The agricultural lands on both sides of the creek are less than 2 m above the creek's riverbed. Hence, the riverbed has a smaller conveyance capacity, and overland flooding is significant in that area, as shown in Figure F-10. The hydraulic model returns significant overtopping of RR 213 and TR 553. The agricultural lands located south of the creek have a lower elevation and are sloping southward, conveying part of the flood water to the adjacent watershed south of Astotin Creek. Despite being heavily flooded, this area acts as a relief point and potentially decreases Astotin Creek flow downstream. However, as noted previously, no water was allowed to leave the hydraulic model, yielding more conservative flows downstream of that point by forcing the entire peak flow to be conveyed through Astotin Creek.

From about 350 m upstream of Highway 15 to 2,100 m downstream of the CN Railway crossing, Astotin Creek is channelized and deepens significantly to about 3-4 m, containing most of the 100-year flood without significant overland flooding. However, the model suggests that overland flooding is expected at TR 554, as shown in Figure F-11.

Just downstream of TR 554, the creek's slope decreases significantly, and the flood flow propagates through a network of interconnected wetlands. RR 214 and TR 560 are expected to overtop at several locations, as illustrated in Figures F-12 and F-13. Overflow at RR 214 is expected to propagate through the AIH towards the North Saskatchewan River, meaning that part of the Astotin Creek flood flow would leave its watershed. The hydraulic model also suggests that overtopping the CN Railway at the intersection with RR 214 can be expected for the 100-year flood. This overflow would then be conveyed northward through a network of wetlands and is not expected to re-enter Astotin Creek. But again, the flow expected to leave Astotin Creek's watershed was not modelled, and the entire flood flow was forced through Astotin Creek, leading to more conservative results in the downstream study reach.

Flowing eastward, flood flow then reaches RR 213, where significant road overtopping is expected, north and south of the crossing, as shown in Figure F-13. Subsequent overtopping of TR 560, the CN Railway, and RR 212 is expected, as shown in Figures F-14 and F-15. Downstream of RR 211, the topography flattens again, and significant overland flooding in agricultural lands is anticipated, as shown in Figure F-16. Between TR 562 and RR 210, Astotin Creek deepens again, and overland flooding is limited, except downstream of TR 562 (Figure F-17). Downstream of RR 210, significant overland crossing can be expected, as shown in Figure F-18, due to a potentially undersized farm crossing located about 650 m downstream of the RR 210 bridge. The 100-year flood is relatively well contained for the remainder of the study reach.

3.2.1 2018 Flood Event Comparison

The modelled flood scenarios were compared with aerial photographs taken during the 2018 flood event to validate the modelled flood extent. Given that the 2018 Astotin Creek peak flow is unknown and that the photos were not necessarily taken at the peak of the flood, modelling the 2018 flood events for calibration purposes was not attempted due to numerous uncertainties. Nonetheless, the 20-year, 50-year, and 100-year modelled flood extents were compared with the available aerial photographs to validate the flood-prone areas identified in the previous section. A sample of the aerial photographs collected during the 2018 flood event is shown in Figure 3.2. Screen captures of the hydraulic model results are provided in Appendix G at specific locations where 2018 aerial photographs are available. This comparison reveals that the 2018 flood event is comparable to the 20-year flood event, but the 2018 water levels are generally slightly lower than the 20-year water levels. As mentioned in Section 3.1.5, the 2018 flood at Pointe-aux-Pins Creek corresponded roughly to a 5-year flood event. Since Astotin Creek peak flows are not necessarily directly proportional to Pointe-aux-Pins Creek flows for any given year, a return period between 5- and 20-years appears reasonable to describe the magnitude of the 2018 flood on Astotin Creek. This compares well with the hydraulic model results.

Figure 3.2: Sample of aerial photographs taken during the 2018 flood event.

3.2.2 Inventory of Flood-Prone Areas

The flood maps were analyzed to identify areas and infrastructure more vulnerable to flood events along Astotin Creek. The identified vulnerable areas are listed in Table 3-4 and their position is illustrated on the maps of Appendix E. Flood-prone areas correspond to the inundated area where the public roads, residential areas, industrial areas, and/or agricultural lands are expected to be affected by the flood. Table 3-4 lists these locations. More detailed information about each location is provided below.

Table 3-4: List of flood-prone areas

Flood-Prone Area #	Distance from Upstream Model Boundary at RR 203 (km)	Flooding Issue
1	2.47	544511 RR 204 is overtopped
2	3.3	544511 RR 204 and RR 204 are overtopped
3	5.74	RR 205 is overtopped
4	7.9	Agricultural lands are flooded RR 210 is overtopped
5	8 -9.5	Agricultural lands are flooded
6	10.2	TR 550 is overtopped
7	10.2-11.4	Residential and agricultural lands are flooded, and RR 210 is overtopped
8	14.5	The inundation area is close to a residential lot
9	17.9	Residential and agricultural lands are flooded, and TR 552 is overtopped
10	20.5-24.2	Agricultural and residential lands are flooded RR 213 and TR 552, and TR 553 are overtopped
11	24.8-25.6	Agricultural lands are flooded RR 214 and TR 554 are overtopped
12	~28.5-30.85	RR 214 and TR 560 are overtopped, and the industrial areas to the west of RR 214 will be affected
13	31.3-32.8	RR 213 and TR 560 are overtopped
14	34-35	RR 211 and CN Railway are overtopped
15	~36.1	Residential and agricultural lands are flooded
16	37.87-40.2	RR 211 is overtopped Agricultural lands are flooded
17	40.83	TR 562 is overtopped
18	43.5	RR 210 is overtopped Residential and agricultural lands are flooded

In addition to the flood-prone areas noted above, the industrial zone west of RR 214 is expected to be partially flooded during the 100-year flood. The model suggests that RR214, north of Highway 15, will be overtopped during the 100-year flood at several locations. The overtopping flow will propagate towards the North Saskatchewan River through the industrial area. Infrastructure located along the flow path will likely be inundated. This area was not included in the hydraulic model, given that this area sits outside the Astotin Creek watershed. A specific flood inundation study focusing on the Industrial Heartland to the west of RR 214 would need to be carried out to delineate the inundation extent in that area accurately.

3.2.3 Sensitivity Analysis

A series of sensitivity analyses were completed to evaluate the hydraulic model's sensitivity to modelling inputs. The analyses were performed on the following variables:

- Downstream boundary condition;
- Computational timestep;
- Roughness coefficients;
- Crossing blockages.

The results of each sensitivity analysis are provided below.

3.2.3.1 Downstream Boundary Condition

To evaluate the effect of the downstream boundary condition on the results, a sensitivity analysis was performed in HEC-RAS for the 100-year scenario. In this analysis, the simulation was repeated for the models with downstream friction slopes ten times lower and ten times higher than the original value. The results show that the friction slope at the downstream boundary condition affects water levels up to 1.5 km upstream of the downstream boundary condition. The water level elevations decrease up to 1.2 m for the downstream model within the influenced area by increasing the friction slope. Decreasing the friction slope increases the water level elevations up to 0.6 m and 1.8 m along the same area of the creek for the upstream model and the downstream model, respectively.

3.2.3.2 Time Step

Another sensitivity analysis parameter is the time step. The computational time step was set to three seconds for all the previous simulations. The 100-year scenario was repeated with a one-second time step to see if lowering the time step affects the results. According to the results, reducing the time step to one second does not affect the results considerably. Water surface changes are below 5 cm along the creek.

3.2.3.3 Roughness coefficient

A sensitivity analysis was performed in the HEC-RAS model to evaluate the influence of roughness coefficients on flood routing results. For the 100-year flood scenario, the Manning's roughness coefficients were increased by 20% (upper limit) and lowered by 20% (lower limit) compared to the original values listed in Table 3-2. Table 3-5 shows the upper limit and lower limits of Manning's roughness coefficients considered in the model. Figure 3.3 shows the profile of water surface changes along the creek due to the Manning's roughness alteration. As expected for a creek with a low riverbed slope, the Manning's roughness coefficients have a minor impact on the water levels. Water surface rise is generally less than 0.1 m (with water rise of about 0.2 m within some local areas) along the creek in the scenario with increased Manning's n values. Water surface elevation is slightly more sensitive to lowering the Manning's n values. In the lower limit scenario, the water surface is up to 0.3 m lower than the base case scenario. But these results suggest that the model is not significantly sensitive to roughness coefficients, given that the water surface elevation changes are generally less than 0.1 m.

Table 3-5: Range of Considered Manning's Roughness values

ID	Land Cover	Manning’s n Value- Lower Limit	Manning’s n Value- Upper Limit
1	Swamp	0.064	0.096
2	Tree	0.08	0.12
3	Agricultural	0.04	0.06
4	Anthropogenic	0.04	0.06
5	Grass land	0.032	0.048
6	Marsh	0.064	0.096
7	Open water	0.036	0.054

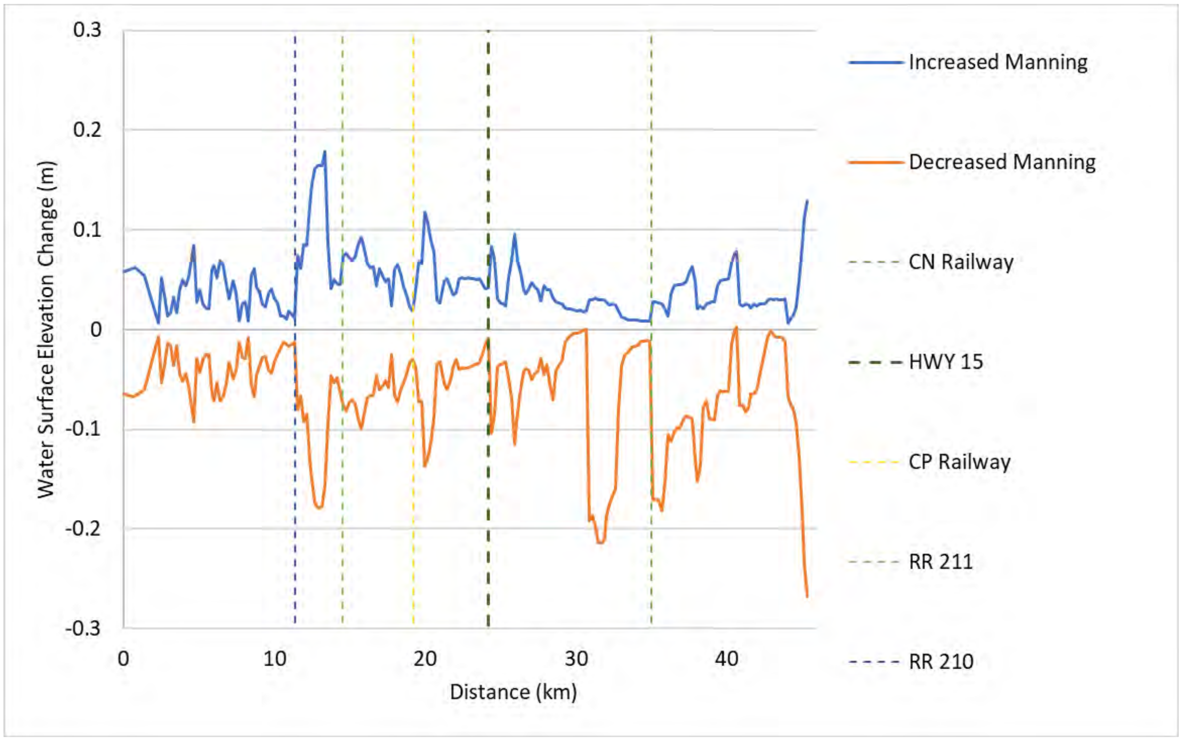


Figure 3.3: Influence of Manning's coefficient on water surface elevation change

3.2.3.4 Crossing Blockages

Debris accumulation was observed at the upstream end of several culverts during the site visit. The observed debris accumulation can potentially be attributed to beaver activity and also normal debris contribution from the creek's banks. Debris accumulation could potentially lower the conveyance capacity at bridges and crossings. To evaluate the effect of crossing blockages on the creek's water level, a sensitivity analysis was performed in HEC-RAS for the 100-year flood scenario. In this analysis, it was assumed that 0.5 m of a bridge opening's height was blocked below the soffit due to floating debris and the culvert depth was blocked up to 30% for smaller culverts (less than 2200 mm), 15% for medium culverts at RR 212 (3200 mm) and TR 560 (2670 mm), and 10% for the two culverts at Highway 15 (5000 mm). Figure 3.4 shows the water surface elevation increase along the creek due to crossing blockages. The results show that the creek water surface elevation increase is generally less than 0.1 m, except for the CP Railway crossing and RR 212 crossing, where the water surface elevation rises are around 0.3 m and 0.2 m, respectively. The water level increase due to blockage caused by debris accumulation is relatively low along the study reach because several crossings are already overtopped during the 100-year flood, suggesting that the overtopping strongly contributes to the conveyance at the undersized crossings. Further blockage does reduce the crossings' conveyance, but the impact on water level is less significant than for crossings that are not overtopped, such as the Highway 15 crossings.

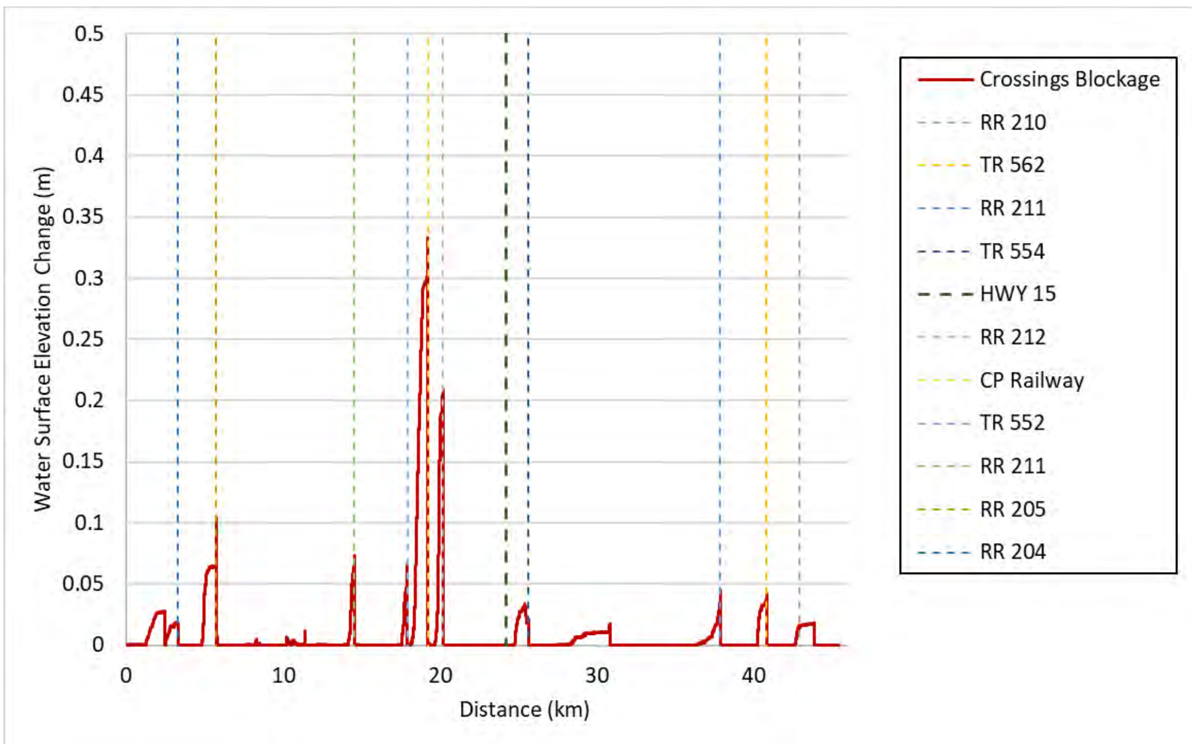


Figure 3.4: Influence of debris blockage on water surface elevation

3.3 Floodway Determination

Flood hazard maps delineating the floodway and flood fringe of Astotin Creek are presented in Appendix H. The floodway is defined as the part of the floodplain where velocity is estimated to be equal or greater than 1 m/s and/or water depth is expected to equal or exceed 1 m during a 100-year event. The flood fringe is the remainder of the flood zone where the flood velocity and water depth are under 1 m/s and 1 m, respectively. If the flood fringe is encroached, the water level rise would be less than 0.3 m in the floodway. Strathcona County land use bylaws do not allow any construction within the floodway. It also requires submitting a geotechnical and flood hazard report containing floodproofing provisions to mitigate flood damages for building applications on existing lots (Strathcona County, 2021a).

Defining the flood fringe in a 2D model is more complex than in a 1D model because there is no direct method of encroachment analysis in the 2D model. In this study, the Manning's roughness values were increased to 10 to mimic the encroachment in the 2D model. Defining the flood fringe is a process (as shown in Figure 3.5) in which first an initial floodway and flood fringe are delineated based on the calculated depth and velocity. Then, the Manning's roughness value is increased to 10 in the flood fringe area, and the Water Surface Elevations (WSE) are calculated based on this new setup. The calculated WSE is compared to the original WSE to define the areas where WSE changes are more than 0.3 m. Next, the flood fringe is modified accordingly, and the process continues until WSE changes are below 0.3 m everywhere within the flood zone.

Figure 3.5: Floodway delineation process in the 2D model

Table 3-6 lists the computed water levels for the natural and encroachment scenarios. These values confirm that the 0.3 m water level difference criteria were not exceeded, validating the floodway and flood fringe delineation provided in Appendix H.

Table 3-6: Comparison of water surface elevations for natural and encroachment conditions

Station (km)	100-yr WSE-Natural (m)	100-yr. WSE-Encroachment (m)	Difference (m)
0.0	712.31	712.39	0.09
2.0	711.17	711.23	0.06
4.0	700.75	700.86	0.12
6.0	688.16	688.24	0.08
8.0	676.84	676.88	0.04

Station (km)	100-yr WSE-Natural (m)	100-yr. WSE-Encroachment (m)	Difference (m)
10.0	667.16	667.45	0.29
12.0	661.66	661.71	0.06
14.0	655.39	655.42	0.03
16.0	648.66	648.70	0.04
18.0	641.95	642.00	0.05
19.22 (CP Railway)	640.16	640.44	0.29
22.0	629.37	629.37	0.00
24.0	629.09	629.11	0.02
38.0	620.27	620.37	0.10
40.0	619.35	619.35	0.00
42.0	618.06	618.14	0.09
44.0	615.45	615.45	0.00

3.4 Climate Change Analysis

As described in Section 2.5, the 100-year flood was increased by 40% to build the climate change scenario. Results show that the water surface increases significantly for the 100-year flood scenario under climate change than in the 100-year flood calculated based on historical data. As shown in Figure 3.6, the water level increase is generally less than 0.4 m for the first 12.5 km of the creek but exceeds 0.4 m between 12.5 km and 27 km. At Highway 15, the water level reaches about 0.8 m above current conditions. In the downstream section of the study reach, the water level increase is less than 0.3 m except for the last 1 km. The inundation maps for the 100-year flood under climate change are provided in Appendix I. The impact of climate change on the flood inundation extent is more noticeable between RR 212 and TR 554, where the agricultural and residential areas are at more severe flood risk. In this model, RR 212 and RR 211 start to be overtopped.

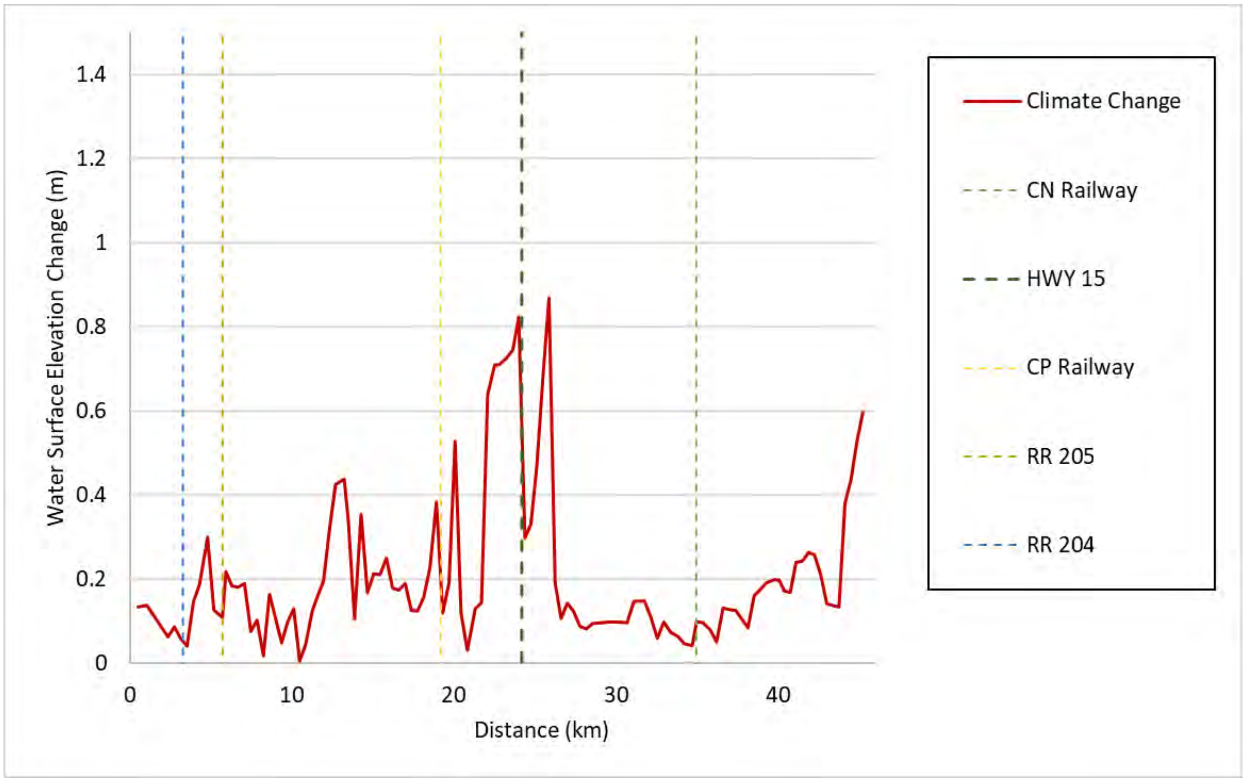


Figure 3.6: Water surface elevation increase for the climate change scenario.

3.5 Erosion Assessment

To evaluate the erosion risk along Astotin Creek, the water velocities for the 100-year event were extracted from the hydraulic model. The velocity maps, presented in Figure 3.7 to Figure 3.9, reveal that the maximum water velocities are expected to be around 2.8 m/s. The deeper sections of the creek, where flood flows are better contained, and therefore the flow per unit width is higher, experience higher velocities. Moreover, the creek section upstream of Highway 15 has a much higher slope than the downstream section, leading to higher velocities. The model also suggests that the numerous beaver dams along the study reach significantly reduce water velocities, thereby reducing erosion risk.

The modelled water velocities are significantly lower in the downstream section where the flow propagates through the wetland, with a maximum velocity of just over 1 m/s and an average velocity of less than 0.3 m/s. Erosion risk is therefore limited downstream of Highway 15. However, the upper reach of Astotin Creek is more vulnerable to erosion given its steeper slope and limited floodplain width. The absence of beaver dams amplifies the erosion risk at certain locations.

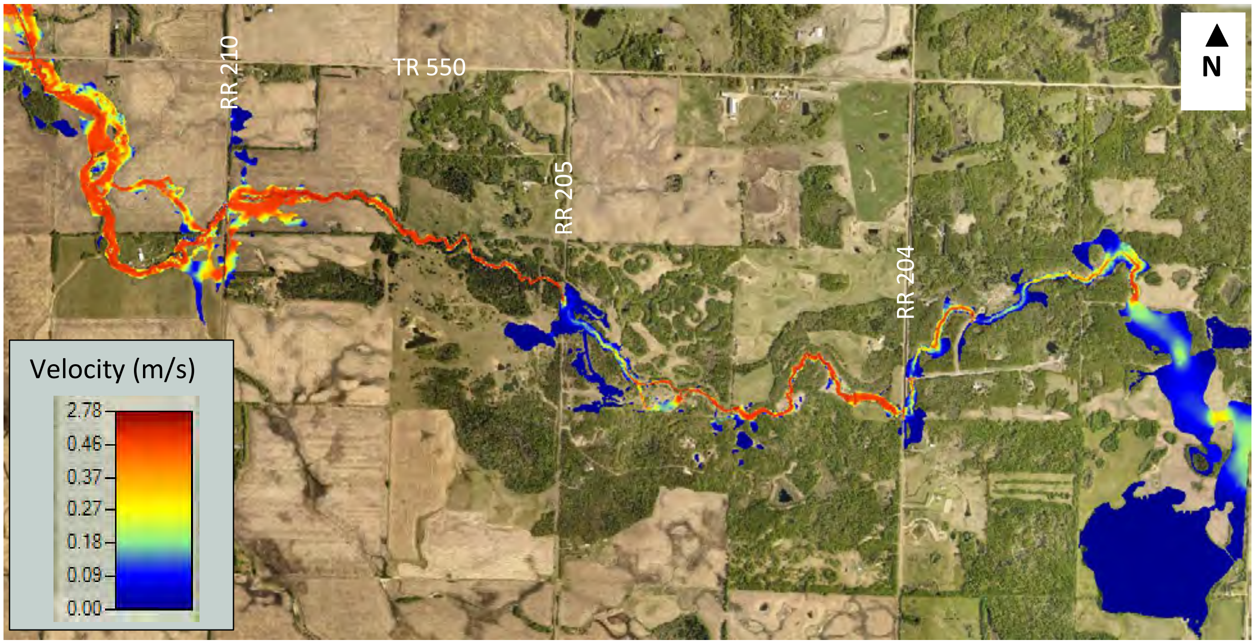


Figure 3.7: 100-year water velocity in the upstream section of the model

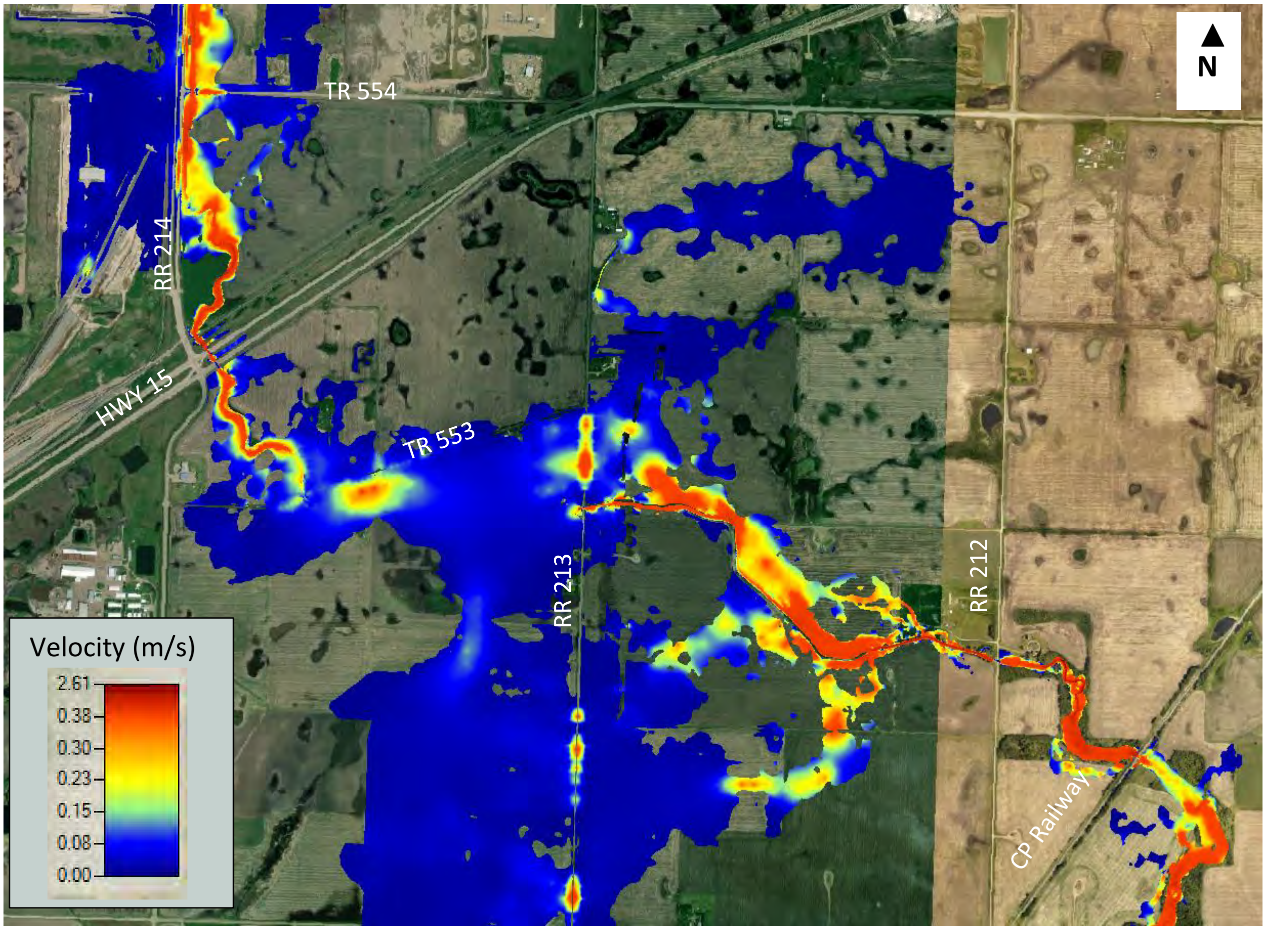


Figure 3.8: 100-year water velocity upstream of Highway 15.

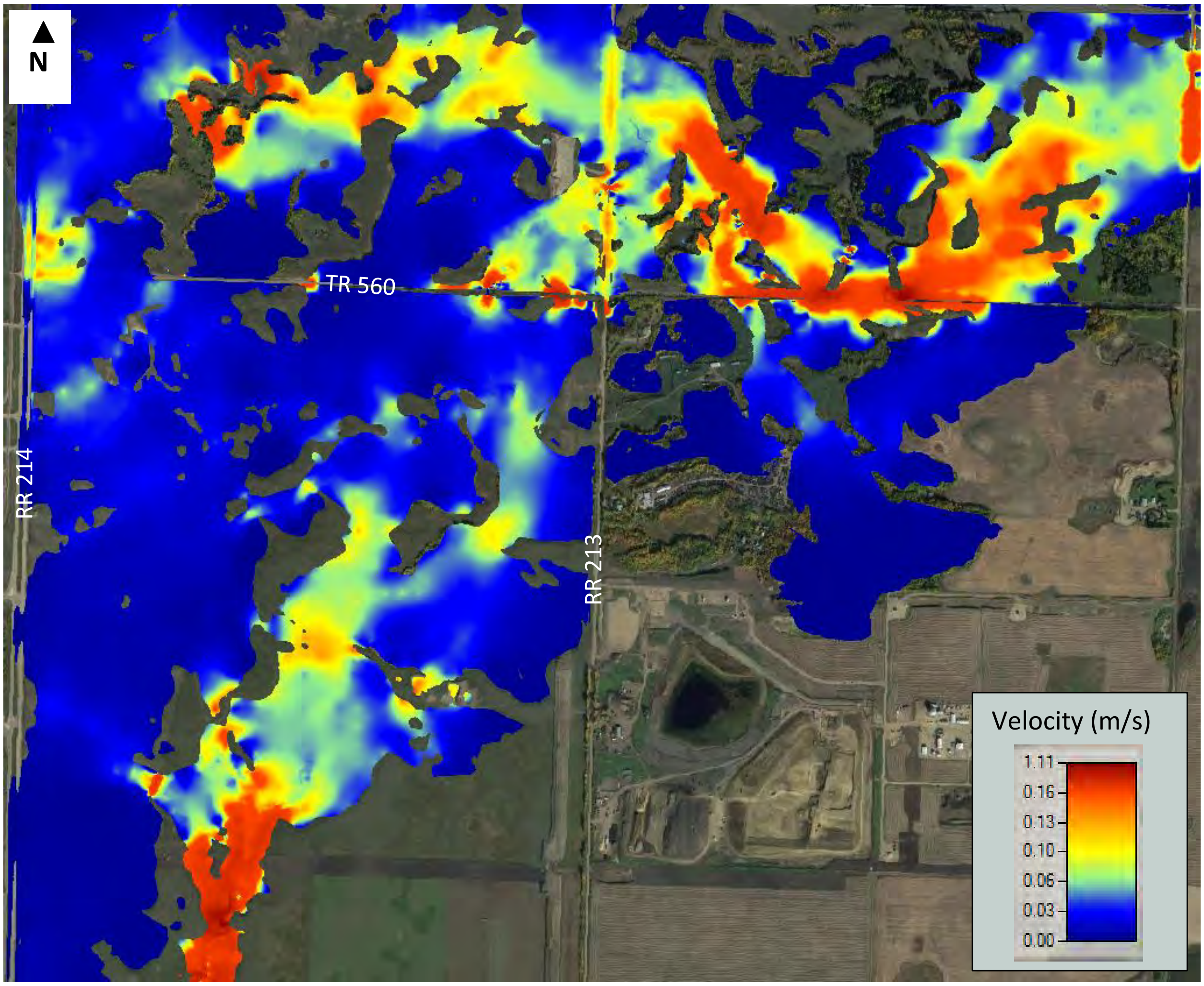


Figure 3.9: 100-year water velocity in the downstream section of the model.

3.6 Impact of Beaver Dams on Water Elevations

Active beaver dams were relatively abundant through the Upper and Middle Assessment Reaches, which may be related to the generally narrower width and steeper slope of the creek in these sections of the watershed. As shown in Figure 3.10, beaver dams can increase flood levels compared to normal conditions. Similar to beaver dams, man-made weir structures along Astotin Creek can also increase local flood levels.

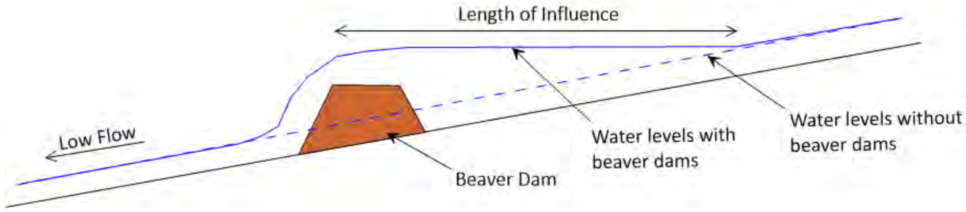


Figure 3.10: Conceptual sketch depicting a beaver dam influence on water levels

The influence length of a beaver dam is strongly dependent on the local characteristics of the creek and the magnitude of the flood event. The impact of the beaver dam on flood elevation is generally less significant for steeper creeks and during large flood events, such as the 20-year flood or more intense floods. Astotin Creek in the upper and middle assessment reach has an average longitudinal slope of about 0.4%, and beaver dams can potentially control water over hundreds of meters upstream of the dam in low flow conditions. This influence decreases as the creek flow increases, the floodplain becomes inundated, and the beaver dams become fully submerged. For example, at quarter section SW12-55-21-4, Astotin Creek's main channel is about 4 m wide and has a relatively low conveyance capacity compared to its floodplain, which is about 90 m wide, as shown in Figure 3.11.

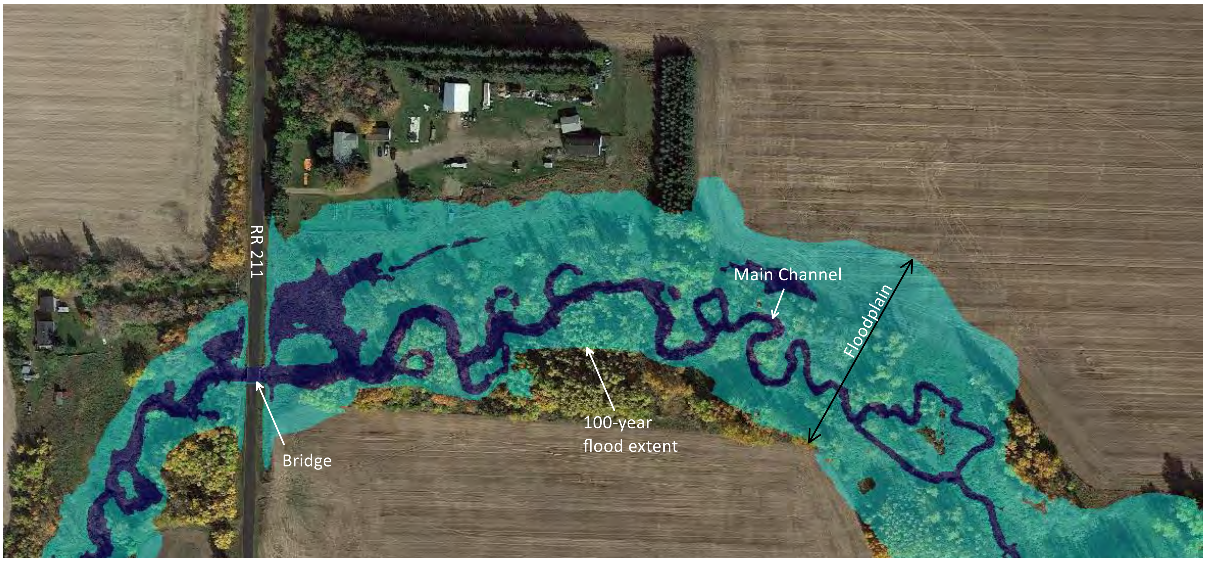


Figure 3.11: 100-year flood extent (current condition) simulation results. The main channel is illustrated in dark blue and the floodplain in light blue.

At quarter section SW12-55-21-4, the hydraulic simulation suggests that about 75% of the 100-year flow is conveyed in the floodplain and about 25% is conveyed in the main channel, showing that the floodplain is the primary flow vehicle to convey floodwater downstream. Moreover, during high flow events, the flow patterns (direction/orientation) change and are more linear, bypassing some of the creek meanders through the floodplain and increasing the flow conveyed in the floodplain. Beaver dams that are limited to the main channel and relatively short have a limited impact on water levels during large flood events, such as the 2018 flood, at that location.

Nonetheless, beaver dams' height and length can sometimes be significant, and they can have a substantial impact on flood levels when they extend beyond the main creek channel into the floodplain and reduce the overall discharge capacity. Moreover, beaver activities can generate a significant amount of debris, which can be carried downstream during significant flood events, leading to potential blockage of crossings. This could lower the existing discharge capacities of the blocked crossings and increase upstream water levels.