



Paddle Prairie Flood Study

Main Report

Submitted to:

Alberta Environment and Protected Areas

11th Floor, Oxbridge Place
9820 - 106th Street NW
Edmonton, Alberta T5K 2J6

Submitted by:

WSP Canada Inc.

237 – 4 Avenue SW, Suite 3300 Fifth Avenue Place
Calgary, Alberta
T2P 4K3

1 403 299 5600

23592570

March 2025

DRAFT



Distribution List

1 Digital Copy - Alberta Environment and Protected Areas

1 Digital Copy - WSP Canada Inc.

DRAFT

Executive Summary

Alberta Environment and Protected Areas (EPA) commissioned WSP Canada Inc. (WSP) in March 2023 to conduct the Paddle Prairie Flood Study. The purpose of the study is to assess and identify flood hazards along the Boyer River through the Community of Paddle Prairie and Paddle Prairie Metis Settlement (PPMS). The study is part of the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancement of public safety and reduction of future flood damages through the identification of flood hazards. Project stakeholders include the Government of Alberta, Community of Paddle Prairie and PPMS. There are no previous flood studies for this area.

This report documents the methodology and results for all components of the study which are listed below:

- Survey and base data collection
- Open water hydrology assessment
- Open water hydraulic modelling
- Flood inundation mapping
- Design flood hazard identification and flood hazard mapping

The total length of the Boyer River study reach is approximately 19.8 km reach through the Community of Paddle Prairie and PPMS. The survey was completed in the summer of 2023 and spring of 2024. The hydraulic features in this study are summarized in Table i. There are no flood control structures or weirs identified in the study area.

Table i: Summary of Survey Features

Feature	Total Number
Cross Sections	164
Bridges	5
Culverts	1

A hydrology assessment was completed to provide the flood peak discharge estimates at key locations in the study area as inputs to the HEC-RAS models.

A two-dimensional HEC-RAS model was setup for the study reach. The models were calibrated based on the following:

- High flow condition (i.e., high water marks collected by EPA) associated with the 2022 flood event on the Boyer River
- Stage-discharge rating curve for the Water Survey of Canada (WSC) gauging station – Boyer River at Paddle Prairie (WSC Station No. 07JF005)

The calibrated Manning's n value was 0.065 for the channel. The calibrated model was used to simulate the water surface profiles for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year flood events in the study area.

The model sensitivity was evaluated using the 100-year open water flood simulation results. The results of the sensitivity analysis show that variation of the channel roughness values has a higher influence on the simulated water levels than variation of the floodplain roughness values along the Boyer River.

Flood inundation and hazard maps were prepared for the study reaches of the Boyer River using ArcGIS. The simulated flood water levels were used to create a continuous water surface. The edge of inundation was delineated by subtracting the LiDAR DTM from the water surface. Direct inundation areas were mapped where there is a direct connection between the main channel and inundated areas on the floodplain. This includes areas where inundation is caused by single or multiple topographic or structural overtopping points or backwater flooding.

Based on the simulation results, various residential and commercial areas would be affected along the Boyer River by direct inundation starting between the 10 to 20-year flood. The full set of open water flood inundation maps was prepared in this study.

The boundary between the floodway and flood fringe is determined based on the adopted criteria using the calibrated HEC-RAS model. The results of the design flood hazard mapping are the delineation of the floodway and flood fringe zones and determination of the design flood water levels. Based on the flood hazard maps, there are no residences or businesses situated in the floodways along the Boyer River.

The residential and development areas in the flood fringe within the study area include a significant portion of the residential and commercial areas of the community. This includes the Fire Hall and Community Centre. The full sets of floodway criteria maps and flood hazard maps are provided in this report.

DRAFT

Acknowledgements

The study was completed by the Government of Alberta under the provincial Flood Hazard Identification Program, the goals of which include enhancement of public safety and reduction of future flood damages through the identification of river and flood hazards. The study was co-funded by the Government of Canada through the federal Flood Hazard Identification and Mapping Program

WSP Canada Inc. (WSP) acknowledges the contributions of the following staff of Alberta Environment and Protected Areas (EPA):

- Mr. Jim Choles, EPA's project manager for the study, coordinated the participation from EPA, and provided technical advice and review of this report.
- Mr. Peter Onyshko, EPA's technical advisor for the study, provided technical review and guidance.

The contributions of the following staff from WSP are acknowledged:

- Mr. Liv Hundal, WSP's project manager, was responsible for regular communications with EPA, technical advisor for hydrology and preparation of this report.
- Dr. Nathan Schmidt, senior reviewer for this study, was responsible for providing senior inputs and review, quality control and assurance for the study, and reviewing this report.
- Dr. Getu Biftu, senior hydrologist, was responsible for review of the open water hydrology assessment.
- Mr. Martin Lacroix, senior hydrologist responsible for the climate change assessment.
- Mr. Jie Chen, a hydrodynamic modelling specialist and project engineer, was responsible for overseeing the HEC-RAS modelling and encroachment analysis, and preparation of the flood hazard maps.
- Ms. Amber Liu conducted HEC-RAS modelling and encroachment analysis, prepared flood hazard maps, and provided inputs to this report.
- Mr. Peter Thiede, a GIS specialist, was responsible for preparation of the flood hazard maps and provided inputs to this report.

Table of Contents

1.0 INTRODUCTION	1
1.1 Study Background	1
1.2 Study Objectives	1
1.3 Study Area.....	2
2.0 SURVEY AND BASE DATA COLLECTION	4
2.1 General.....	4
2.2 Procedures and Methodology	4
2.2.1 Survey Equipment and Control	4
2.2.2 Channel Cross Sections and Longitudinal Profiles.....	5
2.2.3 Hydraulic Structures.....	7
2.3 Survey Standards and Accuracy.....	8
2.4 Cross Sections and Longitudinal Profiles	8
2.5 Discharge and Water Level Measurements.....	9
2.6 Hydraulic Structures.....	9
2.7 Flood Control Structures	10
2.8 Additional Base Data.....	10
3.0 OPEN WATER HYDROLOGY ASSESSMENT	11
3.1 Overview	11
3.2 Flooding History	11
3.2.1 General Information	11
3.2.2 Open Water Flood History	11
3.3 Open Water Flood Frequency Analysis	13
4.0 OPEN WATER HYDRAULIC MODELLING	14
4.1 Overview	14
4.2 Available Data	14
4.2.1 Digital Terrain Model.....	14
4.2.2 High Water Marks	14

4.2.3 Gauge Data and Rating Curves..... 16

4.2.4 Aerial Flood Photography 16

4.3 Stream and Valley Features..... 16

4.3.1 General Description 16

4.3.2 Channel and Floodplain Characteristics 16

4.3.3 Bridges and Culverts..... 17

4.3.4 Weir, Dam and Flood Control Structure..... 17

4.4 Model Construction 17

4.4.1 Methodology..... 17

4.4.2 HEC-RAS Program 17

4.4.5.2 Roughness Coefficients..... 22

4.4.5.3 Bridges and Culvert 24

4.4.5.3.1 Bridges..... 24

4.4.5.3.2 Culvert..... 24

4.4.5.3.3 Weir, Dam and Flood Control Structure..... 24

4.4.6 Model Calibration 24

4.4.6.1 Methodology 24

4.4.6.2 High Flow Calibration..... 25

4.4.6.3 Validation Using WSC Gauge Data and Rating Curves 25

4.4.6.4 Summary of Calibration Results 30

4.4.7 Model Parameters and Options 30

4.4.7.1 Manning’s Roughness Coefficient 30

4.4.7.2 Expansion and Contraction Coefficients..... 30

4.4.8 Open Water Flood Frequency Profiles..... 31

4.4.8.1 Production Model 31

4.4.8.2 Flow Change Locations 31

4.4.8.3 Flood Peak Flows 31

4.4.8.4 Model Boundary Conditions..... 31

4.4.8.5 Open Water Flood Frequency Profiles 31

4.4.9 Model Sensitivity 32

5.0 FLOOD INUNDATION MAPS	33
5.1 Methodology.....	33
5.2 Inundation Polygon Modifications	33
5.2.1 Open Water Inundation Mapping.....	33
5.2.2 Manual Edits	33
5.3 Areas Affected by Floods	35
5.3.1 Residential and Commercial Areas Affected by Floods.....	35
5.3.2 Flooding of Bridges and Culverts.....	35
5.4 Flood Depth Grids	37
5.4.1 GIS Data Specifications	37
5.4.2 General Comments	37
6.0 DESIGN FLOOD HAZARD MAPPING	38
6.1 Flood Hazard Mapping Approach	38
6.2 Design Flood	38
6.3 Floodway and Flood Fringe Terminology.....	38
6.4 Floodway Determination Criteria.....	39
6.5 Floodway Criteria Maps	39
6.5.1 Flood Hazard Maps.....	40
6.6 Design Flood Grids	41
6.6.1 Water Surface Elevation Grids.....	41
6.6.2 Flood Depth Grids.....	41
6.6.3 General Comments.....	41
7.0 POTENTIAL CLIMATE CHANGE IMPACTS	42
8.0 CONCLUSIONS	43
8.1 Survey and Base Data Collection	43
8.2 Open Water Hydrology Assessment.....	43
8.3 Open Water Hydraulic Modelling	43
8.3.1 Model Calibration	43
8.3.2 Model Sensitivity	43

8.3.3	Flood Profiles	44
8.4	Flood Inundation Mapping.....	44
8.5	Design Flood Hazard Mapping.....	44
8.6	Quantitative Climate Change Assessments.....	44

TABLES

Table 2-1: Surveyed Cross Sections within the Study Area.....	8
Table 2-2: Characteristics of Bridge and Culvert Structures	10
Table 3-1: Flood Peak Discharge Estimates and their 95% Confidence Intervals.....	13
Table 4-1: 2022 High Water Mark Data.....	14
Table 4-2: List of Bridges and Culverts within the Study Area	17
Table 4-3: Roughness Classes and Initial Manning's n Values	22
Table 4-4: Manning's n Values for Various Land Uses on the Floodplains.....	30
Table 4-5: Summary of Flood Peak Flows Used in the HEC-RAS Production Model	31
Table 5-1: Locations of Manual Edits for Flood Inundation Polygons	34
Table 5-2: Flooding at the Bridges and Culverts along the Study Reaches of Boyer River.....	36

FIGURES

Figure 1.1: Overview of the Study Area.....	3
Figure 2.1: Schematic of Survey Point Locations and Code Descriptions	6
Figure 2.2: Channel Thalweg and surveyed Surface Water Profile along the Boyer River	9
Figure 3.1: Boyer River Watershed and Regional Gauging Stations	12
Figure 4.1: Locations of Surveyed High Water Marks	15
Figure 4.4: Channel Bathymetry in the Integrated DEM.....	22
Figure 4.5: Distribution of Roughness Classes	23
Figure 4.6: Comparison of Simulated Boyer River Water Surface Profile and Reported High Water Marks for the 2022 Flood Event.....	26
Figure 4.7: Calibration Results based on the WSC Station No. 07BK009 (Boyer River near Paddle Prairie) Rating Curve	27
Figure 4.8: Simulated Water Surface Profiles along the Study Reach.....	29

APPENDICES

APPENDIX A

Locations of Cross Sections, Hydraulic Structures and Flood Control Structures

APPENDIX B

Hydraulic Structure Datasheets

APPENDIX C

Technical Memorandum on Flood Control Structures

APPENDIX D

Technical Memorandum on Open Water Hydrology Assessment

APPENDIX E

Open Water Flood Profiles

APPENDIX F

Open Water Sensitivity Analysis

APPENDIX G

Open Water Inundation Maps

APPENDIX H

Floodway Criteria Maps and Flood Hazard Maps

APPENDIX I

Climate Change Flood Profiles

DRAFT

1.0 INTRODUCTION

1.1 Study Background

Alberta Environment and Protected Areas (EPA) retained WSP Canada Inc. (WSP) in March 2023 to conduct the Paddle Prairie Flood Study. The study is part of the provincial Flood Hazard Identification Program (FHIP), and the purpose of the study is to assess and identify river and flood hazards along the 19.8 km reach of the Boyer River through the Community of Paddle Prairie and Paddle Prairie Metis Settlement (PPMS). The study reach extends downstream from the upstream side of the river crossing on the east edge of NE11-103-22-W5M to the east side of SE29-103-21-W5M.

The study is conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancement of public safety and reduction of future flood damages through the identification of flood hazards. Project stakeholders are the Government of Alberta, Community of Paddle Prairie and PPMS.

There were no previous provincial flood hazard studies for this area.

The study is comprised of multiple components and deliverables. This report documents the methodology and results of all major study components listed below.

- 1) Survey and Base Data Collection.
- 2) Open Water Hydrology Assessment.
- 3) Open Water Hydraulic Modelling.
- 4) Flood Inundation Mapping.
- 5) Design Flood Hazard Identification and Flood Hazard Mapping.

1.2 Study Objectives

The overall goal of the study is to enhance public safety and support the assessment and identification of flood hazards in the study area. The primary focus of the study was open water hydraulic modelling and flood mapping. The study results are intended to reduce potential future flood damages and associated disaster assistance costs, to mitigate flood impacts by informing land use planning decisions, and for emergency preparation.

This report summarizes the work of all five components. The primary tasks, services, and deliverables associated with this report are:

- River cross section surveys
- Hydraulic structure data collection
- Survey and digital terrain model (DTM) data integration
- Documentation of flood history
- Flood hydrology assessment
- Creation, calibration, and validation of a HEC-RAS hydraulic model for hydraulic modelling
- Simulation of selected return-period floods and the creation of water surface profiles throughout the study reach and sensitivity analysis of the model inputs

- Production of flood inundation maps
- Determination of floodway criteria and creation of design flood water surface profiles throughout the study reach
- Production of floodway criteria maps for open water flood and flood hazard maps

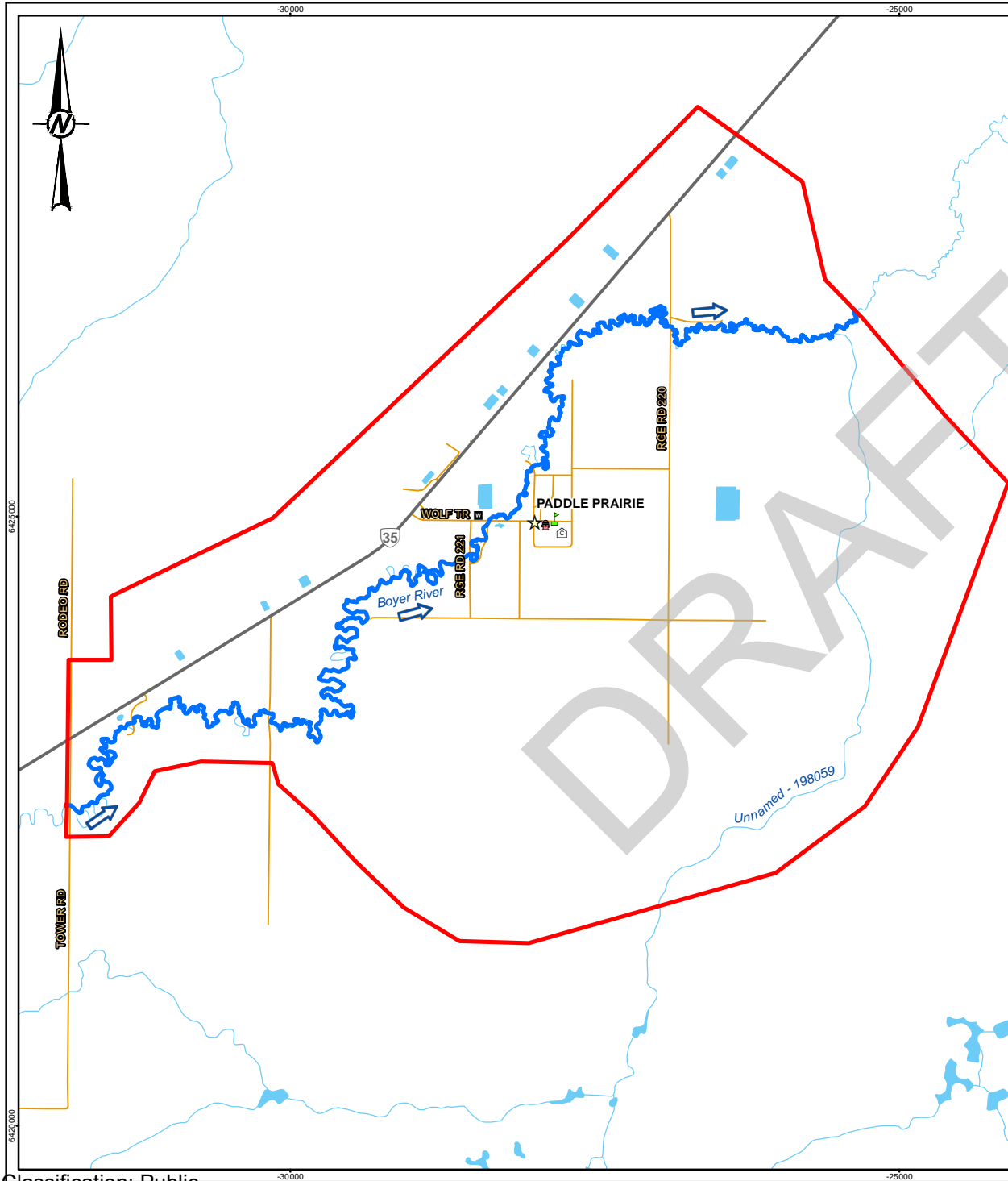
1.3 Study Area

Figure 1.1 provides an overview of the study area. Field survey, hydraulic modelling, and flood mapping were conducted over the study area.

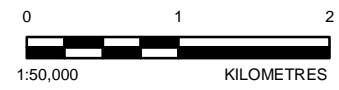
Paddle Prairie Metis Settlement is located in northern Alberta, along the northern boundary of the County of Northern Lights. It is located along the Mackenzie Highway (Highway 35), approximately 72 km south of the Town of High Level. It has a land area of 1,726.45 km²

The population of Paddle Prairie is approximately 800 (<https://paddleprairiemetis.com/>). In the 2021 Census, the population lived in 212 of its 256 total private dwellings. The Paddle Prairie School has approximately 120 students (<https://paddleprairiemetis.com/>).

DRAFT



- LEGEND**
- FLOOD STUDY AREA
 - WATERBODY
 - WATERCOURSE
 - SURVEY REACH
 - ➔ FLOW DIRECTION
 - PRIMARY HIGHWAY
 - LOCAL ROAD
 - ★ SETTLEMENT
 - COMMUNITY CENTRE
 - 🏫 SCHOOL
 - 🚒 FIRE HALL
 - WATER TREATMENT PLANT



REFERENCE(S)
 HYDROGRAPHY, ROADS, AND SETTLEMENTS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED.
 DATUM: NAD 83 CSRS PROJECTION: 3TM 117

CLIENT
ALBERTA ENVIRONMENT AND PROTECTED AREAS *Alberta* **Canada**

PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
LOCATION MAP OF THE STUDY AREA

CONSULTANT	WSP	YYYY-MM-DD	2025-01-21
		DESIGNED	SW
		PREPARED	HB
		REVIEWED	
		APPROVED	

PROJECT NO. 23592570 CONTROL REV. 0 FIGURE 1-1

2.0 SURVEY AND BASE DATA COLLECTION

2.1 General

WSP conducted a topographic survey of the Boyer River within the study area during two separate periods from June 27 to July 6, 2023 and April 26 to 27, 2024. The survey scope included a survey of channel cross sections and hydraulic structures. No flood control structures were identified in the study area.

In addition, five (5) common benchmarks were surveyed upon the request of EPA in support of Light Detection and Ranging (LiDAR) remote sensing data collection (by others) to confirm that the LiDAR based digital terrain model (DTM) meets FHIP accuracy standards and that there is consistency between the LiDAR and ground surveys.

Site reconnaissance was conducted by representatives from EPA, PPMS and WSP on May 31, 2023. The field visits involved the following:

- Reviewed and confirmed the preliminary survey plan
- Confirmed the locations and number of channel cross sections and hydraulic structures to be surveyed
- Confirmed there were no flood control structures in the study area
- Familiarized the project team with Boyer River channel and floodplain in the study area

2.2 Procedures and Methodology

2.2.1 Survey Equipment and Control

The survey equipment used in the collection of the topographic, bathymetric, and structure data for this study included the following:

- Real-time Kinematic (RTK) Global Positioning System (GPS): A Trimble® R8 RTK base station and Trimble® R10 RTK rover units, the latter of which were paired to Trimble® TSC3 hand-held data collectors running Trimble Access® survey software, and used to survey ground features, water levels, and river/creek bed levels in areas where hydraulic conditions allowed the surveyors to wade the channel and walk on the banks. The RTK system was also used to survey the following:
 - Control points and benchmarks that were identified or placed within the study area
 - Bridge structures

The proposed cross section locations were identified in a digital georeferenced vector format, which the survey crew utilized on their data collectors to guide the survey. Uploading a georeferenced survey plan into the data collector aided the surveyor in maintaining precise spacing and alignment of cross sections.

All surveyed points were acquired by wading the channel or walking on the banks. Each survey data point collected was attributed a specific code. A schematic of survey point codes and corresponding descriptions is shown in Figure 2.1, which includes a complete list of survey codes for the RTK.

The data collected using above methods and equipment was referenced to the ASCM benchmark situated within or close to the study area (i.e., ASCM 286864). No calibration of the collected survey data was performed as the Can-Net network covered the area and the collected data was accurate in comparison to the ASCM benchmark. The calibration process involved having the field crew check the survey equipment readings against the ASCM.

Survey crew obtained a secondary check on data accuracy by having the static (temporary) RTK base station log data continuously at the start and end of each survey day.

All survey data was collected in the 3TM 114° W coordinate system and referenced to NAD83 (CSRS) horizontal and CGVD28 vertical datums. The RTK survey data outputs provided an orthometric elevation with correct northing and easting coordinates. The survey data were acquired by pre-loading geoid files into the survey equipment. Ellipsoidal heights were transformed to CGVD28 orthometric heights using the HTv2.0 geoid model.

2.2.2 Channel Cross Sections and Longitudinal Profiles

The locations of representative cross sections were selected to capture the variations in the physical characteristics of the channel and floodplains that could affect flood levels along the study reaches. Considerations of changes to the channel width, cross section area, channel bed and bank materials, and the presence of any confluences or islands, bridges, and other channel features contributed to the selection of the cross section locations.

The alignment of each cross section was established so that it would be orientated perpendicular to the direction of river/creek flow, as anticipated under high flow conditions. A shapefile showing the alignment of each cross section was provided to the survey crew at the outset of the field work and uploaded to the data collectors to provide guidance on where along the study reach to acquire data.

Each survey point collected with the RTK utilized a schematic of survey point codes and corresponding locations as shown in Figure 2.1, which also includes a complete list of survey codes for the RTK.

The quality and accuracy of all survey data were checked by using a Trimble data extraction and processing tool. All survey data was imported into ArcGIS to allow for validation and further processing. Data with horizontal or vertical accuracies of greater than ± 0.05 m was rejected. Daily quality and accuracy checks were conducted in the office. In cases where multiple points with low accuracy were detected at a cross section, the survey crew repeated that survey the next day.

Survey Codes for RTK GPS River Surveys (No Structures)

Purpose: - Create common definitions for survey points collected in the field for easier data processing in the office
 - Reduce confusion or uncertainty for field staff regarding coding of points

Location Code	
G	Ground
T	Top of Bank
B	Bank
O	Toe of Bank
W	Water Level
S	Stream Bottom (under water)
E	Edge of Road/Berm/Pathway/Railway
C	Centre Line of Road/Berm/Pathway/Railway
L	LiDAR control point

Material Code	
1	Mud/Silt (<0.063 mm)
2	Sand (0.063 mm - 2 mm)
3	Gravel (2 mm - 6.4 cm)
4	Cobble (6.4 cm - 25 cm)
5	Boulder (> 25 cm)
6	Bedrock
C	Concrete
G	Grass
R	Riprap
T	Trees (large, trunk > 10 cm)
W	Willows and Shrubs
B	Gabion Basket
A	Asphalt

Examples	
G2	Ground, Sand
G4	Ground, Cobble
W3	Water Level, Gravel
GG	Ground, Grass
GT	Ground, Trees
CA	Centre Line, Asphalt
BR	Bank, Riprap
LC	LiDAR control, Concrete

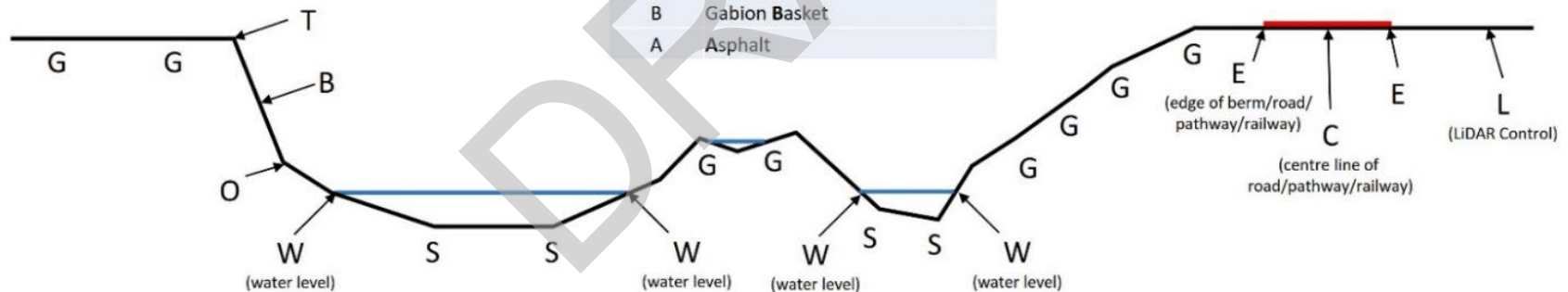


Figure 2.1: Schematic of Survey Point Locations and Code Descriptions

The main objective of the cross section surveys was to capture the characteristics of the main channel. However, limited overbank floodplain areas were also surveyed to overlap with the LiDAR survey (provided by EPA) where LiDAR coverage was assured. The cross sections were extended into the overbank areas during the hydraulic model development using the topographic (LiDAR) data provided by EPA. A breakline survey technique was utilized to capture variances in the bank geometry (i.e., slope breaks), with enough data points collected along each cross section to properly define the channel geometry and the near-bank floodplain.

Each recorded survey data point included Northing and Easting coordinate positions, water surface, and/or ground elevation and was attributed with a survey code that denotes its location (e.g., bank, stream bottom, edge of water, water level, top of bank, etc.).

The field program specifically included a cross section survey at the single Water Survey of Canada (WSC) hydrometric station on Boyer River (WSC Station 07JF005) within the study area (i.e., XS#103). The gauge is located on the left¹ (north) bank downstream of the Wolf Trail bridge.

The following procedures were adhered to in conducting bathymetric survey by wading:

- RTK rover units were used to collect cross section information from a location approximately 2 to 5 m beyond top of bank on one side of the river/creek channel, to a location approximately 2 to 5 m beyond top of bank on the other side. A minimum of 15 survey data points were obtained across the channel, and care was taken to reference points where the transverse bed slope changed significantly.
- Special attention was paid to surveying topographic slope breaks along the banks.
- Each of the surveyed data points was attributed with field codes that described substrate and vegetation types (see Figure 2.1).

The water surface elevation was surveyed at all points along the cross section where the water had contact with the bank.

Reach-representative photographs were taken at key locations within the study area during the site reconnaissance and field survey. The photographs, which include salient details and features at surveyed cross sections, are georeferenced with appropriate metadata.

Discharge measurements were not undertaken during the survey as there was little to no-flow in the channel.

2.2.3 Hydraulic Structures

All hydraulic structures within the study area were surveyed. These structures included bridges and culverts.

The features of each bridge/culvert structure surveyed included the following:

- Length of span (corner points, abutment to abutment)
- Width of bridge (corner points, outside to outside)
- top of curb or solid guard rail elevations
- Low chord elevations
- Number and width of piers

¹ *Left or right* refer to directions as seen by an observer looking downstream.

- Location of piers and the distance of each pier relative to the left abutment
- Type of piers (e.g., concrete, pile bent, steel column)
- Shape of pier (e.g., round nose, wedge, circular)
- Top of road surface profile

2.3 Survey Standards and Accuracy

Quality control and quality assurance (QA/QC) of collected data were conducted in the field at the time of data collection and in the office during data processing. QA/QC of field data was conducted as described below.

- Position and elevation from the RTK rover unit were checked for accuracy each day, based on the ASCM benchmark mentioned previously. All survey data collected during the field program were tied to the ASCM benchmark. Temporary benchmarks were established by the field crew along the watercourses as required to maintain data accuracy.
- The field crew was provided with a shapefile showing cross section alignment for the purpose of guiding the survey along the selected cross sections.
- The RTK data collectors were set up to provide a warning when calculated maximum error exceeded 0.05 m for a manually recorded point. When notified, the surveyor either adjusted their location or waited for a better solution before surveying a point.

The RTK control network is considered accurate to within ± 2 cm at 95 percent confidence in both horizontal and vertical directions. A high level of accuracy was maintained throughout the field program by calibrating the spatial position and elevation of each RTK rover unit to an ASCM benchmark daily. Furthermore, the daily protocol required that the survey crew calibrate to, and then open and close on, an ASCM benchmark to maintain absolute positional accuracy.

The collected survey data were imported into a Geographic Information System (GIS) to allow for validation and further processing. In addition to the QA/QC procedures for field data collection, the technical lead for the field program reviewed the survey data within 24 hours of it being collected to check for outliers (including erroneous or missing data) and to ensure appropriate coverage along each cross section and on the hydraulic structures.

2.4 Cross Sections and Longitudinal Profiles

The surveyed length of the Boyer River was approximately 18.5 km. A total of 164 channel cross sections were surveyed. Table 2-1 provides a summary of surveyed cross sections and Appendix A shows the locations of cross sections and Hydraulic Structures.

Table 2-1: Surveyed Cross Sections within the Study Area

Waterbody	Reach Description	Cross Section ID	No. of Cross Sections	Average Cross Section Spacing (m)
Boyer River	18.5 km reach extending from upstream of Tower Road bridge to 1.7 km downstream of Range Road 220 bridge.	XS1 to XS164	164	112.8

An overview of the surveyed channel thalweg and surface water profiles is provided in Figure 2.2.

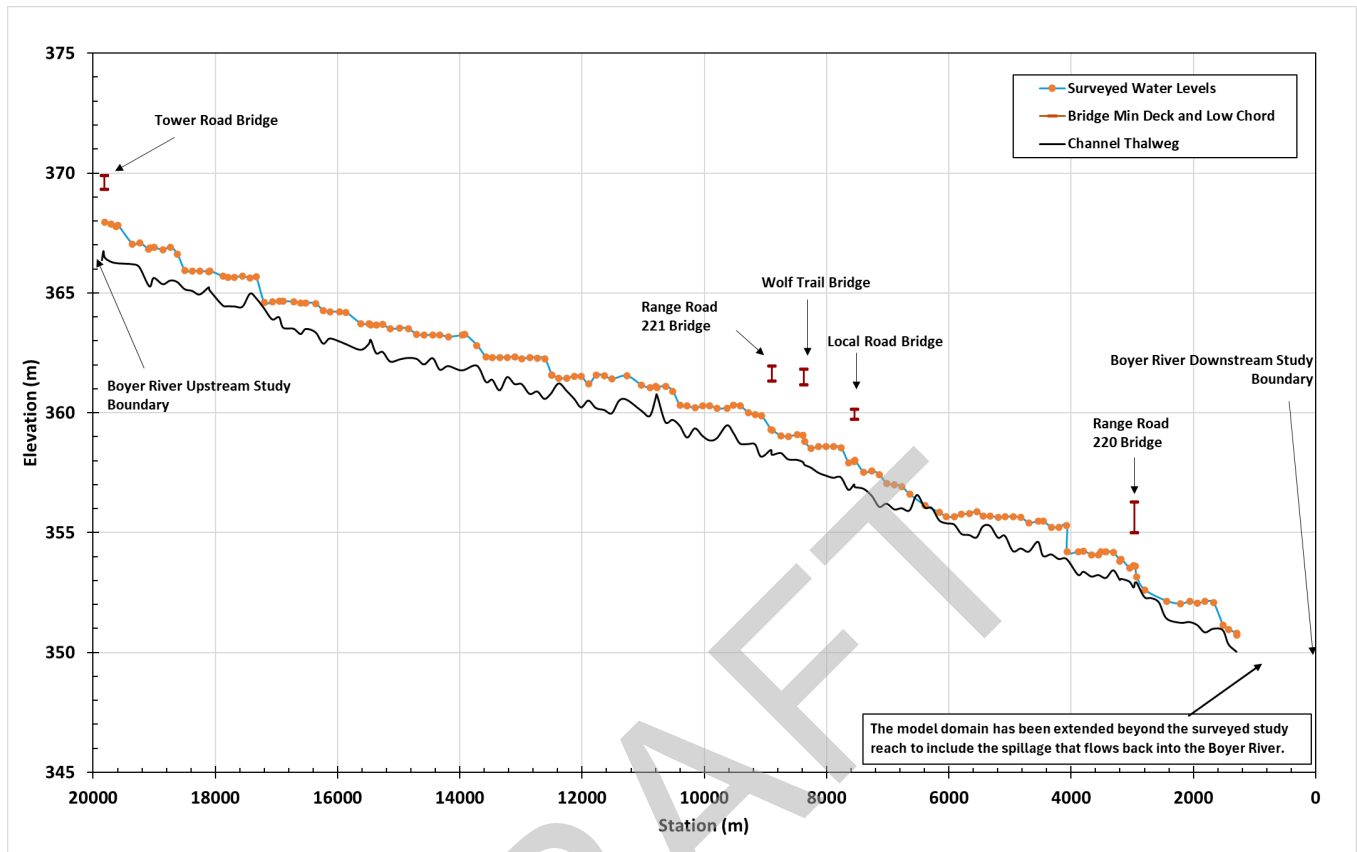


Figure 2.2: Channel Thalweg and surveyed Surface Water Profile along the Boyer River

2.5 Discharge and Water Level Measurements

No discharge measurement was conducted on the Boyer River as there was little to no flow in the channel during the survey. Standing water was present in the channel due to beaver dams and the relatively flat channel gradient. Water levels were recorded during cross section surveys.

2.6 Hydraulic Structures

There are six hydraulic structures (i.e., five bridges and one culvert crossing) in the study area. In addition, there is one culvert crossing washout on the Boyer River. A summary of the general characteristics of the surveyed bridges is provided in Table 2-2. Appendix B shows the hydraulic structure datasheets. The Alberta Transportation and Economic Corridor (TEC) Bridge File (BF) number is shown, where applicable.

Table 2-2: Characteristics of Bridge and Culvert Structures

Bridge ID	Bridge Name	River Station (Approx.)	Type	No. of Bridge Spans/Culvert Barrels
HS-01	Tower Road Bridge (BF79358)	19+800	Traffic	1
HS-02	Local Road Culvert	18+000	Traffic	3
HS-Washout	Local Road Culvert Washout	15+500	None	None
HS-03	Range Road 221 Bridge (BF80980)	8+900	Traffic	1
HS-04	Wolf Trail Bridge (BF75778)	8+400	Traffic	1
HS-05	Local Road Bridge	7+550	Traffic	3
HS-06	Range Road 220 Bridge (BF77963)	2+960	Traffic	1

2.7 Flood Control Structures

As documented in Appendix C, there are no flood control structures on the Boyer River in the study area.

2.8 Additional Base Data

Additional base data collected in support of hydraulic modelling and mapping included the following:

- LiDAR topographic data collected in October 2023 and provided by EPA
- Project Imagery captured October 2023 by OGL Engineering for the Government of Alberta and provided by EPA

3.0 OPEN WATER HYDROLOGY ASSESSMENT

3.1 Overview

A comprehensive open water hydrology assessment for the Boyer River in the study area is provided in Appendix D. The sections below provide a summary of the assessment.

3.2 Flooding History

3.2.1 General Information

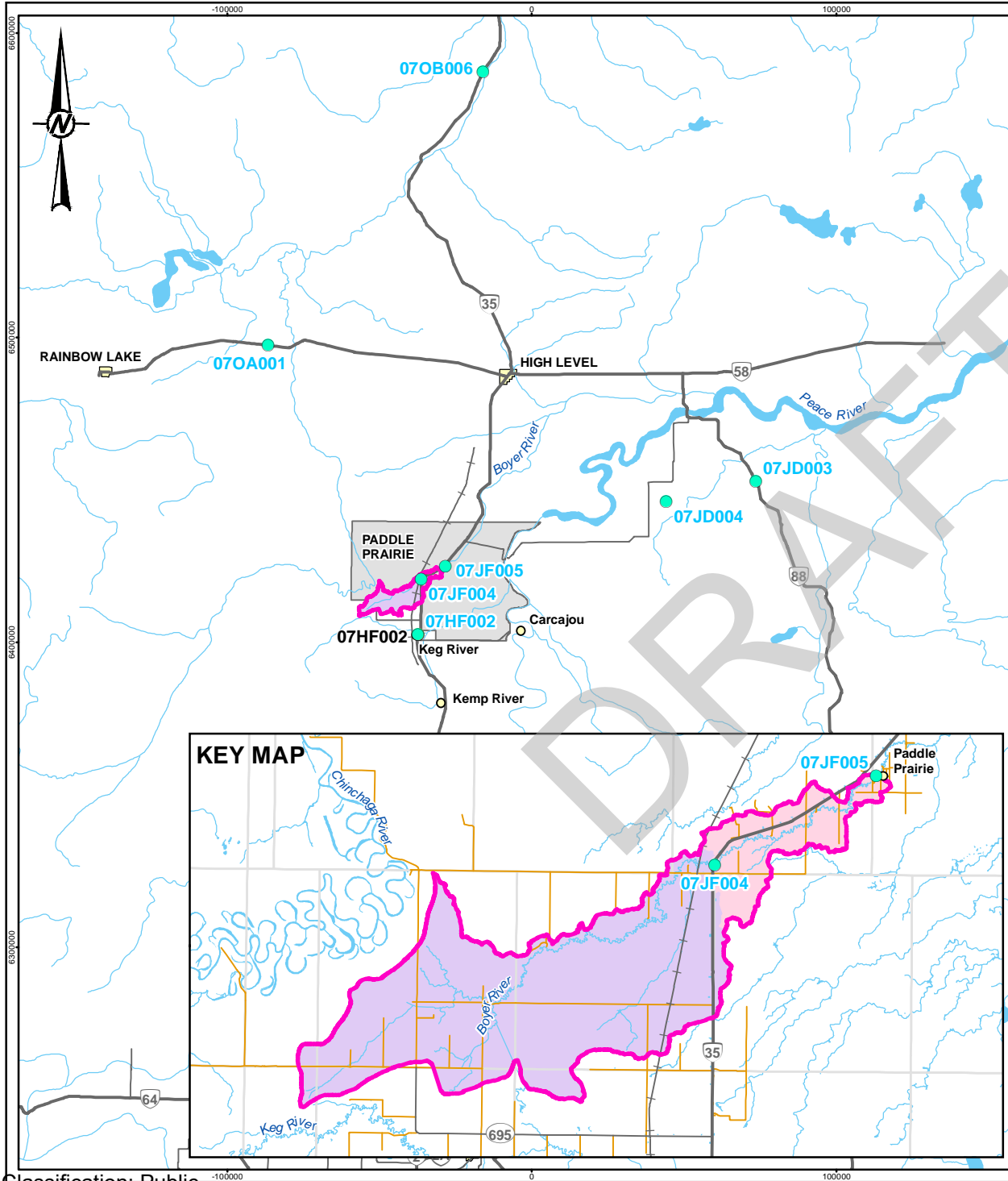
The watershed and regional streamflow gauging stations are shown in Figure 3.1. The Boyer River watershed starts near the intersection of Township Road 1020 and Range Road 243 and northeastward through the lowland physiography of northwestern Alberta. It has a drainage area of 200 km² at Paddle Prairie. Further downstream, it drains northeast to its confluence with the Peace River, near Fort Vermillion. The main drainage area land types are flat agricultural lands and boggy wetlands.

3.2.2 Open Water Flood History

Listed below are the two Water Survey of Canada (WSC) hydrometric stations located on the Boyer River near Paddle Prairie.

- The discontinued gauge Boyer River Near Paddle Prairie (07JF004) has a drainage area of 141 km², recorded data from 1979 to 2007 and was located 8.5 km upstream of the study area (distance measured along the channel centreline). The largest recorded flood occurred on May 1st, 1979, with an instantaneous discharge of 21.4m³/s. Other large floods occurred in April 1989 and April 1997.
- The Boyer River at Paddle Prairie (07JF005) is located in the study area and has a drainage area of 200 km², and recorded data from 2008 onwards (i.e., currently active). The largest recorded flood was on May 6th, 2013, with an instantaneous discharge of 29.7m³/s. Other large floods occurred in April 2009 and May 2022.

The available records indicate that major flood events occurred on the Boyer River in 1979, 1989, 1997, 2009, 2013 and 2022. The majority of the floods for both stations were recorded in April to May. This suggests a homogenous data set resulting from spring snowmelt, or possibly snowmelt combined with rainfall:

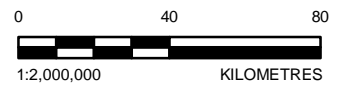


LEGEND

- HYDROMETRIC GAUGING STATION
- HYDROMETRIC GAUGING STATION NOT USED IN ANALYSIS
- +
 RAILROAD
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- WATERCOURSE
- WATERBODY
- METIS SETTLEMENT
- POPULATED PLACE
- BOYER RIVER AT PADDLE PRAIRIE WSC 07JF005

BOYER RIVER WATERSHED

- BOYER RIVER NEAR PADDLE PRAIRIE WSC 07JF004
- BOYER RIVER AT PADDLE PRAIRIE WSC 07JF005



REFERENCE(S)
 HYDROMETRIC STATIONS OBTAINED FROM WATER SURVEY OF CANADA (WSC) AND USGS. HYDROGRAPHY, METIS SETTLEMENTS, ROADS, AND POPULATED PLACES OBTAINED FROM ALTALIS. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. REGIONAL HYDROGRAPHY OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. PROJECTED COORDINATE SYSTEM: NAD 1983 CSRS 3TM 117

CLIENT
 ALBERTA ENVIRONMENT AND PROTECTED AREAS

PROJECT
 PADDLE PRAIRIE FLOOD STUDY

TITLE
BOYER RIVER WATERSHED AT PADDLE PRAIRIE AND REGIONAL GAUGING STATIONS

CONSULTANT	YYYY-MM-DD	2025-01-24
	DESIGNED	CC
	PREPARED	HB/BS
	REVIEWED	
	APPROVED	

PROJECT NO. 23592570 CONTROL REV. 0 FIGURE 3-1

3.3 Open Water Flood Frequency Analysis

Flood frequency analyses of the annual maximum instantaneous discharge at the study area was conducted to estimate the discharges and water levels of various return periods (i.e., 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year floods).

Table 3-1 summarizes the flood peak discharge estimates and the associated upper and lower 95% confidence intervals. The annual maximum instantaneous discharge series used in the flood frequency analyses, the various frequency distributions, and the best-fit distributions along with their 95% confidence intervals are provided in Appendix D.

Table 3-1: Flood Peak Discharge Estimates and their 95% Confidence Intervals

Return Periods (Years)	Annual Probability Of Exceedance (%)	Flood Frequency Analysis (M ³ /S)		
		Value	Lower 95% Limit	Upper 95% Limit
2	50	4.3	3.06	5.77
5	20	9.6	7.00	12.78
10	10	14.5	9.97	20.25
20	5.0	20.1	12.97	30.48
25	4.0	22.1	14.06	34.41
35	2.9	25.4	15.66	41.10
50	2.0	29.1	17.45	49.59
75	1.3	33.6	19.57	59.87
100	1.0	37.1	21.15	69.06
200	0.5	46.3	24.97	94.36
350	0.29	54.7	28.38	118.84
500	0.20	60.6	30.66	138.19
750	0.13	67.7	33.15	161.35
1,000	0.10	73.1	34.97	180.63

4.0 OPEN WATER HYDRAULIC MODELLING

4.1 Overview

The following sections describe the methodology and results of the open water hydraulic modelling component. The scope of this component includes summary of available data, description of the flooding history and stream/valley features in the study area, hydraulic model setup, hydraulic model calibration and validation, sensitivity analysis, and generation of open water flood frequency profiles. The results of this component are used in the flood inundation mapping, flood hazard identification, and governing design flood hazard mapping components.

4.2 Available Data

4.2.1 Digital Terrain Model

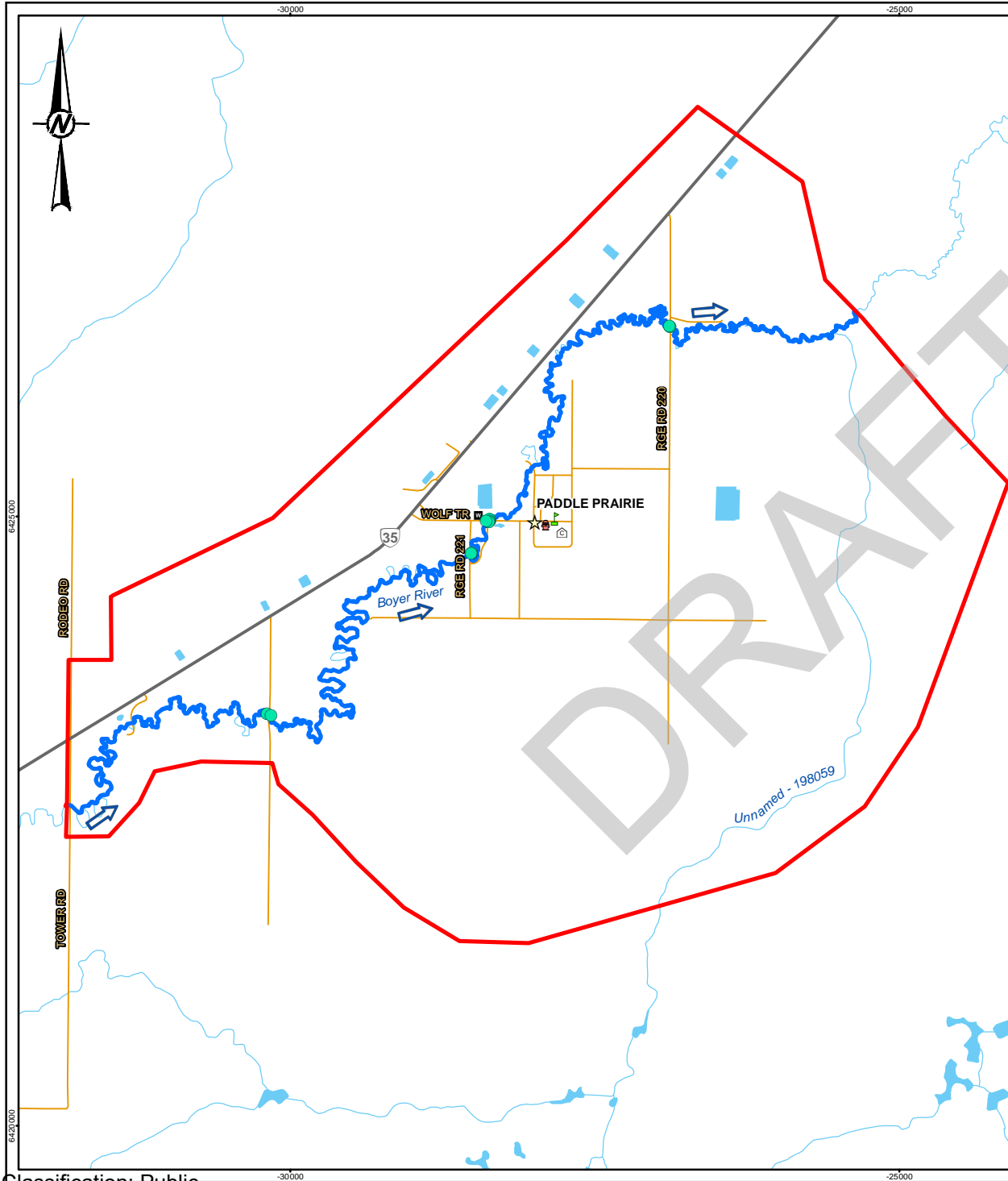
Digital Terrain Model (DTM) data was provided by EPA for this study. The DTM was derived from survey-verified high-accuracy Light Detection and Ranging (LiDAR) remote sensing data set acquired during October 2023

4.2.2 High Water Marks

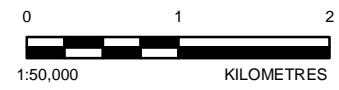
Several High Water Marks (HWM) of the 2022 flood were documented by EPA and subsequently surveyed by WSP. The HWM used for this study are listed in Table 4-1 and locations of HWMs are shown in Figure 4.1.

Table 4-1: 2022 High Water Mark Data

No.	Approximate River Stations	Description	Elevation (m)	Adjacent Structure
1	15369	debris in tree u/s of crossing on right bank	364.548	Local Resident Road
2	15331	debris in bush d/s road on right bank	364.486	Local Resident Road
3	8911	d/s bridge on left bank	359.716	Range Road 221 Bridge
4	8906	d/s bridge on right bank	359.917	Range Road 221 Bridge
5	8353	NE corner (d/s side) of bridge on wingwall	361.335	Wolf Trail Bridge
6	8347	debris in bushes d/s bridge on right bank	360.774	Wolf Trail Bridge
7	8341	debris beside road u/s of bridge on right bank	361.730	Wolf Trail Bridge
8	8330	debris in bush u/s of bridge on right bank	361.083	Wolf Trail Bridge
9	8325	debris on ground u/s of bridge	361.449	Wolf Trail Bridge
10	3103	SE corner of bridge	355.112	Range Road 220 Bridge
11	3103	NW corner of bridge	355.172	Range Road 220 Bridge



- LEGEND**
- FLOOD STUDY AREA
 - WATERBODY
 - WATERCOURSE
 - SURVEY REACH
 - ➔ FLOW DIRECTION
 - PRIMARY HIGHWAY
 - LOCAL ROAD
 - ★ SETTLEMENT
 - 🏠 COMMUNITY CENTRE
 - 🎓 SCHOOL
 - 🚒 FIRE HALL
 - 🏭 WATER TREATMENT PLANT
 - HIGH WATER MARK**
 - 2022



REFERENCE(S)
 HYDROGRAPHY, ROADS, AND SETTLEMENTS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED.
 DATUM: NAD 83 CSRS PROJECTION: 3TM 117

CLIENT
ALBERTA ENVIRONMENT AND PROTECTED AREAS *Alberta* **Canada**

PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
HIGH WATER MARKS

CONSULTANT	WSP	YYYY-MM-DD	2025-01-21
		DESIGNED	SW
		PREPARED	BS
		REVIEWED	
		APPROVED	

PROJECT NO. 23592570 CONTROL REV. 0 FIGURE 4-1

4.2.3 Gauge Data and Rating Curves

Station No. 07JF005 – Boyer River at Paddle Prairie is the only active Water Survey of Canada (WSC) hydrometric gauging station located within the study area. It is located on the left (north) bank of the Boyer River, at the Water Treatment Plant immediately downstream of the Wolf Trail bridge, which is shown in Figure 3.1. The stage-discharge rating curve for the Boyer River gauging station was used for the model calibration.

4.2.4 Aerial Flood Photography

There is no aerial flood photography available for this study.

4.3 Stream and Valley Features

4.3.1 General Description

PPMS is located in northwest Alberta, approximately 68 km south of the Town of High Level. The Boyer River headwater areas are located approximately 20 km south-south-east of the study area near the intersection of Township Road 1020 and Range Road 243 and drains approximately 35.8 km to WSC station (07JF005). The Boyer River at the WSC station has a drainage area of 200 km² and there are no significant tributaries contributing flow within the study area. The headwater areas of the basin are approximately 410 m above sea level and the elevations decrease gradually to the study area portions of the basin at an elevation of approximately 360 m. Hence, the average channel slope from the watershed boundary to the PPMS is 0.0014 m/m. The Boyer River enters the study area from the south and flows northeast.

The highway/local road bridges and culvert which are relevant for hydraulic modeling are listed in Table 4-2 and described in detail in Appendix B.

4.3.2 Channel and Floodplain Characteristics

The Boyer River drains northeast approximately 19.8 km through study reach. The channel characteristics are described below.

- The typical channel bankfull width ranges from 15 m to 20 m and the typical bankfull depth ranges from 1.2 m to 1.8 m.
- The channel bed and banks are composed of fine textured substrates. The banks are well vegetated with grass, willows and shrubs.
- The channel has a relatively flat gradient (0.0006m/m) and a tortuous meander pattern with numerous beaver dams and cutoffs (i.e., oxbow channels). The width of the channel meander belt varies from 10 m to 80 m and this area is generally are well vegetated with grass, willows and shrubs. The channel sinuosity is 2.6.
- The land adjacent to the channel meander belt is flat and is generally agricultural land, with the exception of the PPMS community where the land use is rural residential. The channel is unconfined by natural topographic features, although it is confined in a few locations by roads and associated crossings. Highway 35 confines the floodplain to the north. The floodplain is unconfined to the south and the east and the agricultural land extends approximately 1,100 m to 1,700 m past the channel in this direction. The agricultural land is bounded to the south and east by flat, marshy wetlands.

- The channel has a low conveyance capacity and is prone to overbank flooding for discharges greater than and equal to the 1:5-year return period. There are numerous spill locations, particularly in the area of the PPMS community and further downstream. This overbank flow spreads across the wide and flat adjacent areas, eventually following drainage paths that drain back into the Boyer River channel. Depending on the flood magnitude, some of these drainage paths can be quite lengthy, with the overbank flow being decoupled from the main the channel. This process is discussed in detail in the modeling and mapping section of the report.

4.3.3 Bridges and Culverts

There are five bridge crossings and one culvert crossing in the study area (see Appendix B and Table 4-2). Additionally, one road crossing washout was documented during the 2023 site visit and survey (see Appendix B and Table 4-2).

Table 4-2: List of Bridges and Culverts within the Study Area

Bridge ID	Bridge Name	River Station (Approx.)	Type	No. of Bridge Spans/Culvert Barrels
HS-01	Tower Road Bridge	19+800	Traffic	1
HS-02	Local Road Culvert	18+000	Traffic	3
HS-Washout	Local Road Culvert Washout	15+500	None	None
HS-03	Range Road 221 Bridge	8+900	Traffic	1
HS-04	Wolf Trail Bridge	8+400	Traffic	1
HS-05	Local Road Bridge	7+550	Traffic	3
HS-06	Range Road 220 Bridge	2+960	Traffic	1

4.3.4 Weir, Dam and Flood Control Structure

There is no weir, dam or flood control structure along the study reach of the Boyer River.

4.4 Model Construction

4.4.1 Methodology

The latest HEC-RAS program (Version 6.4.1, March 2019) was used to develop a two-dimensional (2D) hydraulic model for the study area.

4.4.2 HEC-RAS Program

The HEC-RAS program was developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE). The software has a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, and graphics and reporting facilities. HEC-RAS is a commonly-used program in North America and around the world.

The HEC-RAS program was designed to perform one-dimensional (1D), two dimensional (2D) or combined 1D and 2D hydraulic calculations for a full network of natural and constructed channels. The program supports steady-state and unsteady-state hydraulic simulation. HEC-RAS can be used to calculate water surface profiles for gradually varied flow. In this study, the program was used for 2D unsteady-state simulation.

The program can be used to simulate the effects of various obstructions such as bridges, culverts, weirs, levees and other structures. The program is capable of simulating the water surface profiles associated with subcritical, supercritical and mixed flow regimes.

4.4.3 Modelling Approach

In this study, a full 2D HEC-RAS model was set up for entire study area. The rationale for selecting the 2D HEC-RAS modelling approach is provided below:

- In the study area, the Boyer River consists of many tortuous meanders and a wide, relatively flat floodplain on agricultural lands. It would be challenging to define cross section alignments using a 1D modelling approach in this area. Significant manual edit efforts and professional judgment would be required to define the cross sections.
- There are multiple oxbows, wetlands, and ponds situated within the study reaches, and a large number of ineffective areas would be required to represent the effective flow area per cross section.
- There are many ill-defined drainage channels on the floodplain, which present challenges in defining the cross sections in a 1D model or coupled 1D/2D model.
- A large part of the community would be prone to flooding under moderate to extreme flood conditions (100-year to 1,000-year return period). The 2D modelling approach would provide more accurate definition of the water levels in the study area, especially for extreme events when there would be widespread flooding.
- There are roads within the floodplains. Our past modelling experience indicates that in the event of overtopping of these linear infrastructures away from the main channel, limitations of a 1D model approach may lead to inaccuracies.
- The study area will be modelled fully in 2D to avoid internal boundary conditions that would be required in a 1D model or coupled 1D/2D model and to account for the complex interactions between multiple watercourses on the same floodplain.
- The mesh along the main channel of the Boyer River can be further refined to represent the channel characteristics in 2D domain.

The 2D HEC-RAS model offers the following benefits:

- A 2D model allows the highwater marks at exactly individual locations to be appropriately compared with the simulated water levels for model calibration.
- A 2D model reduces the uncertainty in defining the alignment of cross section and the selection of appropriate ineffective flow areas for large floodplains in the model domain.
- A 2D model lowers the risk of profiles crossing at the locations where ineffective area would be activated when flood control structures, levees or roads would be overtopped.
- A 2D model allows for direct detailed inundation mapping without interpolating water levels between cross sections, which significantly reduces efforts in flood mapping and increases the accuracy of flood mapping.
- A 2D model will drastically reduce efforts for model setup comparing to coupled 1D/2D model. Significant efforts would be required to set up the lateral structures required for connecting 1D component and 2D component in a coupled 1D/2D model.

4.4.4 General Model Setup

4.4.4.1 Model Domain

It is generally desirable to use a single geometry file to simulate floods of various return periods. Therefore, the model domain needs to be defined to cover inundation extents of the largest flood event to be simulated. The model domain extent was defined to include all the developed agricultural land to the south and east of the Boyer River. As discussed previously in section 4.3, the floodplain is unconfined to the south and the east and the agricultural land extends approximately 1,100 m to 1,700 m south and east of the channel. The agricultural land is bounded to the south and east by flat, marshy wetlands that are undeveloped. As an additional buffer, the model domain was conservatively extended 1 to 2 km into this undeveloped area. Flow continuity was maintained within the model domain area (i.e., there was no flow leakage at the lateral boundaries of the model domain).

Figure 4.2 presents the model domain for this study.

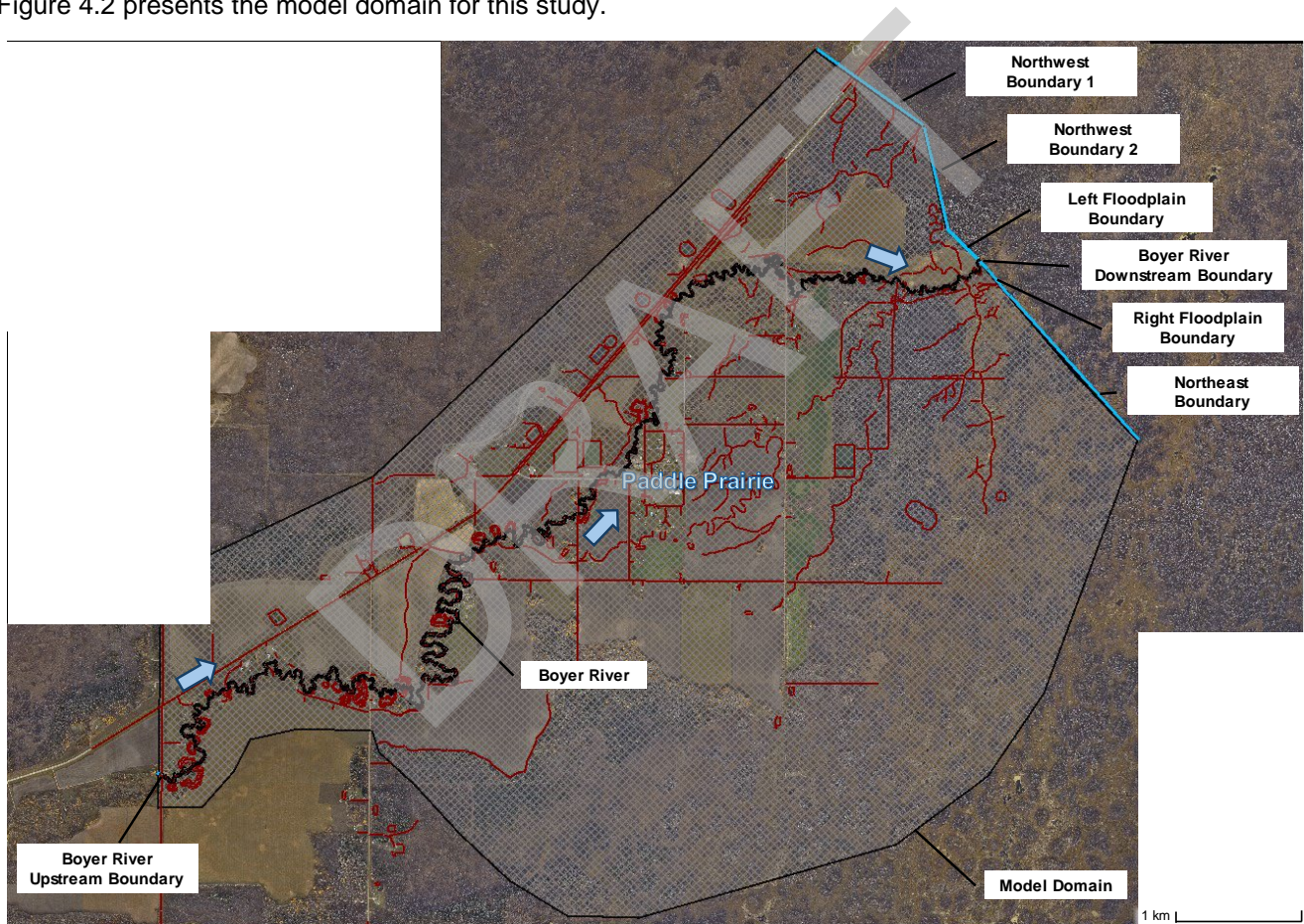


Figure 4.2: Model Domain

4.4.4.2 Model Mesh

The model mesh includes the following:

- The mesh along the main channel of the Boyer River, was further refined to 2 m x 2 m to represent the channel characteristics. Breaklines were defined along both banks and channel centre line.
- Floodplains were defined with an average mesh size of 15 x 15 m, with small elements used in areas where topographic details were important to adequately simulate the local hydraulic conditions. Local refinements were performed along key structures, side channels and oxbow channels.
- Some key linear structures were set up as weirs to simulate the flow pattern more accurately near those structures. Due to the numerical solver used in HEC-RAS, numerical leakage through high ground is possible, even though the water surface elevation is lower than the top elevation of high ground when using the breakline feature, causing unrealistic inundation downstream of the structure. This was resolved by using weir features rather than just breaklines along some structures. The elevations of the weir features were defined to correspond with the top elevation of the structure from the LiDAR data or the survey data. These structures included Highway 35 and several local roads. The mesh near these structures was also refined to a resolution of 5 m to better represent their physical features.

Figure 4.3 illustrates final model mesh and the mesh refinement near Range Road 220 Bridge and Highway 35.

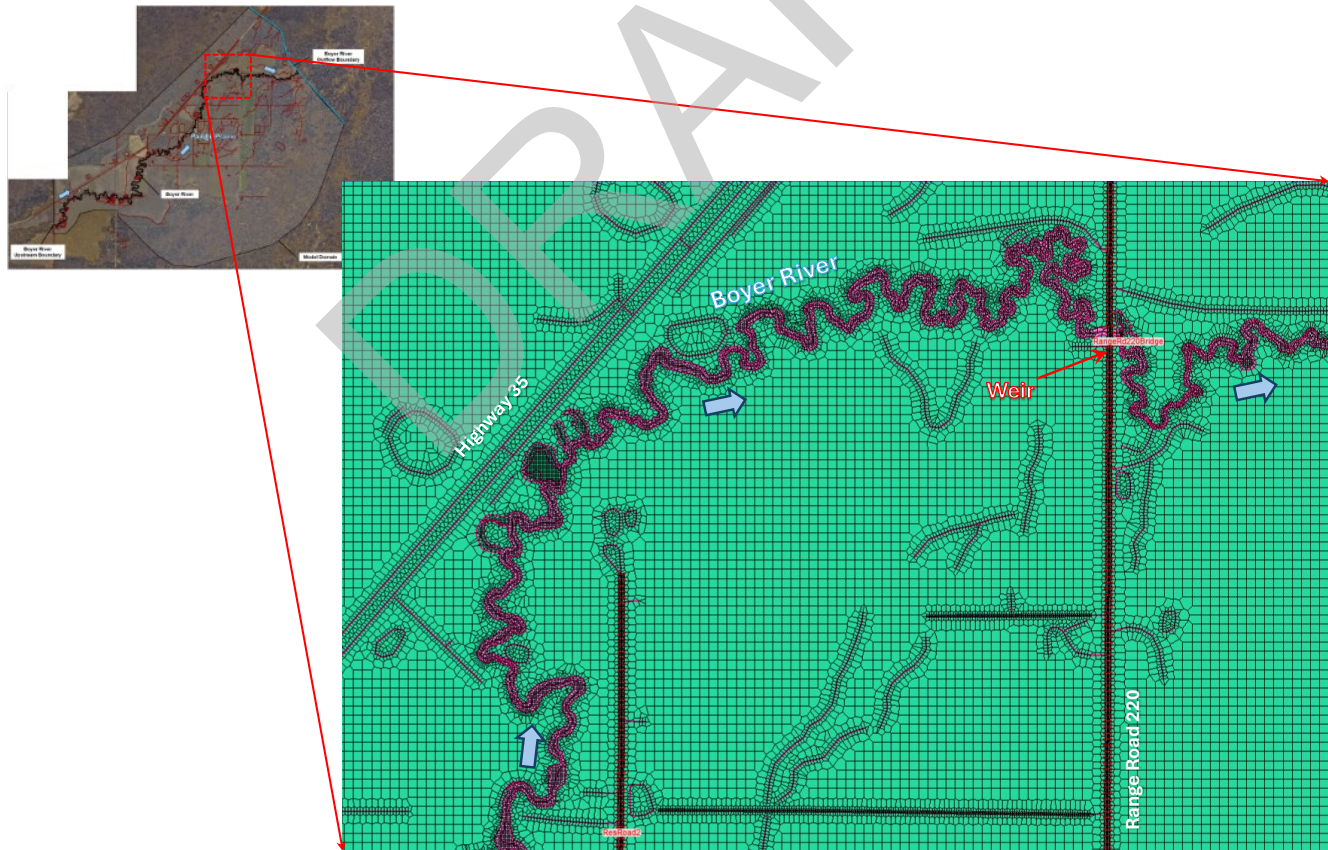


Figure 4.3: Example of Local Mesh Refinement

4.4.4.3 Boundary Conditions

The 2D HEC-RAS model requires specification of boundary conditions at all open boundaries. The open boundaries of the hydraulic model (see Figure 4.2) are listed below:

- Discharges at the upstream model boundary of the Boyer River
- Normal flow condition (with an estimated energy slope of 0.10%) at Northwest Boundary 1 of the Boyer River
- Normal flow condition (with an estimated energy slope of 0.42%) at Northwest Boundary 2 of the Boyer River
- Normal flow condition (with an estimated energy slope of 0.36%) at Left Floodplain Boundary of the Boyer River
- Normal flow condition (with an estimated energy slope of 0.10%) at Boyer River Downstream Boundary of the Boyer River
- Normal flow condition (with an estimated energy slope of 0.27%) at Right Floodplain Boundary of the Boyer River
- Normal flow condition (with an estimated energy slope of 0.14%) at Northeast Boundary of the Boyer River

4.4.5 Geometric Data Base

4.4.5.1 Integrated DEM

The LiDAR data provided for this study did not include the channel bathymetry below the water surface when the LiDAR was collected. Therefore, a bathymetry terrain surface had to be generated to represent the channel bathymetry.

The surveyed cross section data along the Boyer River was imported to HEC-RAS. The left and right edges of water were delineated in terms of the LiDAR and imagery. Using the RAS Mapper, a bathymetric terrain surface within the water edge lines was generated by interpolation based on the surveyed cross section data. The interpolated bathymetric surfaces replaced the topography within the water edges in the LiDAR to create an integrated DEM that included channel bathymetry. This integrated DEM was used for HEC-RAS model development. Figure 4.4 compares the terrain surface with and without channel bathymetry.

The integrated DEM did not include the building layer as suggested by EPA, because including the building footprints would make the flood mapping more complicated. Also, the amount of flow conveyed through built up areas in the community is considered small and would therefore not significantly impact modelling results. Only bare-earth LiDAR was used to create the integrated DEM.

The integrated DEM was checked to ensure that it represented the channel features along all of the study reaches. Figure 4.4 compares a cross section based on the bare-earth LiDAR (without channel bathymetry) and integrated DEM (with channel bathymetry). The comparison illustrates that channel bathymetry was included in the integrated DEM.

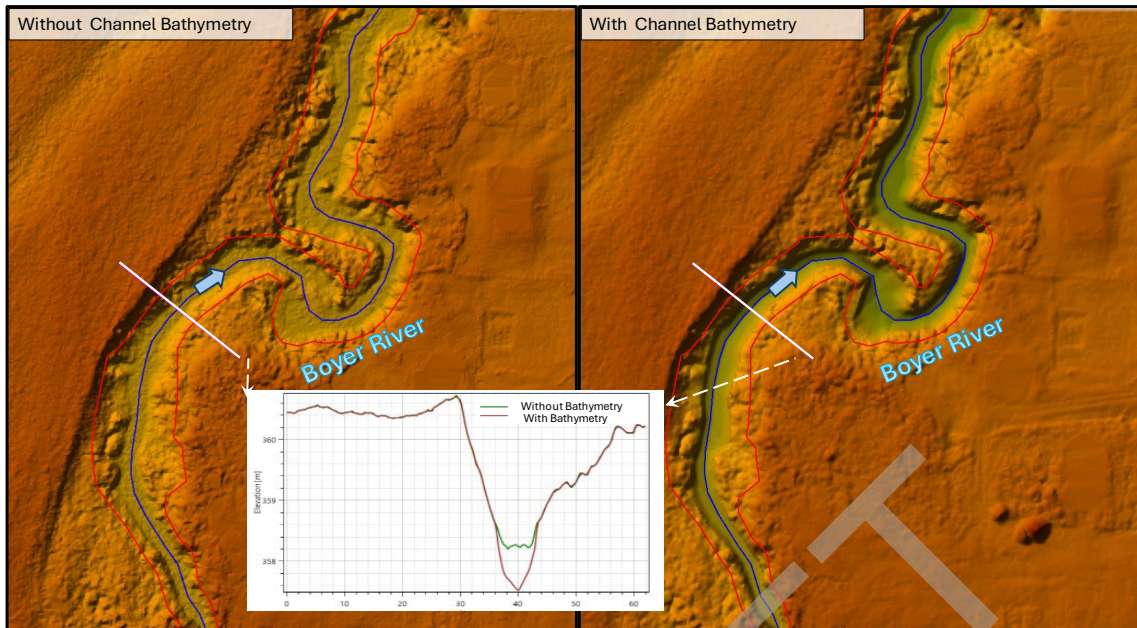


Figure 4.4: Channel Bathymetry in the Integrated DEM

4.4.5.2 Roughness Coefficients

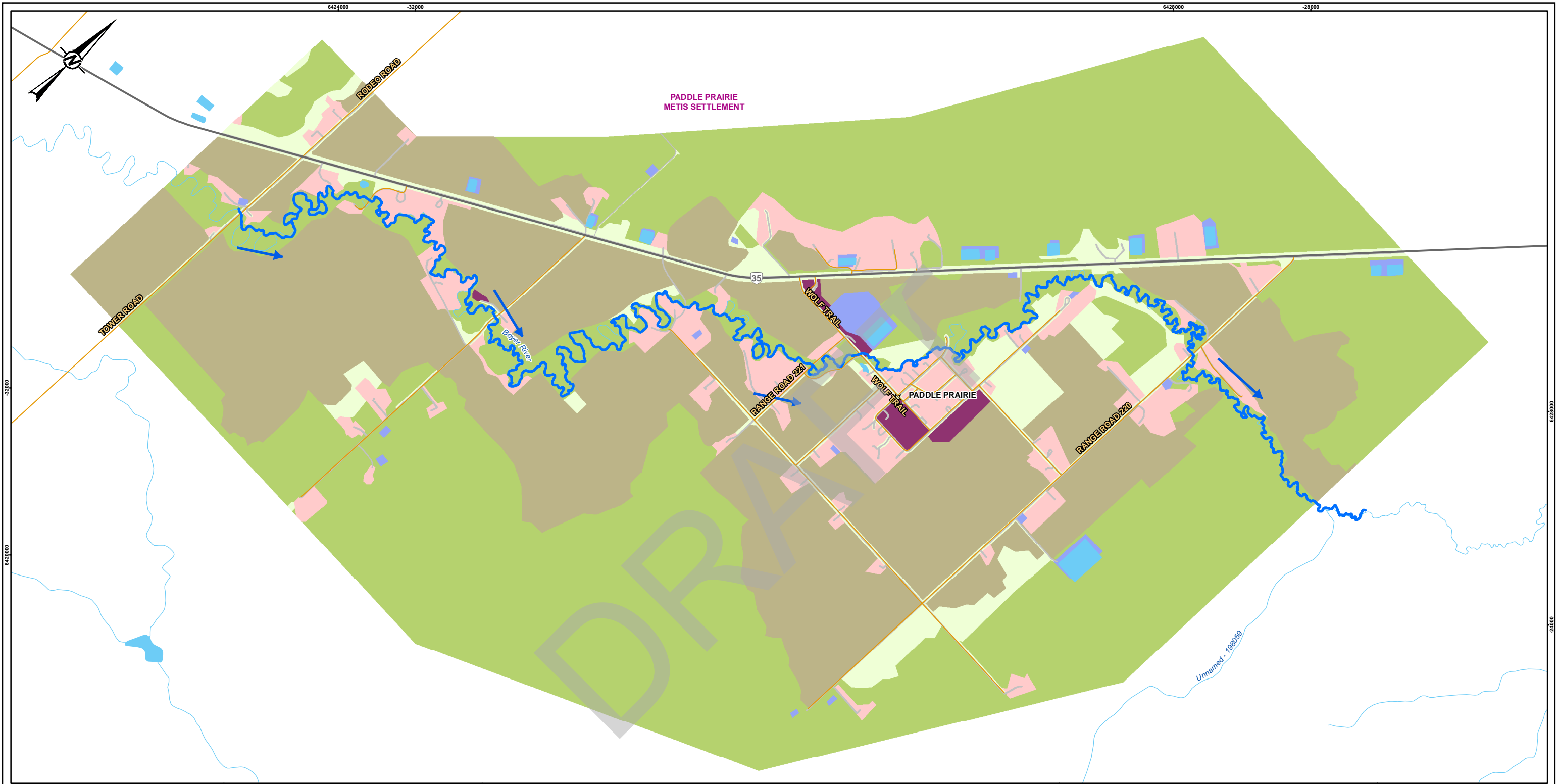
The left and right bank stations defining the main channel were determined using RAS Mapper based on the 2023 LiDAR data, 2023 aerial imagery and survey data. Manning’s *n* values were specified using the distributed roughness approach, which allows for multiple, varying roughness values within each cross section. The initial roughness distribution was specified based on the following data:

- Bank lines established from the LiDAR data, aerial imagery and surveys to identify the main channels
- Land use information from Government of Alberta

Eight roughness classes were used for the model setup. The initial Manning’s *n* values assigned to the classes are listed in Table 4-3. These initial values were selected based on channel bed materials, vegetation types, etc. (Chow 1959; USACE 2025). These roughness values were modified at some locations during the model calibration process. The roughness values were specified in the cross sections using RAS Mapper. Figure 4.5 shows the distribution of the roughness classes.

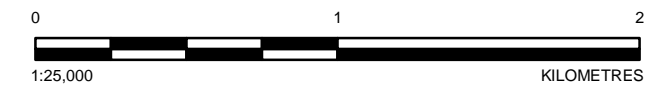
Table 4-3: Roughness Classes and Initial Manning's n Values

Number	Description	Initial Manning's <i>n</i>
1	River Main Channel	0.06
2	Urban Mixture (Residential)	0.08
3	Urban Mixture (Commercial)	0.06
4	Streets	0.03
5	Grassland and Open Space	0.05
6	Agriculture	0.05
7	Ponds	0.03
8	Dense Vegetation	0.15



LEGEND

☆ SETTLEMENT	ROUGHNESS CLASS
— PRIMARY HIGHWAY	AGRICULTURE
— LOCAL ROAD	DENSE VEGETATION
— WATERCOURSE	GRASSLAND AND OPEN SPACE
— WATERBODY	POND
— SURVEY REACH	RIVER-MAIN CHANNEL
→ FLOW DIRECTION	STREET
	URBAN MIXTURE (INDUSTRIAL)
	URBAN MIXTURE (RESIDENTIAL)



CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



CONSULTANT	YYYY-MM-DD	2025-01-24
	DESIGNED	CC
	PREPARED	HB/BS
	REVIEWED	-
	APPROVED	-

REFERENCE(S)
ROUGHNESS CREATED AND MODIFIED FROM ABMI HUMAN FOOTPRINT INDEX 2021. HYDROGRAPHY, ROADS, AND SETTLEMENTS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. IMAGERY OBTAINED FROM ESRI WORLD IMAGERY COPYRIGHT © 20230615 ESRI AND ITS LICENSORS. SOURCE: ESRI, MAXAR, EARTHSTAR GEOGRAPHICS, AND THE GIS USER COMMUNITY. USED UNDER LICENSES, ALL RIGHTS RESERVED. PROJECTED COORDINATE SYSTEM: NAD 1983 CSRS 3TM 117

PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
DISTRIBUTION OF ROUGHNESS CLASSES

PROJECT NO.	CONTROL	REV.	FIGURE
23592570		0	4-5

C:\CLIENTS\GOVERNMENT_OF_ALBERTA\23592570_Paddle_Prairie\FloodStudy\Hydrology\03_Open_Water_Hydraulic_Modeling\23592570_Fig4_3_Roughness_Class_Distribution_Rev.mxd PRINTED ON: 2025-01-24 AT: 1:24:17 PM

25mm IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

4.4.5.3 Bridges and Culvert

4.4.5.3.1 Bridges

The bridge geometries used in the HEC-RAS model were defined based on the river and bridge surveys conducted in 2023 (see Section 2.0).

The five bridges (see Section 4.4) were represented in the HEC-RAS model. The bridge deck, pier and abutment information were included in the model. Losses through bridges were calculated in the model using the energy equation (i.e., standard step method). Flows over the bridge and approach embankment were calculated using the standard weir equation.

4.4.5.3.2 Culvert

There is one culvert in the study area. It was represented in the HEC-RAS model based on the survey data. The pertinent culvert information, including size, length, and upstream and downstream invert elevations, was specified in the model. For the culverts in the 2D domain, entrance and exit loss coefficients were selected based on the configuration of culvert inlet and outlet.

4.4.5.3.3 Weir, Dam and Flood Control Structure

There are no weir, dam or flood control structures in the study area. Therefore, these features were not represented in the HEC-RAS model.

4.4.6 Model Calibration

4.4.6.1 Methodology

The Manning's n and contraction/expansion coefficients are the primary model parameters which values were adjusted, if necessary, in calibrating the HEC-RAS model. Selection of the initial Manning's n values before model calibration included consideration of stream bed/bank materials, vegetation cover, site information collected during the field inspection, and WSP's experience from previous hydraulic modelling studies.

Manning's n value may reduce with increased stage. High flow model calibrations were performed to determine appropriate Manning's n values across a wide range of flows. A low flow calibration was not conducted since there was little to no flow in the Boyer River during the survey. The following scenarios were included in the model calibration and validation:

- **High Flow Calibration:** Available HWMs on the Boyer River for the 2022 flood event was used for the high flow calibration. This was the largest recent event was documented in terms of peak flow estimate and available HWMs.
- **Validation Based on Gauging Station Data and Rating Curve:** The stage-flow rating curve at the WSC gauging station (i.e., WSC Station No. 07JF005) and surveyed water level and discharge data, were used for validating the calibrated model for the Boyer River.

The model calibration process involved multiple iterations to adjust the model parameter values, conduct simulations, and compare the simulated water levels to the HWMs (for the high flow calibration) or the surveyed water levels (for the low flow calibration). The objective of the model calibration was to achieve good matches between the simulated water levels and the HWMs or measured water levels.

The model validation process involved simulation of a range of flows by maintaining the calibrated model parameter values and comparing the simulated water levels to the recorded water levels at the Boyer River gauging station. The objective of the model validation was to confirm if the calibrated model can be reliably used to simulate flood flow conditions on the Boyer River.

4.4.6.2 High Flow Calibration

Historic HWM data is available for the 2022 flood event for the Boyer River study area. The HEC-RAS model for the Boyer River was calibrated using these HWM data. The model calibration was achieved by mainly adjusting the channel Manning's n values so that the simulated water levels were in good agreement with these HWMs. Floodplain roughness values were found to have least effects on the model calibration.

The estimated flood peak discharge on the Boyer River at WSC Station 07JF005 was 17.9 m³/s on May 31, 2022.

Figure 4.6 shows a comparison between the eleven (11) HWM data points and the simulated water surface profile along the Boyer River based on the calibrated channel Manning's n values of 0.065. For the 2022 flood event, the average difference between the simulated and measured water levels is 25 cm, with a range of -15 cm to +148 cm.

4.4.6.3 Validation Using WSC Gauge Data and Rating Curves

The available stage-flow rating curve at the WSC Station No. 07JF005 (Boyer River near Paddle Prairie) were used to validate the model calibration for the Boyer River to quantify the variability of the main channel roughness over a range of flows (see Figure 4.7). The results in this figure show that the simulated water levels match reasonably well with the measured data points at the gauging station for a large range of flows.

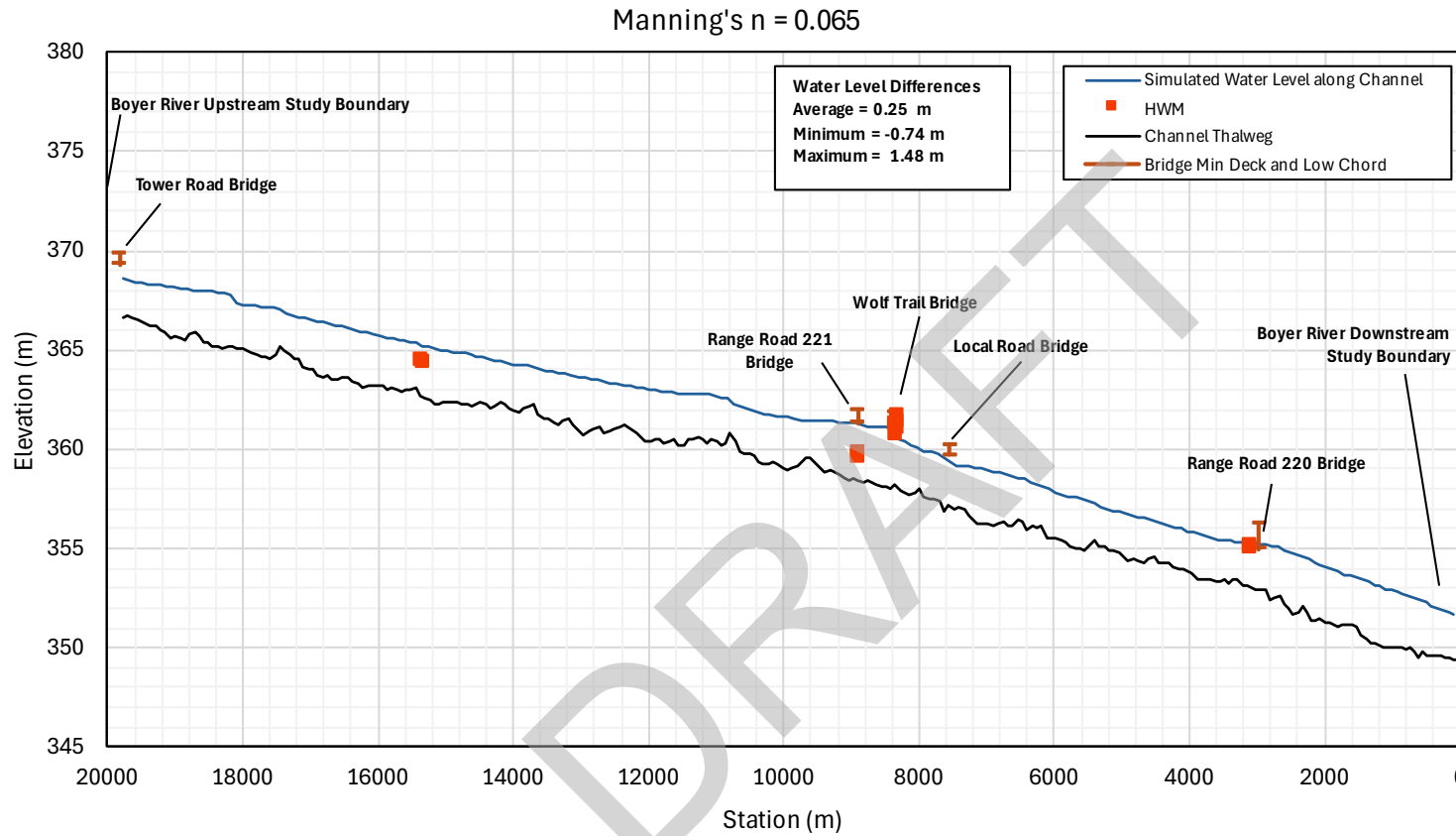


Figure 4.6: Comparison of Simulated Boyer River Water Surface Profile and Reported High Water Marks for the 2022 Flood Event

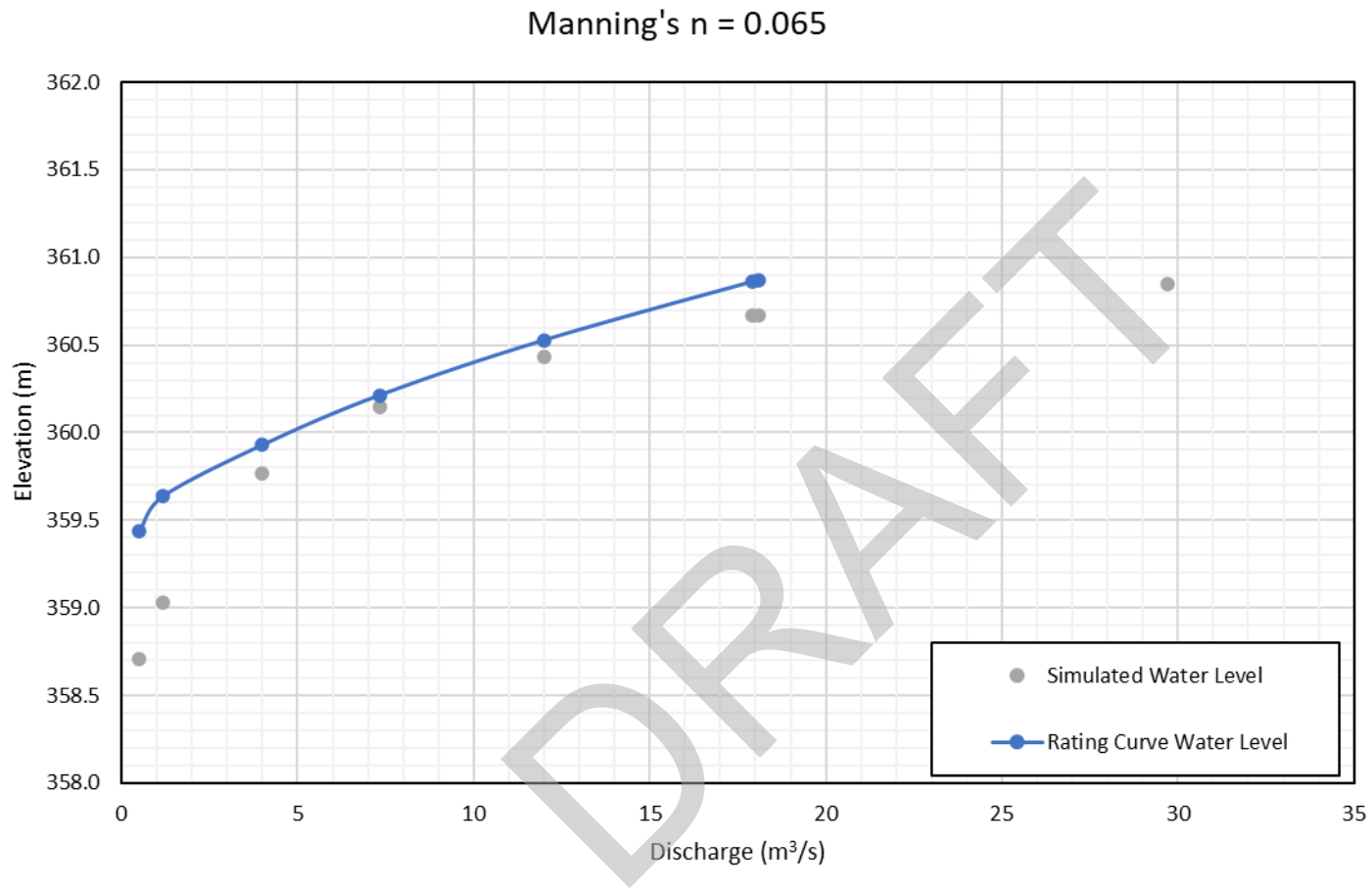


Figure 4.7: Calibration Results based on the WSC Station No. 07BK009 (Boyer River near Paddle Prairie) Rating Curve

The simulated water surface profiles along the reach are presented in Figure 4.8 for the 13 flood events. These results show the following:

- Boyer River overbank flooding into the Paddle Prairie community occurs for simulated floods with return periods in the range of 10 to 20 years and higher

DRAFT

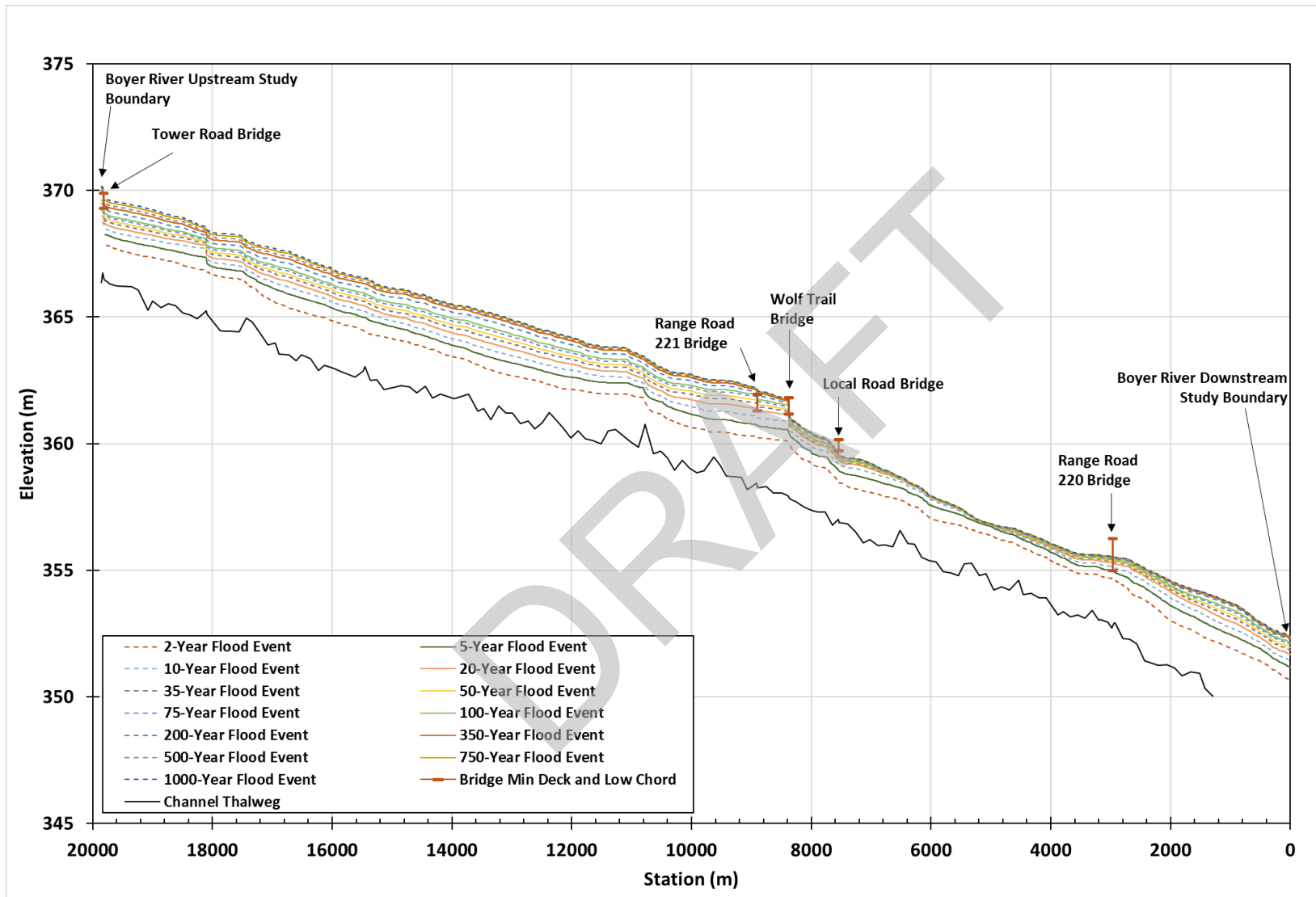


Figure 4.8: Simulated Water Surface Profiles along the Study Reach

4.4.6.4 Summary of Calibration Results

The HEC-RAS model for the study reaches of the Boyer River was calibrated validated. The results are summarized below:

- The high flow calibration results show that the simulated water levels compare well to the available HWMs for the Boyer River. The channel Manning's n value were calibrated based on the 2022 flood HWMs.
- The validation results based on the stage-flow rating curve for the WSC gauging station on the Boyer River show that the simulated water levels generally compare well with the measured water levels.
- The Manning's n values of 0.065 for the Boyer River main channel can be reliably used for simulating flood levels.

The calibrated channel Manning's n values summarized above are within the typical range of roughness values for similar streams (Chow 1959), and the calibrated values were subsequently used for generating the simulated flood profiles for all 13 flood events.

4.4.7 Model Parameters and Options

4.4.7.1 Manning's Roughness Coefficient

Channel Roughness

For the final model runs, the calibrated Manning's n values of 0.0065 was selected for the Boyer River

The selections were based on the model calibration and validation results (see Section 4.4.6), literature values, and WSP's modelling experience and professional judgement. The selected Manning's n values are in the reasonable range in comparison to typical values of comparable streams (Chow 1959).

Overbank Roughness

Table 4-4 presents the selected overbank Manning's n values based on the various land uses on the floodplains.

Table 4-4: Manning's n Values for Various Land Uses on the Floodplains

Land Use	Initial Manning's n Value	Selected Manning's n Value
Urban Mixture (Residential)	0.08	0.08
Urban Mixture (Commercial)	0.06	0.06
Streets	0.03	0.03
Grassland and Open Space	0.05	0.05
Agriculture	0.05	0.05
Ponds	0.03	0.03
Dense Vegetation	0.15	0.15
River Main Channel	0.06	0.065

4.4.7.2 Expansion and Contraction Coefficients

The contraction and expansion coefficient values were selected to be 0.3 and 0.5.

4.4.8 Open Water Flood Frequency Profiles

4.4.8.1 Production Model

The HEC-RAS production model was developed based on the calibrated and estimated Manning’s *n* values. The flood peak flows used in the HEC-RAS production model were estimated based on the hydrology assessment results (see Section 3.0). Surface water profiles were simulated for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year flood events using the production model.

The simulation period was set to 120 hours in order for the model to reach steady state conditions throughout the model domain.

4.4.8.2 Flow Change Locations

There is no flow change location along the study reach.

4.4.8.3 Flood Peak Flows

The estimates of flood peak flows at the upstream model boundary in the HEC-RAS production model are summarized in Table 4-5.

Table 4-5: Summary of Flood Peak Flows Used in the HEC-RAS Production Model

Discharges of Various Return Periods (m ³ /s)												
2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1,000-year
4.3	9.6	14.5	20.1	25.4	29.1	33.6	37.1	46.3	54.7	60.6	67.7	73.1

4.4.8.4 Model Boundary Conditions

The boundary conditions of the HEC-RAS production model (see Figure 4.2) are listed below:

- The discharges specified for the locations as shown in Table 4-5.
- Normal flow condition (with an estimated energy slope of 0.10%) at Northwest Boundary 1 of the Boyer River
- Normal flow condition (with an estimated energy slope of 0.42%) at Northwest Boundary 2 of the Boyer River
- Normal flow condition (with an estimated energy slope of 0.36%) at Left Floodplain Boundary of the Boyer River
- Normal flow condition (with an estimated energy slope of 0.10%) at Boyer River Downstream Boundary of the Boyer River
- Normal flow condition (with an estimated energy slope of 0.27%) at Right Floodplain Boundary of the Boyer River
- Normal flow condition (with an estimated energy slope of 0.14%) at Northeast Boundary of the Boyer River

4.4.8.5 Open Water Flood Frequency Profiles

Since there are no cross sections within the 2D model domain, water levels were extracted from the 2D model results along the main channel in regular intervals of 500 m. The channel stations are presented in the inundation maps. The simulated open water flood profiles along the study reach of the Boyer River are presented in Figure E-1 in Appendix E. The simulated open water flood water levels at individual cross sections along the study reach of the Boyer River are listed in Table E-1 in Appendix E.

4.4.9 Model Sensitivity

A model sensitivity analysis was conducted to evaluate the effects of changing model roughness values and downstream boundary conditions on the simulated water levels. The discharges used for the model sensitivity analysis were the 100-year flood peak flows. The results of the sensitivity analysis were used to quantify the level of uncertainty associated with the simulated flood levels along the study reach of the Boyer River.

The analysis of model sensitivity to Manning's n involves the following two sets of Manning's n values for the river channels and floodplains and one set of downstream boundary condition:

- $\pm 10\%$ changes of the base channel Manning's n values only
- $\pm 10\%$ changes of the base floodplain Manning's n values only
- $\pm 20\%$ changes of the specified energy slope for the downstream boundary.

Figures F-1 to F-3 in Appendix F graphically present the differences between the simulated water levels for the 100-year flood along the study reach of the Boyer River. The results of the sensitivity analysis indicate the following:

- The uncertainty in the simulated flood levels, on average, is within a range of ± 0.12 m (with standard deviation of 0.08 m) along the entire study reach, based on the differences in the simulated flood levels for the $\pm 10\%$ changes to the base channel Manning's n values only.
- The uncertainty in the simulated flood levels, on average, is within a range of ± 0.01 m (with standard deviation of 0.001 m) along the entire study reach, based on the differences in the simulated flood levels for the $\pm 10\%$ changes to the base floodplain Manning's n values only.
- A $\pm 20\%$ change to the energy slope at the downstream boundary of the Boyer River influences the simulated flood levels by a range of -0.002 to 0.003 m for approximately 1.0 km upstream of the downstream boundary.

5.0 FLOOD INUNDATION MAPS

5.1 Methodology

The flood inundation maps were prepared based on the following information:

- The simulated water levels for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year flood events
- Topography from the 2023 LiDAR survey
- Aerial imagery of the study area collected in October 2023

Direct flood inundation areas are identified either as being part of the actively-flowing river channels or flooded overbank areas directly connected to the actively-flowing areas. The following general procedure was used in ArcGIS to develop the inundation extent of the 13 open water flood events:

- Flood inundation boundaries, water level grids and depth grids are exported from the 2D HEC-RAS model. The last time step results were exported from HEC-RAS to ensure that the model reached a steady state.
- Areas that are not directly connected to the main river channels are manually removed. Areas where there is no direct overland connection but a hydraulic connection through culverts or other features, may be included in the inundation extent.

5.2 Inundation Polygon Modifications

5.2.1 Open Water Inundation Mapping

One set of open water flood inundation maps was prepared for each of the 13 flood events. The study area is covered by a total of three sheets (11 inch x 17 inch). The mapping scale is 1:10,000. The maps were prepared using the local 3-Degree Transverse Mercator (3TM) zone and the Canadian Spatial Reference System North American Datum of 1983 (NAD83 CSRS) coordinate system and datum.

The maps include the 2023 aerial imagery and other base data (roads and railways) provided by EPA. The resulting inundation maps for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year flood events are presented in a separate document (i.e., Appendix G: Open Water Flood Inundation Map Library).

The flood inundation maps were prepared in a geographical information system. The maps including all layers were provided to EPA as digital files in the ESRI ArcGIS file format.

5.2.2 Manual Edits

Flood inundation mapping at some locations required manual edits to produce reasonable inundation extents. These manual edits are summarized in Table 5-1.

Table 5-1: Locations of Manual Edits for Flood Inundation Polygons

Floodplain	Closest River Station	Description	Flood Events
West side of loop road around fire hall and community centre.	8100	Added road overtopping since not represented in model outputs.	20y-200y
East side of loop road around fire hall and community centre.	8000	Added road overtopping since not represented in model outputs.	35y-1000y
Range Road 220	8100	Added road overtopping since not represented in model outputs.	75y-1000y
T-intersection at north of loop road around school.	7400	Added road overtopping since not represented in model outputs.	50y-1000y
T-intersection of road originating from Paddle Prairie and Range Road 220	7200	Added road overtopping (both Range Road and road originating from Paddle Prairie) since not represented in model outputs.	35y

After applying the manual edits, the flood inundation polygons underwent automated smoothing and filtering to create more simplified inundation extents. All dry areas fully enclosed by inundation polygons (“islands”) smaller than 25 m² were filled and added to the inundated areas. The flood inundation polygons were also smoothed using the PEAK (Polynomial Approximation with Exponential Kernel) algorithm with a smoothing tolerance of 15 m. This smoothing tolerance generally results in changes to the inundation boundary well below 1 m in most areas.

5.3 Areas Affected by Floods

5.3.1 Residential and Commercial Areas Affected by Floods

Based on the simulation results, various residential and commercial areas would be affected along the Boyer River by direct inundation starting between the 10 to 20-year flood. Detailed inundation maps are provided in Appendix G.

5.3.2 Flooding of Bridges and Culverts

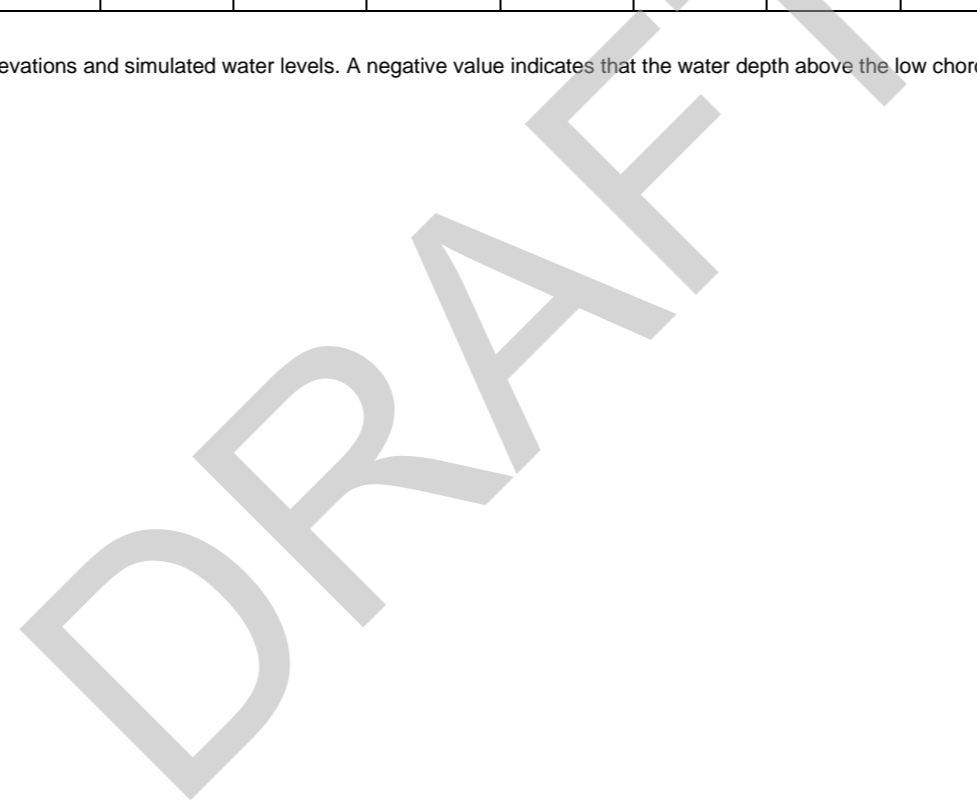
A bridge is considered affected by flooding when flood waters reach its low chord. A culvert is considered affected by flooding when the flood waters reach the road surface. Four (4) bridges along the Boyer River would be affected during the 100-year flood event. The one (1) culvert would be affected during the 100-year flood event.

The simulated water levels at the bridges and culverts along the Boyer River for the various flood events, as well as the flow velocities and clearances during the 100-year flood event are summarized in Table 5-2.

Table 5-2: Flooding at the Bridges and Culverts along the Study Reaches of Boyer River

Bridge Station (m)	Name	Minimum Deck/Road Surface Elevation (m)	Minimum Low Chord Elevation (m)	Simulated Water Level at the Bridges for the Various Flood Events (m)													Average Flow Velocity for the 100-year Flood Event (m/s)	Clearance for 100-year Flood Event ^a (m)	Flood Event Causing Pressure Flow or Overtopping Road Surface (Return Period)
				2-Year	5-Year	10-Year	20-Year	35-Year	50-Year	75-Year	100-Year	200-Year	350-Year	500-Year	750-Year	1,000-Year			
19818	Tower Road Bridge	369.89	369.32	367.91	368.38	368.65	368.89	369.08	369.22	369.36	369.47	369.70	369.80	369.88	369.95	370.01	0.91	-0.15	75-year
18098	Local Road Culvert	367.17	365.37	364.49	364.99	365.24	365.45	365.63	365.73	365.86	365.95	366.16	366.32	366.41	366.50	366.56	0.63	0.58	>20-year
8900	Range Road 221 Bridge	361.95	361.31	361.87	362.16	360.25	360.73	361.06	361.36	361.56	361.67	361.80	361.99	362.08	362.12	362.14	0.70	-0.36	50-year
8376	Wolf Trail Bridge	361.83	361.16	361.36	361.58	360.04	360.47	360.76	361.02	361.15	361.22	361.30	361.45	361.52	361.55	361.57	0.45	-0.06	2-year
7544	Local Road Bridge	360.15	359.72	359.49	359.62	358.50	358.95	359.20	359.36	359.41	359.44	359.47	359.56	359.59	359.60	359.61	0.54	0.28	350-year
2965	Range Road 220 Bridge	356.27	355.00	355.45	355.54	354.67	354.97	355.13	355.29	355.36	355.39	355.43	355.50	355.52	355.53	355.53	0.21	-0.39	2-year

Note:
 (a) The clearances for the 100-year flood event are the elevation differences between bridge low chord elevations and simulated water levels. A negative value indicates that the water depth above the low chord for a bridge.



5.4 Flood Depth Grids

5.4.1 GIS Data Specifications

The following GIS data is provided to EPA for each of the 13 flood events:

- Inundation polygons
- Water surface elevation raster
- Flood depth raster

All GIS data was created in ArcGIS 10.7.1 compatible format in the native study coordinate system (Canadian Spatial Reference System, North American Datum of 1983 [CSRS NAD83], Epoch 2002 and 3-Degree Transverse Mercator projection with the Central Meridian of 111° [3TM 111]). All raster files have a spatial resolution of 0.5 m.

The inundation polygons and raster files were stored in ArcGIS file geodatabases, Version 10.8.

5.4.2 General Comments

The flood water level data, provided as rasters, cover all areas within the study area including dry areas. The flood water depth rasters only include the areas with a water depth of more than 0.01 m.

DRAFT

6.0 DESIGN FLOOD HAZARD MAPPING

6.1 Flood Hazard Mapping Approach

The flood hazard mapping approach is described in detail in the Flood Hazard Identification Program (FHIP) – Flood Study Technical Guidelines (AEP 2022). The major technical changes compared to previous mapping are outlined below:

- Encroachment analysis will no longer be used to define floodway limits or determine 100-year design flood levels. The 0.3 m water level rise criterion is no longer used to define the floodway limit.
- Existing floodways from previous flood studies will not typically get larger when flood hazard maps are updated. For areas with previously defined floodways, the initial new floodway location will typically correspond to the existing floodway. The floodway can only get larger or smaller if it is deemed necessary with new modelling results based on consultation with local authorities.
- A new high hazard flood fringe zone will highlight parts of the flood fringe with deeper or faster moving water than the rest of the flood fringe outside of the floodway. The new high hazard flood fringe zone will be defined where the water is 1 m deep or greater or local velocities are 1 m/s or faster within the flood fringe zone.
- The protection provided by dedicated flood berms will be reflected in new flood hazard maps. Areas behind flood berms will still be mapped as flooded if they are overtopped, but areas at risk of flooding behind dedicated flood berms that are not overtopped will be mapped as a protected flood fringe zone.
- Flood hazard maps will show areas at risk of more severe flooding than just the 100-year design flood. Areas of incremental flood risk outside of the 100-year flood hazard area will be highlighted, including the 200-year and 500-year flood extents.

6.2 Design Flood

The 100-year open water flood was selected as the design flood in accordance with the Flood Hazard Identification Program (FHIP) Flood Study Technical Guidelines (AEP 2022). The 100-year flood water levels simulated in open water flood frequency profiles (Section 4.0) were selected as the final design flood levels. The design flood levels for 500 m stationing intervals along the Boyer River are provided in Appendix E.

6.3 Floodway and Flood Fringe Terminology

The flood hazard area is the area of land that will be flooded during the design flood event. The flood hazard area is typically divided into two zones: floodway and flood fringe. Flood hazard maps can also show additional flood hazard information, including areas of high hazard within the flood fringe and incremental areas at risk for more severe floods such as the 200-year and 500-year floods. Flood hazard mapping is typically used for long-term flood hazard area management and land-use planning. The floodway and flood fringe zones are defined as follows:

- **Floodway:** When a floodway is first defined on a flood hazard map, it typically represents the area of highest flood hazard where flows are deepest, fastest, and most destructive during the 100-year design flood. The floodway generally includes areas where the water is 1 m deep or greater and the local velocities are 1 m/s or faster. The floodway typically includes the main channel of a stream and a part of the adjacent overbank area. Previously mapped floodways do not typically become larger when a flood hazard map is updated, even if the flood hazard area becomes larger or design flood levels become higher. New development is discouraged in the floodway and may not be permitted in some communities.

- **Flood Fringe:** The flood fringe is the part of the flood hazard area outside of the floodway. The flood fringe typically represents areas with shallower (less than 1 m deep), slower (less than 1 m/s velocity), and less destructive flooding during the 100-year design flood. However, areas with deep or fast moving water may also be identified as high hazard flood fringe within the flood fringe. Areas at risk behind flood berms may also be mapped as protected flood fringe areas. New development in the flood fringe may be permitted in some communities.

6.4 Floodway Determination Criteria

In areas being mapped for the first time, the floodway typically represents the area of highest hazard where flows are deepest, fastest, and most destructive during the design flood. The following criteria, based on those described in current FHIP guidelines (AEP 2022), are used to delineate the floodway in such cases:

- Areas in which the depth of water exceeds 1 m or the flow velocities are greater than 1 m/s shall be part of the floodway
- Exceptions may be made for small backwater areas, ineffective flow areas, and to support creation of a hydraulically smooth floodway
- For reaches of supercritical flow, the floodway boundary should correspond to the edge of inundation or the main channel, whichever is larger

When a flood hazard map is updated, an existing floodway will not change in most circumstances. Exceptions to this would be: (1) a floodway could become larger if the main channel has shifted outside of a previously-defined floodway, or (2) a floodway could become smaller if an area of previously-defined floodway is no longer flooded by the design flood. Furthermore, the existing floodway near its ends may be revised to allow for smoother transitions between the existing floodway and extended area of the updated floodway when the updated floodway extends beyond the existing floodway limits.

Areas of deeper or faster moving water outside of the floodway are identified as high hazard flood fringe. These high hazard flood fringe zones are identified in all areas, whether they are newly-mapped or have an existing floodway.

The depth and velocity criteria used to define high hazard flood fringe zones will be aligned with the 1 m depth and 1 m/s velocity floodway determination criteria for newly-mapped areas.

All areas protected by dedicated flood berms that are not overtopped during the design flood are excluded from the floodway. Areas behind flood berms will still be mapped as flooded if they are overtopped, but areas at risk of flooding behind dedicated flood berms that are not overtopped will be mapped as a protected flood fringe zone.

The governing criteria for the Boyer River were based on the depth and velocity criteria as presented on the Floodway Criteria Maps in Appendix H.

6.5 Floodway Criteria Maps

Floodway criteria maps show the basis for determining the floodway, high hazard flood fringe zone, protected flood fringe areas and flood fringe zone for the design flood and documenting the results of water levels, depths, and flow velocities. The floodway criteria maps include the following information:

- Inundation extents of the 100-year design flood
- Areas meeting or exceeding the 1 m depth floodway criterion for the design flood

- Areas meeting or exceeding the 1 m/s velocity floodway criterion for the design flood
- Proposed floodway boundary for the design flood
- Background aerial imagery collected in October 2023
- Roads, bridges, culverts and flood control structures as applicable

The open water design flood water surface elevations and flow velocities were generated from the 2D HEC-RAS model. The model was run until it reached steady state conditions. The last simulation time step was then used to extract the flood water surface elevations and flow velocities directly from the RAS Mapper tool of the HEC-RAS model.

The floodway boundary was delineated in a way that is considered hydraulically smooth. Therefore, most of the side channels and oxbow channels were not included in the floodway.

The floodway criteria maps were produced using the same template as the inundation maps. The maps are provided in Appendix H.

6.5.1 Flood Hazard Maps

The flood hazard maps display the areas in the floodway and flood fringe zones. The floodway was determined as part of the floodway criteria mapping. Flood hazard maps can also show additional flood hazard information, including areas of high hazard within the flood fringe and incremental areas at risk for more severe floods, like the 200-year and 500-year floods. Flood hazard mapping is typically used for long-term flood hazard area management and land-use planning. All areas within the floodway boundary are shown as part of the floodway, even if the water levels of the design flood would not indicate a location as inundated (i.e., “islands” of dry ground within the floodway shown on the floodway criteria maps are not present on the flood hazard maps).

The flood hazard maps were produced using the same template as the inundation maps. The maps are provided in Appendix H.

Areas in the Floodway

Based on the flood hazard maps, there are no residences or businesses situated in the floodways along the Boyer River.

Areas in the Flood Fringe

The residential and development areas in the flood fringe within the study area include a significant portion of the residential and commercial areas of the community. This includes the Fire Hall and Community Centre. The full sets of floodway criteria maps and flood hazard maps are provided in this report.

6.6 Design Flood Grids

6.6.1 Water Surface Elevation Grids

The water surface elevation grid was output directly from the RAS Mapper tool of the HEC-RAS model. Where manual edits were applied to the flood inundation extents, these edits are reflected in the grids as well. Generally, the water surface elevations provided by RAS Mapper were replaced with higher elevations and slightly extended where required. The water surface elevation grid has the same resolution (0.5 m) and alignment as the DTM. The water surface elevation raster was then clipped to the directly-inundated areas. The results from the last time step of the simulation were used, when the model had reached steady state conditions.

6.6.2 Flood Depth Grids

The flood depth grid was created by subtracting the water surface elevation grid from the DTM. The flood depth grid has the same resolution (0.5 m) and alignment as the DTM. The extent of the depth grid is limited to the directly-inundated areas.

6.6.3 General Comments

All GIS data were created in ArcGIS Version 10.7.1 compatible format in the native study coordinate system [Canadian Spatial Reference System, North American Datum of 1983 (CSRS NAD83), Epoch 2002 and 3-Degree Transverse Mercator projection with the Central Meridian of 111° (3TM 111)].

DRAFT

7.0 POTENTIAL CLIMATE CHANGE IMPACTS

A cursory examination of potential increases in 100-year design water levels associated with climate change were performed to understand the possible impacts of climate change on flood levels. The effect of the 100-year flood conditions more severe than the baseline was assessed under the following two open water flow scenarios:

- 1) 100-year open water discharge +10%
- 2) 100-year open water discharge +20%

No hydraulic modelling parameters were varied other than discharges under the open water conditions. Water level profiles were produced along the study reaches for the two additional flow scenarios. The water level differences compared to the baseline 100-year open water discharge were calculated and summarized below. These water level differences were identified as potential “freeboards” that could be applied to the design water levels to account for flow changes that could result from climate change.

- For the Boyer River reach, the average increases in open water flood levels are 0.060 m for a 10 percent increase in flow, and 0.114 m for a 20 percent increase in flow.

The above analyses are not based on a regional climate change impact assessment but on a simplified assumption that climate change will result in increased flood peak flows. The presented values can be viewed as a general range of potential climate change “freeboard” that could be considered in addition to the computed design flood water levels.

The difference between the simulated water levels difference between 100-year flood event and climate-affected flood along the study reaches, are presented in Figure I-1 in Appendix I. The simulated climate-affected open water flood water levels at individual river stations are compared to the baseline 100-year open water discharge in Table I-1 in Appendix I.

8.0 CONCLUSIONS

8.1 Survey and Base Data Collection

Topographic, bathymetric, and supporting base data required for this study were collected in accordance with the requirements by EPA. The following conclusions are made:

- *Cross Section Surveys* – Cross section survey data collected in July 2023 meets the current study requirements with regard to cross section spacing and alignment, extents of cross sections on the floodplains, labeling of survey points, and data accuracy.
- *Hydraulic and Flood Control Structure Surveys* – Hydraulic structure survey data collected in July 2023 and April 2024 meet the study requirements and include the necessary details for the hydraulic modelling.
- *Digital Terrain Model* – The differences in elevation between the selected survey points and the DTM data are considered to be within an acceptable range. Therefore, the DTM is considered suitable for overbank cross section data extraction and flood mapping.

8.2 Open Water Hydrology Assessment

The results of the open water hydrology assessment completed in this study support the following conclusions:

- The flood frequency estimates obtained in this study are the most up to date for the study area. These estimates provide the updated flood hydrology information as inputs to the other components of the study (e.g., hydraulic modelling). Estimates of flood peak discharges were obtained for various return periods ranging from 2 to 1,000 years, including the 95% upper and lower confidence intervals.
- The flood frequency estimates were based on the recorded data for the following Boyer River gauging stations: (1) The discontinued gauge Boyer River Near Paddle Prairie (07JF004) has a drainage area of 141 km², and recorded data from 1979 to 2007; and (2) the Boyer River at Paddle Prairie (07JF005) has a drainage area of 200 km², and recorded data from 2008 onwards (i.e., currently active).

8.3 Open Water Hydraulic Modelling

8.3.1 Model Calibration

The 2D HEC-RAS model, set up for the study reach of the Boyer River was calibrated and validated based on the available high flow data. The calibrated HEC-RAS model can be reliably used in this study for simulating various flood events with return periods ranging from 2 to 1,000 years.

The calibrated channel Manning's n value for high flow conditions is 0.065 along the Boyer River study reach.

The Manning's n values for the floodplain areas were estimated and calibrated based on the land use types.

8.3.2 Model Sensitivity

The model sensitivity analysis was conducted for the 100-year flood event to evaluate the effects of changing model roughness values and downstream boundary conditions on the simulated water levels. The results of the sensitivity analysis indicate the following:

- The uncertainty in the simulated flood levels for changing roughness values of the channel, on average, is within a range of -0.041 to 0.036 m along the Boyer River.

- The uncertainty in the simulated flood levels for changing roughness values of the floodplain, on average, is within a range of -0.024 to 0.022 m along the Boyer River.
- The $\pm 20\%$ changes of the energy slope at the downstream boundary of Boyer River influence the simulated flood levels by a range of -0.002 to 0.002 m along approximately 19.8 km reach immediately upstream from the downstream boundary of the Boyer River.

8.3.3 Flood Profiles

The HEC-RAS model is a reliable tool for simulating the flood profiles of the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year flood events in the study area.

8.4 Flood Inundation Mapping

The HEC-RAS model results and the LiDAR DTM were used for preparing inundation maps for the 13 open water flood events (i.e., 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year open water floods), including direct flood inundation areas and other indirect flood inundation areas.

Based on the simulation results, the main areas to be affected by open water flooding have been identified as follows:

- A significant portion of the residential and commercial areas of the community. This includes the Fire Hall and Community Centre
- Four (4) bridges and one (1) culvert crossing along the Boyer River would be affected during the 100-year flood event or higher

8.5 Design Flood Hazard Mapping

The 100-year open water flood is selected as the design flood for the study area in accordance with the Flood Hazard Identification Program (FHIP) Guidelines (AEP 2022). The floodway was determined as part of the floodway criteria mapping.

Areas in the Floodway

Based on the flood hazard maps, there are no residences or businesses situated in the floodways along the Boyer River.

Areas in the Flood Fringe

The residential and development areas in the flood fringe within the study area include a significant portion of the residential and commercial areas of the community. This includes the Fire Hall and Community Centre. The full sets of floodway criteria maps and flood hazard maps are provided in this report.

8.6 Quantitative Climate Change Assessments

Potential effects of climate change on open water floods were assessed through a sensitivity analysis of flood water level differences due to 10- and 20-percent increases in the 100-year flood peak flows. These water level differences were identified as potential “freeboards” that could be applied to the design water levels to account for flow changes that could result from climate change. The results of the climate change effects assessment are summarized below:

- For the Boyer River, the average increases in the open water flood levels are 0.060 m for a 10% increase in flow, and 0.114 m for a 20% increase in flow

The analysis in this study was not based on a regional climate change impact assessment but on a simplified assumption of increased flood peak flows that could result from climate change.

Signature Page

WSP Canada Inc.

Prepared by:

Reviewed by:



Amber Liu, M.Sc., E.I.T.
Water Resources Engineer



Jie Chen, M.Sc., P.Eng.
Water Resources Engineer

DRAFT

L.S. Hundal, M.Eng., P.Eng.
Senior Principal Water Resources Engineer

Third Party Disclaimer

This report has been prepared by WSP Canada Inc. (WSP) for the benefit of the client to whom it is addressed. The information and data contained herein represent WSP's best professional judgment in light of the knowledge and information available to WSP at the time of preparation. Except as required by law, this report and the information and data contained herein are to be treated as confidential and may be used and relied upon only by the client, its officers and employees. WSP denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this report or any of its contents without the express written consent of WSP and the client.

DRAFT

References

AEP (Alberta Environment and Parks). 2022. Flood Hazard Identification Program Flood Study Technical Guidelines. June 2022

Chow, V.T. 1959. Open-channel Hydraulics. McGraw-Hill, New York, 680 p.

USACE (U.S. Army Corps of Engineers). 2025. HEC-RAS River Analysis System, User's Manual. Version 6.4.

DRAFT



DRAFT

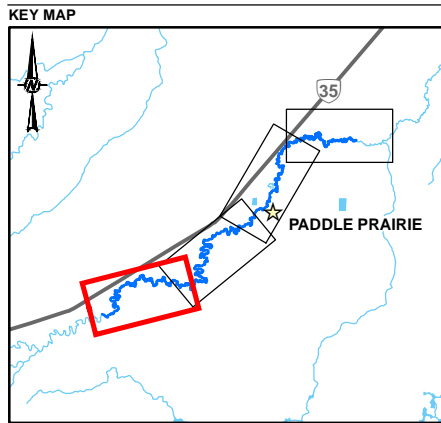
APPENDIX A

**Locations of Cross Sections,
Hydraulic Structures and Flood
Control Structures**

THE CLIENTS GOVERNMENT OF ALBERTA\33592570_Paddle_Prairie\Map\img\hydro\001_Survey & Base Data Collection\33592570_Apennick_A_Structures_enC.mxd PRINTED ON: 2024-08-14 AT: 1:45:01 PM



- LEGEND**
- FLOW DIRECTION
 - PRIMARY HIGHWAY
 - LOCAL ROAD
 - WATERCOURSE
 - HYDRAULIC STRUCTURE
 - SURVEY REACH
 - SURVEYED CROSS SECTION



CLIENT
ALBERTA ENVIRONMENT AND PROTECTED AREAS

CONSULTANT
wsp

DESIGNED	CC
PREPARED	HB
REVIEWED	-
APPROVED	-

DATE: 2024-08-14

REFERENCE(S)
 HYDROGRAPHY, ROADS, AND SETTLEMENTS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA.
 DATUM: NAD 83 CSRS PROJECTION: 3TM 117

PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
LOCATIONS OF CROSS SECTIONS, HYDRAULIC STRUCTURES AND FLOOD CONTROL STRUCTURES

PROJECT NO.	CONTROL	REV.	FIGURE
23592570		0	A-1

SHEET 2 ↓

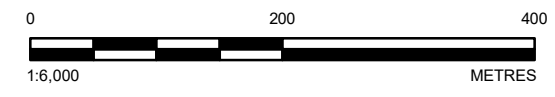
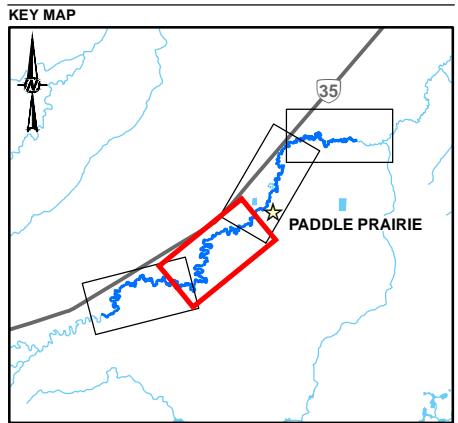
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B



SHEET 1 ↑

↓ SHEET 3

- LEGEND**
- FLOW DIRECTION
 - PRIMARY HIGHWAY
 - LOCAL ROAD
 - HYDRAULIC STRUCTURE
 - SURVEY REACH
 - SURVEYED CROSS SECTION



CLIENT	ALBERTA ENVIRONMENT AND PROTECTED AREAS	
CONSULTANT	wsp	
DATE	YYYY-MM-DD	2024-08-14
DESIGNED	CC	
PREPARED	HB	
REVIEWED	-	
APPROVED	-	

REFERENCE(S)
 HYDROGRAPHY, ROADS, AND SETTLEMENTS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA.
 DATUM: NAD 83 CSRS PROJECTION: 3TM 117

PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
LOCATIONS OF CROSS SECTIONS, HYDRAULIC STRUCTURES AND FLOOD CONTROL STRUCTURES

PROJECT NO.	CONTROL	REV.	FIGURE
23592570		0	A-2

THE CLIENTS GOVERNMENT OF ALBERTA \ 3392570_Paddle_PrairieMetisSettlement\001_Survey & Base Data Collection\3392570_Apennak_A_Structures_enC.mxd PRINTED ON: 2024-08-14 AT: 1:45:08 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

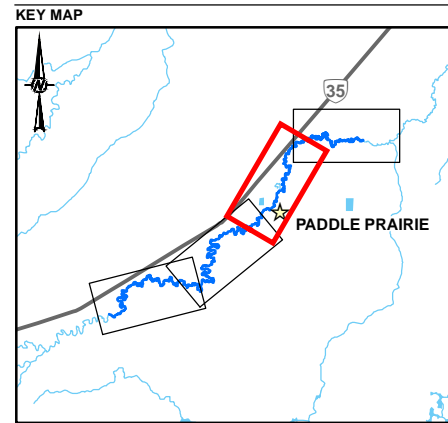


SHEET 2 ↑

↓ SHEET 4

THE CLIENTS GOVERNMENT OF ALBERTA 33592570_Paddle_PrairieMapingHydrology01_Survey & Base Data Collection 23592570_Apennak_A_Structures_enrC.mxd PRINTED ON: 2024-08-14 AT: 1:45:19 PM

- LEGEND**
- FLOW DIRECTION
 - PRIMARY HIGHWAY
 - LOCAL ROAD
 - WATERCOURSE
 - HYDRAULIC STRUCTURE
 - SURVEY REACH
 - SURVEYED CROSS SECTION



CLIENT	ALBERTA ENVIRONMENT AND PROTECTED AREAS	
CONSULTANT	wsp	
DATE	YYYY-MM-DD	2024-08-14
DESIGNED	CC	
PREPARED	HB	
REVIEWED	-	
APPROVED	-	

REFERENCE(S)
 HYDROGRAPHY, ROADS, AND SETTLEMENTS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA.
 DATUM: NAD 83 CSRS PROJECTION: 3TM 117

PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
LOCATIONS OF CROSS SECTIONS, HYDRAULIC STRUCTURES AND FLOOD CONTROL STRUCTURES

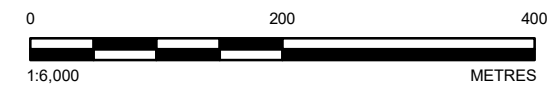
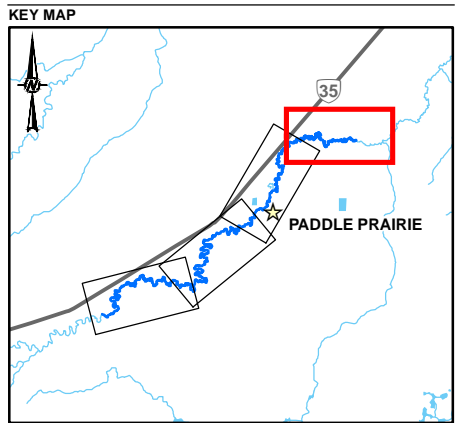
PROJECT NO.	CONTROL	REV.	FIGURE
23592570		0	A-3

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B



SHEET 3 ↑

- LEGEND**
- FLOW DIRECTION
 - PRIMARY HIGHWAY
 - LOCAL ROAD
 - WATERCOURSE
 - HYDRAULIC STRUCTURE
 - SURVEY REACH
 - SURVEYED CROSS SECTION



CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



CONSULTANT	YYYY-MM-DD	2024-08-14
	DESIGNED	CC
	PREPARED	HB
	REVIEWED	-
	APPROVED	-

REFERENCE(S)
HYDROGRAPHY, ROADS, AND SETTLEMENTS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
**LOCATIONS OF CROSS SECTIONS, HYDRAULIC STRUCTURES
AND FLOOD CONTROL STRUCTURES**

PROJECT NO.	CONTROL	REV.	FIGURE
23592570		0	A-4

I:\CLIENTS\GOVERNMENT_OF_ALBERTA\33592570_Paddle_Prairie\FloodStudy\Hydro\001_Survey & Base Data Collection\33592570_Apennak_A_Structures_enr\c.mxd PRINTED ON: 2024-08-14 AT: 1:45:24 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B



DRAFT

APPENDIX B

Hydraulic Structure Datasheets



TITLE	
HS-01 HYDRAULIC STRUCTURE DATASHEET - TOWER ROAD BRIDGE	
LOCATION	BOYER RIVER
DESCRIPTION	TOWER ROAD BRIDGE (BF 79358)
BRIDGE FILE NUMBER	BF 79358
TOTAL LENGTH OF SPAN (m)	8.5
DECK WIDTH OF BRIDGE (m)	8.3
AVERAGE TOP OF CURB OR SOLID GUARD RAIL ELEVATION (m)	369.84
AVERAGE LOW CHORD ELEVATION (m)	369.32
BRIDGE OBSTRUCTION HEIGHT (m)	0.52
NUMBER OF PIERS	0

PIER	CENTRE STATION (m)	WIDTH (m)	TYPE	SHAPE
1	-	-	-	-
2	-	-	-	-

- LEGEND**
- BRIDGE SURVEY POINT
 - ➔ FLOW DIRECTION
 - ROAD

NOTE(S)
BRIDGE SURVEY DETAILS WERE USED FOR HYDRAULIC MODELLING.

REFERENCE(S)
BRIDGE SURVEY AND BRIDGE PHOTOS BY WSP CANADA INC., APRIL 2024.
ROADS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED.
IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

CLIENT
ALBERTA ENVIRONMENT AND PROTECTED AREAS



PROJECT
PADDLE PRAIRIE FLOOD STUDY

CONSULTANT	WSP	YYYY-MM-DD	2025-01-24
		DESIGNED	CC
		PREPARED	HB/BS
		REVIEWED	-
		APPROVED	-

PROJECT NO. 23592570	CONTROL	REV. 0	FIGURE B-1
-------------------------	---------	-----------	----------------------

PHOTO 1 RIGHT BANK, LOOKING UPSTREAM



PHOTO 2 RIGHT BANK, LOOKING DOWNSTREAM



PHOTO 3 TOP OF THE DECK



IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET HAS BEEN MODIFIED FROM ANSIA



TITLE
HS-02 HYDRAULIC STRUCTURE DATASHEET - LOCAL ROAD CULVERT CROSSING

LOCATION	BOYER RIVER
NUMBER OF CULVERTS	3
RISE OF CULVERT (m)	-
SPAN OF CULVERT (m)	-
CULVERT TYPE	CSP
CULVERT SHAPE	CIRCULAR

CULVERT	LENGTH (m)	DIAMETER (m)	UPSTREAM INVERT ELEVATION (m)	DOWNSTREAM INVERT ELEVATION (m)
1	10.1	1.8	365.356	365.469
2	9.9	1.4	365.112	365.366
3	10.1	1.8	365.347	365.370

- LEGEND**
- CULVERT SURVEY POINT
 - ➡ FLOW DIRECTION
 - ROAD

NOTE(S)
 CULVERT SURVEY DETAILS WERE USED FOR HYDRAULIC MODELLING. CULVERTS ARE LABELLED FROM NORTH TO SOUTH.

REFERENCE(S)
 BRIDGE SURVEY AND BRIDGE PHOTOS BY WSP CANADA INC., APRIL 2024.
 ROADS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED.
 IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA.
 DATUM: NAD 83 CSRS PROJECTION: 3TM 117

CLIENT
 ALBERTA ENVIRONMENT AND PROTECTED AREAS



PROJECT
 PADDLE PRAIRIE FLOOD STUDY

CONSULTANT	WSP
YYYY-MM-DD	2025-01-24
DESIGNED	CC
PREPARED	HB/BS
REVIEWED	-
APPROVED	-



PROJECT NO. 23592570	CONTROL	REV. 0	FIGURE B-2
-------------------------	---------	-----------	---------------

PHOTO 1 TOP OF ROAD, LOOKING UPSTREAM **PHOTO 2** TOP OF ROAD, LOOKING DOWNSTREAM **PHOTO 3** RIGHT BANK, LOOKING UPSTREAM



IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET HAS BEEN MODIFIED FROM ANS/A



TITLE
HS-WASHOUT HYDRAULIC STRUCTURE DATASHEET - LOCAL ROAD CULVERT CROSSING

LOCATION	BOYER RIVER
NUMBER OF CULVERTS	NO CULVERTS DUE TO WASHOUT
RISE OF CULVERT (m)	-
SPAN OF CULVERT (m)	-
CULVERT TYPE	-
CULVERT SHAPE	-

PRIOR TO WASHOUT, CULVERT CROSSING CONSISTED OF THREE (3) ONE (1) METRE DIAMETER CORRUGATED STEEL PIPES (CSP). SEE PHOTO 1 BELOW (TAKEN 27 JULY 2022).

- LEGEND**
- CULVERT SURVEY POINT
 - ➔ FLOW DIRECTION
 - ROAD

NOTE(S)
 IN THE HYDRAULIC MODELLING, NO CULVERTS WERE MODELLLED AT THIS SITE.

REFERENCE(S)
 BRIDGE SURVEY AND BRIDGE PHOTOS BY WSP CANADA INC., APRIL 2024.
 ROADS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED.
 IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA.
 DATUM: NAD 83 CSRS PROJECTION: 3TM 117

CLIENT
 ALBERTA ENVIRONMENT AND PROTECTED AREAS



PROJECT
 PADDLE PRAIRIE FLOOD STUDY

CONSULTANT	WSP
YYYY-MM-DD	2025-01-24
DESIGNED	CC
PREPARED	HB/BS
REVIEWED	-
APPROVED	-

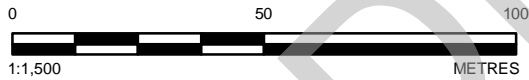
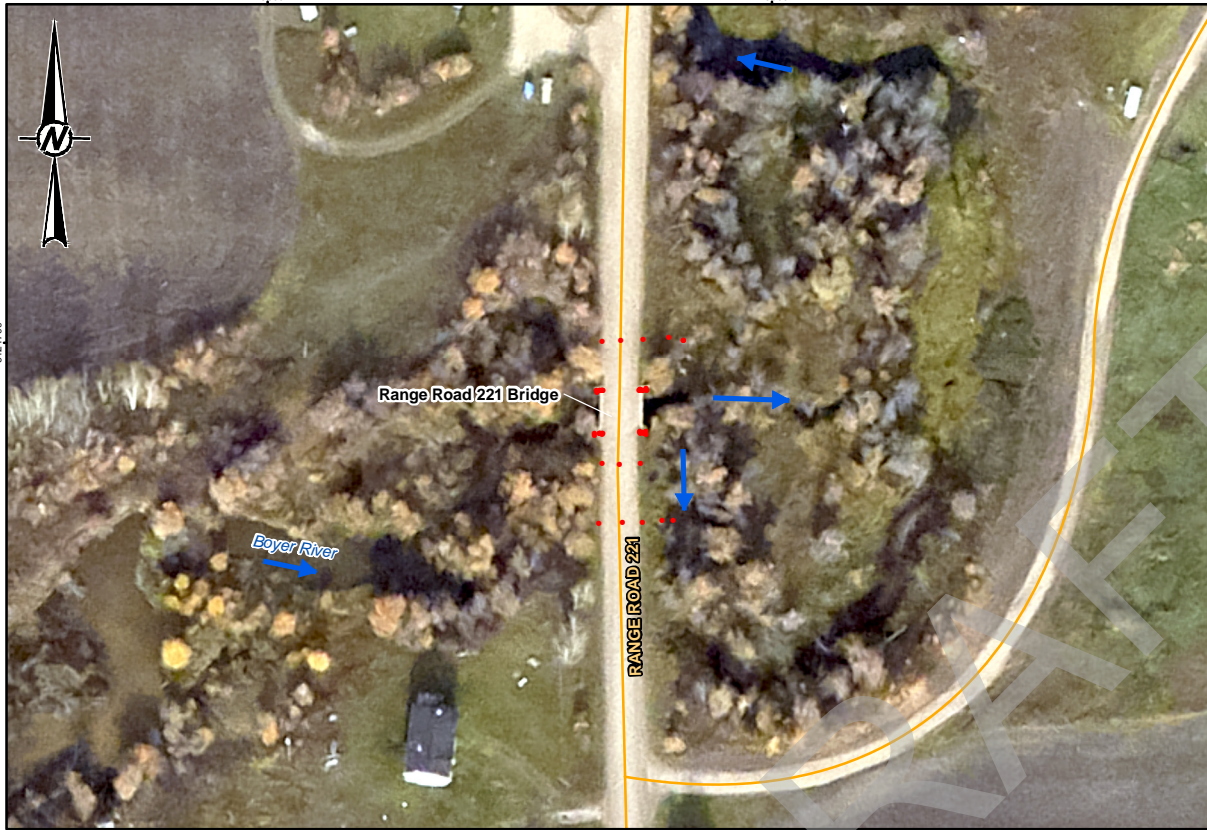


PROJECT NO.	CONTROL	REV.	FIGURE
23592570		0	B-3

PHOTO 1 PRE-WASHOUT CULVERT **PHOTO 2** WASHOUT CULVERT **PHOTO 3** WASHOUT CULVERT



IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET HAS BEEN MODIFIED FROM ANS/A



TITLE
HS-03 HYDRAULIC STRUCTURE DATASHEET - RANGE ROAD 221 BRIDGE

LOCATION	BOYER RIVER
DESCRIPTION	RANGE ROAD 221 BRIDGE
BRIDGE FILE NUMBER	BF 80980
TOTAL LENGTH OF SPAN (m)	8.5
DECK WIDTH OF BRIDGE (m)	8.5
AVERAGE TOP OF CURB OR SOLID GUARD RAIL ELEVATION (m)	361.899
AVERAGE LOW CHORD ELEVATION (m)	361.312
BRIDGE OBSTRUCTION HEIGHT (m)	0.587
NUMBER OF PIERS	0

PIER	CENTRE STATION (m)	WIDTH (m)	TYPE	SHAPE
1	-	-	-	-
2	-	-	-	-

LEGEND

- BRIDGE SURVEY POINT
- ➔ FLOW DIRECTION
- ROAD

NOTE(S)

BRIDGE SURVEY DETAILS WERE USED FOR HYDRAULIC MODELLING.

REFERENCE(S)

BRIDGE SURVEY AND BRIDGE PHOTOS BY WSP CANADA INC., APRIL 2024.
 ROADS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED.
 IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA.
 DATUM: NAD 83 CSRS PROJECTION: 3TM 117

CLIENT

ALBERTA ENVIRONMENT AND PROTECTED AREAS



PROJECT

PADDLE PRAIRIE FLOOD STUDY

CONSULTANT



YYYY-MM-DD	2025-01-24
DESIGNED	CC
PREPARED	HB/BS
REVIEWED	-
APPROVED	-

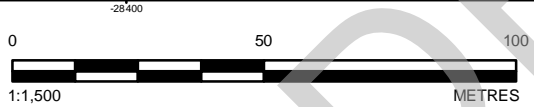
PHOTO 1

TOP OF THE DECK

PHOTO 2

RIGHT BANK, LOOKING UPSTREAM





TITLE
HS-04 HYDRAULIC STRUCTURE DATASHEET - WOLF TRAIL BRIDGE

LOCATION	BOYER RIVER
DESCRIPTION	WOLF TRAIL BRIDGE
BRIDGE FILE NUMBER	BF 75778
TOTAL LENGTH OF SPAN (m)	14
DECK WIDTH OF BRIDGE (m)	9
AVERAGE TOP OF CURB OR SOLID GUARD RAIL ELEVATION (m)	361.875
AVERAGE LOW CHORD ELEVATION (m)	361.152
BRIDGE OBSTRUCTION HEIGHT (m)	0.723
NUMBER OF PIERS	0

PIER	CENTRE STATION (m)	WIDTH (m)	TYPE	SHAPE
1	-	-	-	-
2	-	-	-	-

- LEGEND**
- BRIDGE SURVEY POINT
 - ➔ FLOW DIRECTION
 - ROAD

NOTE(S)
 BRIDGE SURVEY DETAILS WERE USED FOR HYDRAULIC MODELLING.

REFERENCE(S)
 BRIDGE SURVEY AND BRIDGE PHOTOS BY WSP CANADA INC., APRIL 2024.
 ROADS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED.
 IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA.
 DATUM: NAD 83 CSRS PROJECTION: 3TM 117

CLIENT
 ALBERTA ENVIRONMENT AND PROTECTED AREAS

PROJECT
 PADDLE PRAIRIE FLOOD STUDY

CONSULTANT	WSP	YYYY-MM-DD	2025-01-24
		DESIGNED	CC
		PREPARED	HB/BS
		REVIEWED	-
		APPROVED	-

PROJECT NO. 23592570 CONTROL REV. 0 FIGURE B-5

PHOTO 1 RIGHT BANK, LOOKING DOWNSTREAM



PHOTO 2 LEFT BANK, LOOKING UPSTREAM





TITLE
HS-05 HYDRAULIC STRUCTURE DATASHEET - LOCAL ROAD BRIDGE

LOCATION	BOYER RIVER
DESCRIPTION	LOCAL ROAD BRIDGE
BRIDGE FILE NUMBER	N/A
TOTAL LENGTH OF SPAN (m)	17.7
DECK WIDTH OF BRIDGE (m)	3.5
AVERAGE TOP OF CURB OR SOLID GUARD RAIL ELEVATION (m)	360.107
AVERAGE LOW CHORD ELEVATION (m)	359.71
BRIDGE OBSTRUCTION HEIGHT (m)	0.397
NUMBER OF PIERS	2

PIER	CENTRE STATION (m)	WIDTH (m)	TYPE	SHAPE
1	11.79	0.3	WOOD	CIRCULAR
2	17.53	0.3	WOOD	CIRCULAR

LEGEND

- BRIDGE SURVEY POINT
- ➔ FLOW DIRECTION
- ROAD

NOTE(S)

BRIDGE SURVEY DETAILS WERE USED FOR HYDRAULIC MODELLING.

REFERENCE(S)

BRIDGE SURVEY AND BRIDGE PHOTOS BY WSP CANADA INC., APRIL 2024.
 ROADS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED.
 IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA.
 DATUM: NAD 83 CSRS PROJECTION: 3TM 117

CLIENT

ALBERTA ENVIRONMENT AND PROTECTED AREAS



PROJECT

PADDLE PRAIRIE FLOOD STUDY

CONSULTANT



YYYY-MM-DD	2025-01-24
DESIGNED	CC
PREPARED	HB/BS
REVIEWED	-
APPROVED	-

PROJECT NO.
23592570

CONTROL

REV.
0

FIGURE
B-6

PHOTO 1 RIGHT BANK, LOOKING DOWNSTREAM



PHOTO 2 RIGHT BANK, LOOKING UPSTREAM





TITLE
HS-06 HYDRAULIC STRUCTURE DATASHEET - RANGE ROAD 220 BRIDGE

LOCATION	BOYER RIVER
DESCRIPTION	RANGE ROAD 220 BRIDGE (BF 77963)
BRIDGE FILE NUMBER	BF 77963
TOTAL LENGTH OF SPAN (m)	14
DECK WIDTH OF BRIDGE (m)	8
AVERAGE TOP OF CURB OR SOLID GUARD RAIL ELEVATION (m)	355.95
AVERAGE LOW CHORD ELEVATION (m)	355.4
BRIDGE OBSTRUCTION HEIGHT (m)	0.55
NUMBER OF PIERS	0

PIER	CENTRE STATION (m)	WIDTH (m)	TYPE	SHAPE
1	-	-	-	-
2	-	-	-	-

- LEGEND**
- BRIDGE SURVEY POINT
 - ➔ FLOW DIRECTION
 - ROAD

NOTE(S)
 BRIDGE SURVEY DETAILS WERE USED FOR HYDRAULIC MODELLING.

REFERENCE(S)
 BRIDGE SURVEY AND BRIDGE PHOTOS BY WSP CANADA INC., APRIL 2024.
 ROADS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED.
 IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA.
 DATUM: NAD 83 CSRS PROJECTION: 3TM 117

CLIENT
 ALBERTA ENVIRONMENT AND PROTECTED AREAS



PROJECT
 PADDLE PRAIRIE FLOOD STUDY

CONSULTANT	WSP	YYYY-MM-DD	2025-01-24
		DESIGNED	CC
		PREPARED	HB/BS
		REVIEWED	-
		APPROVED	-



PROJECT NO.	23592570	CONTROL		REV.	0	FIGURE	B-7
--------------------	----------	----------------	--	-------------	---	---------------	-----

PHOTO 1 TOP OF THE DECK, LOOKING SOUTH



PHOTO 2 TOP OF DECK, LOOKING UPSTREAM



PHOTO 3 TOP OF DECK, LOOKING DOWNSTREAM



25mm IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET HAS BEEN MODIFIED FROM ANSIA



DRAFT

APPENDIX C

**Technical Memorandum on Flood
Control Structures**



MEMO

TO: Jim Choles, P.Eng.
COMPANY: Alberta Environment and Protected Areas (EPA)
FROM: Liv Hundal
DATE: November 1, 2024
CC:
PROJECT NO.: 23592570 (CW2432)
SUBJECT: TECHNICAL MEMORANDUM ON FLOOD CONTROL STRUCTURE FOR THE PADDLE PRAIRIE FLOOD STUDY

1 INTRODUCTION

Alberta Environment and Protected Areas (EPA) retained WSP Canada Inc. (WSP) to conduct the Paddle Prairie Flood Study. The study is part of the provincial Flood Hazard Identification Program (FHIP), and the purpose of the study is to assess and identify river and flood hazards along the approximately 18 km reach of Boyer River through the Community of Paddle Prairie and Paddle Prairie Metis Settlement (PPMS). The study reach extends downstream from the upstream side of the river crossing on the east edge of NE11-103-22-W5M to the east side of NE20-103-21-W5M.

This memorandum documents there is no flood control structure within the above noted study reach.

2 CLOSURE

WSP Canada Inc. (WSP) prepared this report solely for the use of the intended recipient, Alberta Environment and Protected Areas (EPA), 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.

Yours sincerely,

Prepared by:

Liv Hundal, M.Eng., P.Eng.
Senior Principal Engineer, Water Resources

Reviewed by:

Nathan Schmidt, Ph.D., P.Eng.
Senior Principal Engineer, Water Resources



DRAFT

APPENDIX D

**Technical Memorandum on
Open Water Hydrology Assessment**



MEMO

TO: Jim Choles, P.Eng.
COMPANY: Alberta Environment and Protected Areas (EPA)
FROM: Liv Hundal and Martin Lacroix
DATE: January 7, 2025
CC: Getu Biftu
PROJECT NO.: 23592570 (CW 2432)
SUBJECT: OPEN WATER HYDROLOGY ASSESSMENT – PADDLE PRAIRIE FLOOD STUDY

1 INTRODUCTION

1.1 STUDY AREA AND SCOPE

Alberta Environment and Protected Areas (EPA) retained WSP Canada Inc. (WSP) to conduct the Paddle Prairie Flood Study. The study is part of the provincial Flood Hazard Identification Program (FHIP), and the purpose of the study is to assess and identify river and flood hazards along the 18 km reach of Boyer River through the Community of Paddle Prairie and Paddle Prairie Metis Settlement (PPMS). The study reach extends downstream from the upstream side of the river crossing on the east edge of NE11-103-22-W5M to the east side of NE20-103-21-W5M. The open water hydrology assessment results stated in this memorandum will be used as the flood discharges for the hydraulic modeling and open water hydraulic flood mapping. The scope of this memorandum includes data series preparation, regional flood flow regression, flood frequency analysis and climate change commentary.

1.2 STUDY OBJECTIVE

The objective of open water hydrology assessment is to determine flood peak discharge estimates at the study reach of Boyer River near Paddle Prairie. The assessment included frequency flows of 2-, 5-, 10-, 20-, 25-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year return period open water flood peak discharges.

1.3 WATERSHED CHARACTERISTICS AND HISTORICAL FLOODS

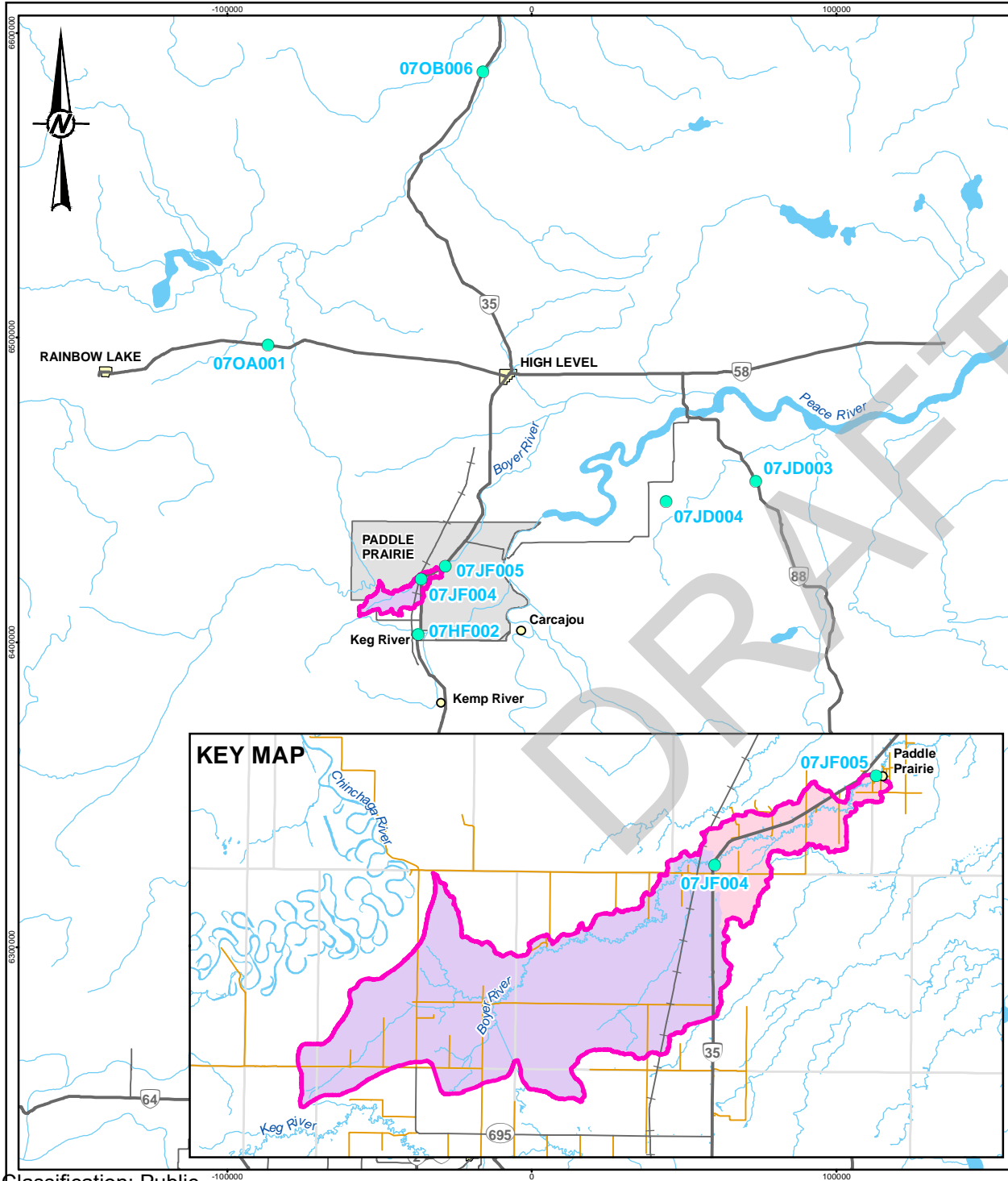
The Boyer River watershed starts near the intersection of Township Road 1020 and Range Road 243 and northeastward through the lowland physiography of northwestern Alberta. It has a drainage area of 200 km² at Paddle Prairie. Further downstream, it drains northeast to its confluence with the Peace River, near Fort Vermillion. The main drainage area land types are flat agricultural lands and boggy wetlands. An overall map of the study area hydrometric stations is presented in Figure 1.

Listed below are the two Water Survey of Canada (WSC) hydrometric stations located on the Boyer River near Paddle Prairie. The majority of the floods for both stations were recorded in April to May. This suggests a homogenous data set resulting from spring snowmelt, or possibly snowmelt combined with rainfall.

- The discontinued gauge Boyer River Near Paddle Prairie (07JF004) has a drainage area of 141 km², recorded data from 1979 to 2007 and was located 8.5 km upstream of the study area (distance measured along the channel centreline). The largest recorded flood occurred on May 1st, 1979, with an instantaneous discharge of 21.4m³/s. Other large floods occurred in April 1989 and April 1997.
- The Boyer River at Paddle Prairie (07JF005) is located in the study area and has a drainage area of 200 km², and recorded data from 2008 onwards (i.e., currently active). The largest recorded flood was on May 6th, 2013, with an instantaneous discharge of 29.7m³/s. Other large floods occurred in April 2009 and May 2022.

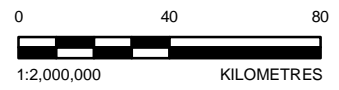
WSP Canada Inc
3300, 237 – 4th Avenue SW
Calgary, AB T2P 4K3

T: +1 403-243-8380
wsp.com



LEGEND

- HYDROMETRIC GAUGING STATION
- RAILROAD
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- WATERCOURSE
- WATERBODY
- METIS SETTLEMENT
- POPULATED PLACE
- BOYER RIVER AT PADDLE PRAIRIE WSC 07JF005
- BOYER RIVER NEAR PADDLE PRAIRIE WSC 07JF004
- BOYER RIVER AT PADDLE PRAIRIE WSC 07JF005



REFERENCE(S)
 HYDROMETRIC STATIONS OBTAINED FROM WATER SURVEY OF CANADA (WSC) AND USGS. HYDROGRAPHY, METIS SETTLEMENTS, ROADS, AND POPULATED PLACES OBTAINED FROM ALTALIS. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. REGIONAL HYDROGRAPHY OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. PROJECTED COORDINATE SYSTEM: NAD 1983 CSRS 3TM 117

CLIENT
 ALBERTA ENVIRONMENT AND PROTECTED AREAS

PROJECT
 PADDLE PRAIRIE FLOOD HAZARD STUDY

TITLE
BOYER RIVER WATERSHED AT PADDLE PRAIRIE AND REGIONAL GAUGING STATIONS

CONSULTANT	YYYY-MM-DD	2025-01-07
	DESIGNED	CC
	PREPARED	HB
	REVIEWED	LH
	APPROVED	LH



PROJECT NO. 23592570 CONTROL REV. 1 FIGURE 1

25mm IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET HAS BEEN MODIFIED FROM ANS/A

2 FLOW DATA

The data from Station 07JF004 and 07JF005 were used to determine the flood frequency flows of Boyer River at Paddle Prairie. Station 07JF004 is located further upstream from Paddle Prairie and has a drainage area of 140.7 km² and was operated from 1979 to 2007. Station 07JF005 is located at Paddle Prairie and has a drainage area of 200 km² and has been in operation since 2008. A discharge relationship between the two stations would result in study area discharges from 1979 onwards. As there is no overlap in the period of record for the two stations, a regional relationship was developed using nearby hydrometric stations to prorate the discharges recorded at 07JF004 for 07JF005.

The regional hydrometric stations were selected based on their proximity to the study area, similar periods of records, similar sizes in drainage areas and similar hydrologic characteristics. Other nearby stations, such as Keg River at Hwy 35 (07HF002), were also considered and are shown in Figure 1. However, the average unit peak discharge (i.e., discharge divided by area) and basin elevation were significantly different than the study area, hence the station was not used. A summary of hydrologic information used in the regional flood frequency analysis is presented in Table 1.

Table 1 Summary of Hydrometric Stations

WSC STATION NUMBER	WSC STATION NAME	LATITUDE	LONGITUDE	APPROXIMATE DISTANCE FROM STUDY AREA (km)	DRAINAGE AREA (km ²)	EFFECTIVE DRAINAGE AREA (km ²)	PERIOD OF RECORD	LENGTH OF RECORD (years)	AVERAGE UNIT PEAK DISCHARGE (m ³ /s/ km ²)
07JF005	Boyer River at Paddle Prairie	57° 56' 54"	117° 28' 49"	0	200	200	2008 - 2022	15	0.044
07JF004	Boyer River near Paddle Prairie	57° 54' 30"	117° 36' 45"	8.5	141	141	1979 - 2007	29	0.039
07OB006	Lutose Creek near Steen River	59° 24' 20"	117° 16' 50"	162.8	292	292	1977 - 2022	46	0.026
07OA001	Sousa Creek near High Level	58° 35' 29"	118° 29' 27"	92.6	820	820	1970 - 2022	53	0.023
07JD003	Jackpine Creek at Highway No 88	58° 11' 34"	115° 44' 55"	106.3	582	582	1971 - 2022	52	0.033
07JD004	Teepee Creek near La Crete	58° 08' 14"	116° 15' 01"	76.2	136	136	1980 - 2022	43	0.053

3 PREPARATION OF FLOOD FLOW DATA SERIES

3.1 REGIONAL FLOOD FLOW REGRESSIONS

Regional flood flow regressions were developed to estimate discharges at 07JF005 for the period 1979 to 2007, which is the period that 07JF004 was active. Empirical relationships were developed between the drainage areas and flood frequency estimates for the regional WSC hydrometric stations listed below. The best fit power functions were used, and the following steps were undertaken to complete the flood frequency estimates:

- The following WSC hydrometric stations were selected for the regional flood flow regression: 07JF004, 07OB006, 07OA001, 07JD003, 07JD004.

- The drainage areas, annual maximum daily discharges, and annual maximum instantaneous discharges for WSC hydrometric stations were compiled.
- Graphical regressions between event based annual maximum daily discharges and annual maximum instantaneous discharges (same flood event for both values) were developed for each WSC hydrometric station to derive missing annual maximum instantaneous discharges (graphs are provided in Appendix A).
- The complete sets of annual maximum instantaneous discharges were used to estimate flood frequency flows for a range of return periods from 2 to 1000-year (frequency analyses for different station are provided in Appendix B).
- The flood frequency estimates and corresponding drainage areas for each station were plotted, and graphical regressions were developed for each return period.

The resulting regional flood flow regressions for the 2 to 50-year return periods are presented in Figure 2. As discussed in the next section, these were the curves that were used to develop a relationship between 07JF004 and 07JF005.

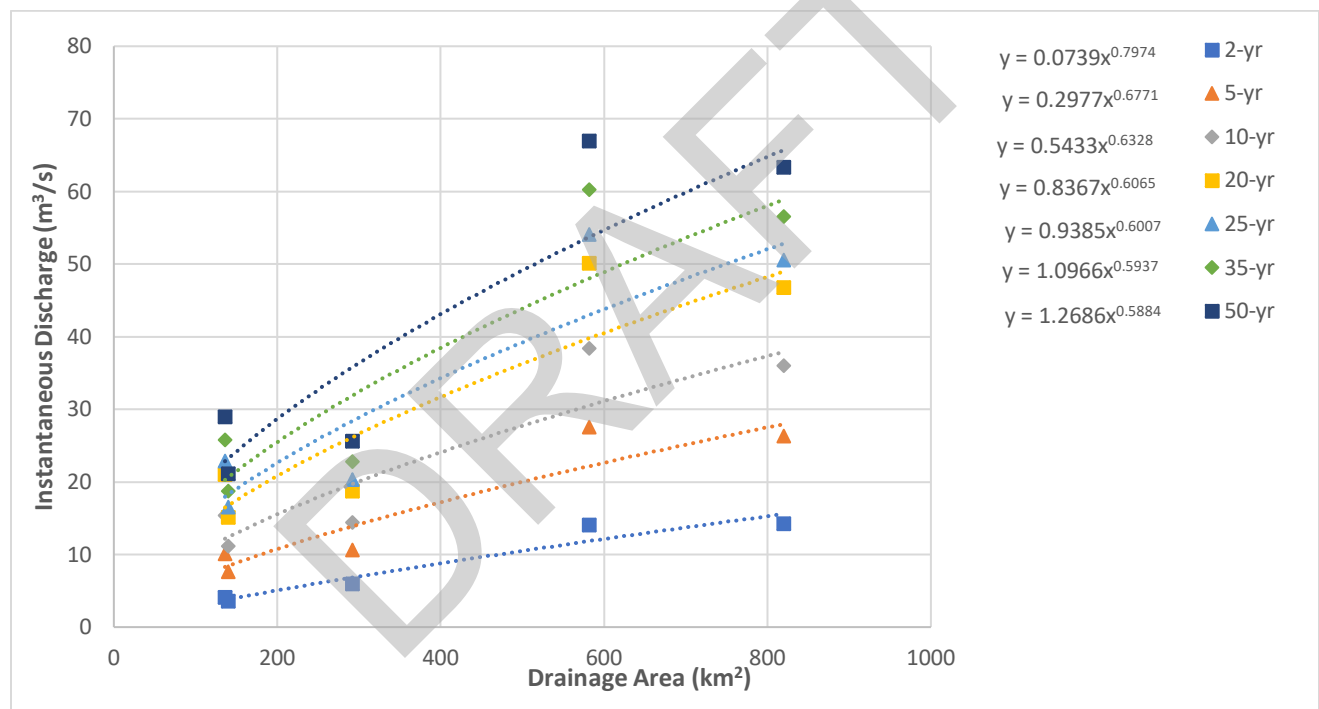


Figure 2 Regional Flood Flow Regressions between Flood Peak Flows and Drainage Areas

3.2 FLOOD FLOW SERIES FOR STUDY AREA

The flood flow series used for flood frequency analysis were derived from recorded maximum instantaneous discharge series of the study area stations (07JF004 and 07JF005). A linear graphical regression of recorded annual maximum daily versus annual maximum instantaneous discharges was used to estimate the values missing from the period of record. These graphical regressions are presented in Figures 3 and 4 for 07JF004 and 07JF005, respectively. The resulting annual maximum instantaneous discharge data series from 1979 to 2022 is presented in Figure 5. It should be noted that Figure 5 presents a mixed data set with different drainage areas (i.e., 07JF004 with a drainage area of 141 km² from 1979 to 2007 and 07JF005 with a drainage area of 200 km² from 2008 to 2022).

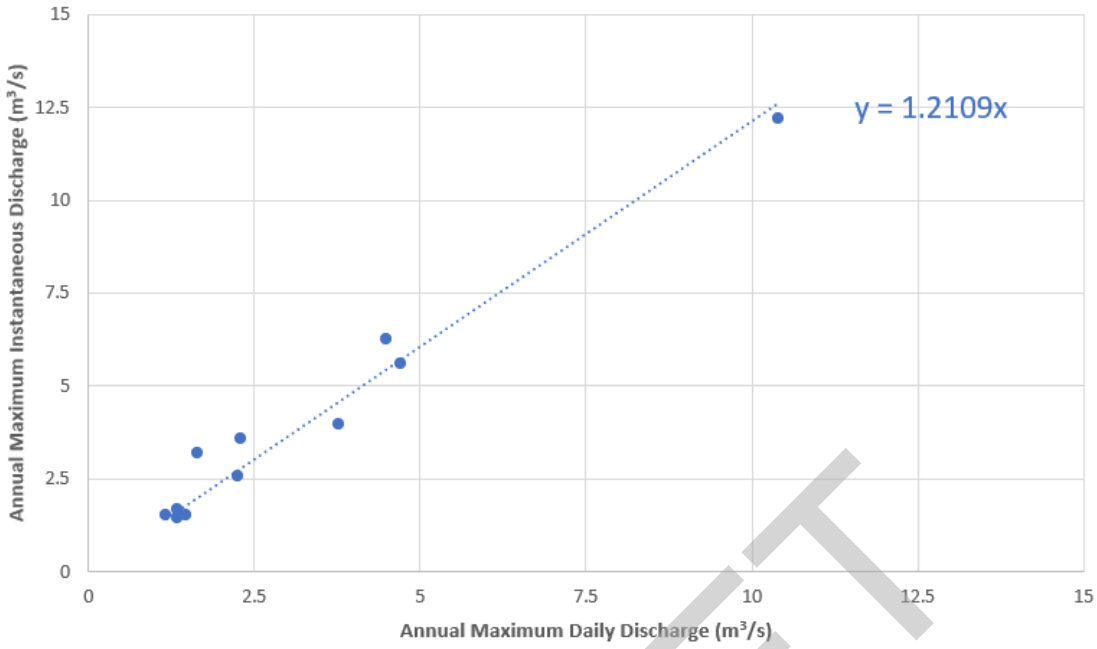


Figure 3 Linear Regression for 07JF004

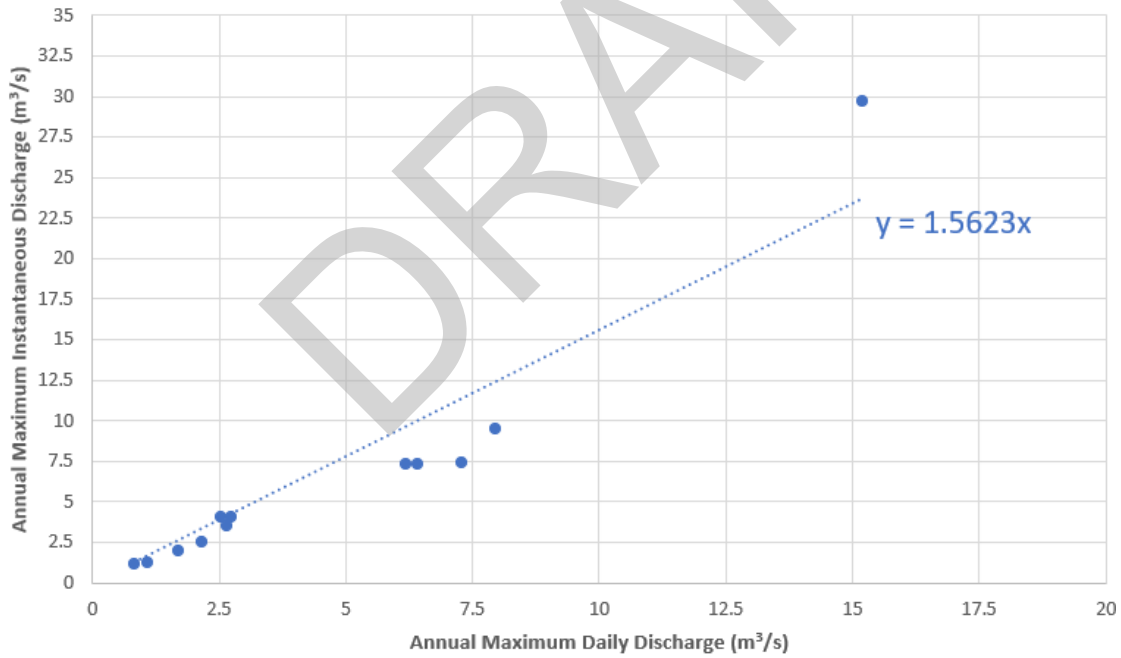


Figure 4 Linear Regression for 07JF005

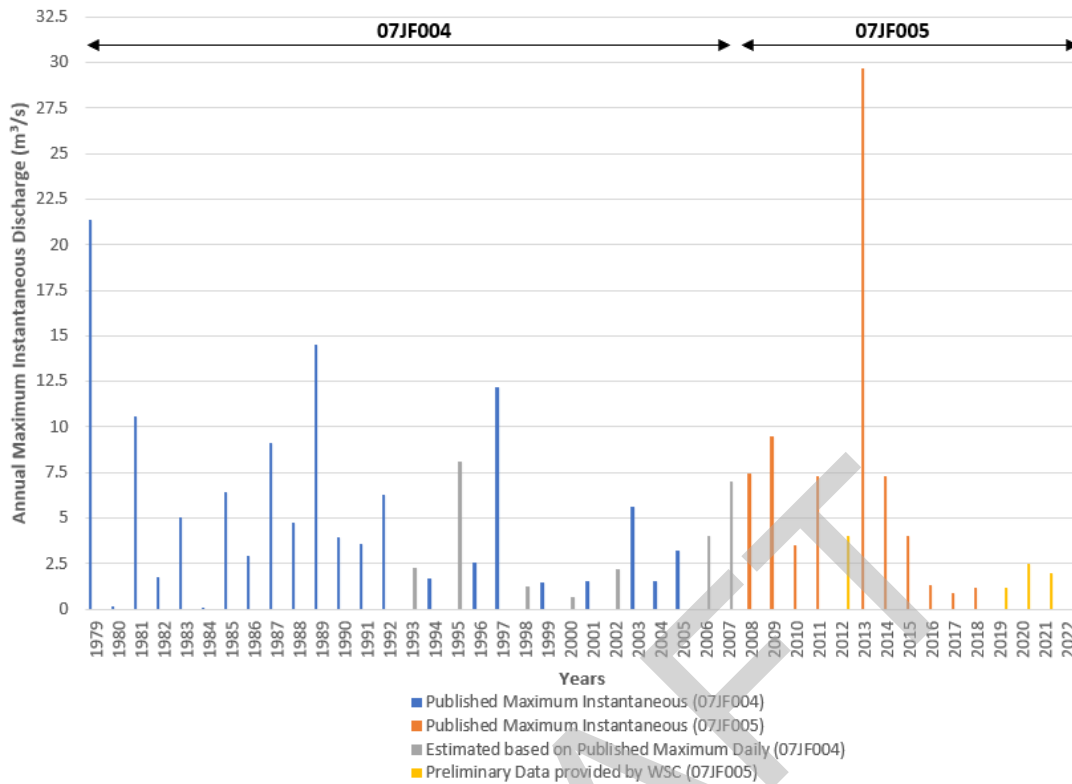


Figure 5 Annual Maximum Instantaneous Discharges for 07JF004 and 07JF005

After estimating the maximum instantaneous discharge series for both stations (i.e., Figure 5), the regional flood flow regressions (Section 3.1) were used to prorate the 07JF004 discharges to 07JF005, for the period 1979 to 2007. The largest recorded maximum instantaneous discharge at 07JF004 of 21.4m³/s had a return period of 50 years based on the 07JF004 regional flood flow regression analysis. Hence, WSP used the average of powers between 2 to 50-year regional regressions for the prorating empirical equation since it better represents the regional watershed characteristics and recorded flows. The prorated empirical equation is shown below and results are shown in Figure 6.

$$Q_{DS} = Q_{US} \left(\frac{DA_{DS}}{DA_{US}} \right)^n$$

Where:

Q_{DS} = Downstream Flow

Q_{US} = Upstream Flow

DA_{DS} = Downstream Drainage Area

DA_{US} = Upstream Drainage Area

n = Average of Powers between 2 to 50-year Regional Regressions (equals to 0.642)

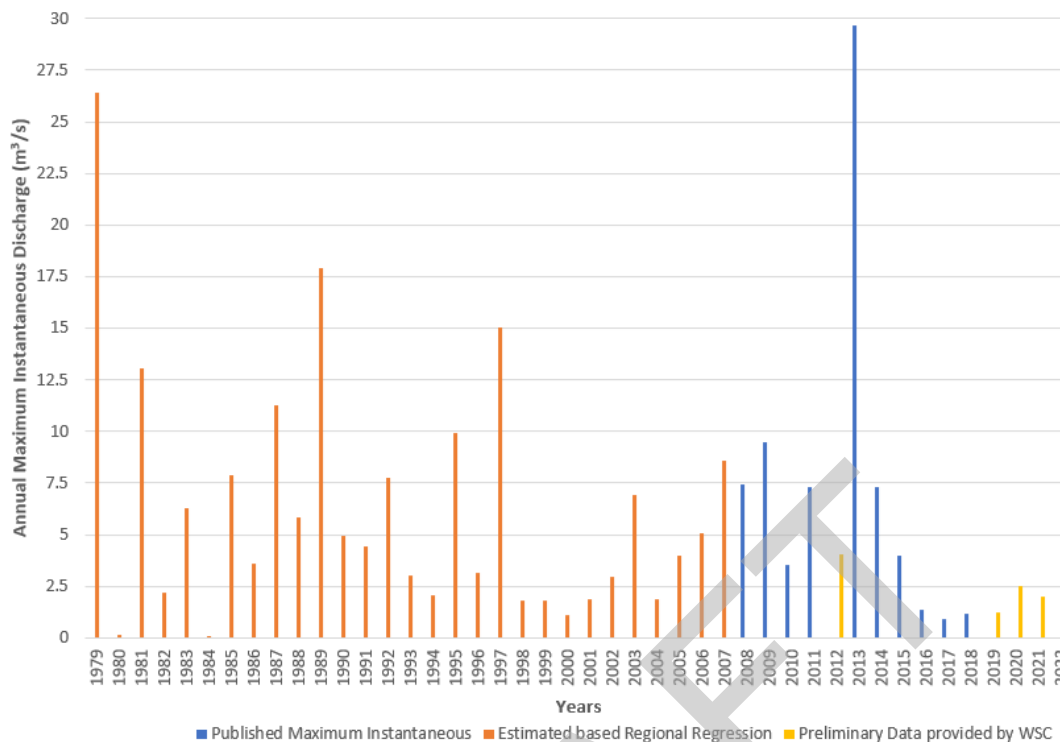


Figure 6 Derived Flood Flow Series for 07JF005

The derived flood flow series for 07JF005 from 1979 to 2022, shown in Figure 6 was used for the study area flood frequency analysis. Station 07JF005 is in the lower half of the hydraulic model river reach. At very large magnitude flood events (e.g., 1:1000-year return period), upstream of 07JF005, part of the flow splits and is decoupled from the main channel. However, the flow balance is maintained at the model domain boundary (i.e., there is no loss of flow at the domain boundary). Since the flow split only occurs at very large flows (i.e., greater than those shown in Figure 6), The flood frequencies derived below (and based on Figure 6) are applicable for the entire hydraulic model study reach.

4 FLOOD FREQUENCY ANALYSIS

4.1 METHODOLOGY

Flood frequency analysis was completed for 07JF005 using a spreadsheet WSP developed with enhanced statistical capabilities. Before selecting an appropriate frequency distribution for the flood flow series, statistical tests for independence, trends, randomness, and homogeneity were completed to determine the quality of the data. Then, a series of frequency distributions were analyzed using different parameter estimation methods (method of moments, maximum likelihood, method of L-moments). The frequency distributions used were: Three-parameter Log Normal distribution, Generalized Extreme Value distribution (1,2 and 3), Log-Pearson Type 3 distribution and Weibull distribution. Modern boot strapping methods and estimation of confidence intervals were utilized for each frequency distribution. Best fit distributions were selected based on the non-parametric Anderson-Darling test. This methodology was also used for regional flood flows to develop regional flood flow regressions.

4.2 RESULTS

The three-parameter Log Normal distribution using maximum likelihood parameterization yielded the best fit results for 07JF005. The flood discharge estimates with the associated upper and lower 95% confidence intervals

are shown in Table 2. A comparison with regional flood flow regressions is also shown in Table 2. Other graphs and tables related to the flood frequency analysis are summarized in Appendix B.

Table 2 07JF005 Flood Frequency Estimates with Confidence Intervals and Comparison with Regional Flood Regressions

RETURN PERIODS (years)	ANNUAL PROBABILITY OF EXCEEDANCE (%)	FLOOD FREQUENCY ANALYSIS (m ³ /s)			REGIONAL FLOOD REGRESSION (m ³ /s)
		VALUE	LOWER 95% LIMIT	UPPER 95% LIMIT	
2	50	4.3	3.06	5.77	5.1
5	20	9.6	7.00	12.78	10.8
10	10	14.5	9.97	20.25	15.5
20	5.0	20.1	12.97	30.48	20.8
25	4.0	22.1	14.06	34.41	22.6
35	2.9	25.4	15.66	41.10	25.5
50	2.0	29.1	17.45	49.59	28.7
75	1.3	33.6	19.57	59.87	32.5
100	1.0	37.1	21.15	69.06	35.3
200	0.5	46.3	24.97	94.36	42.6
350	0.29	54.7	28.38	118.84	49.0
500	0.20	60.6	30.66	138.19	53.4
750	0.13	67.7	33.15	161.35	58.5
1,000	0.10	73.1	34.97	180.63	62.4

The result of flood frequency analysis estimates was consistent with the regional flood flows for all the return periods. From 2 to 35 years, regional flood flows were somewhat higher than the frequency estimates. From 50 to 1000 years, the frequency estimates were somewhat higher, and the difference increased for higher return periods.

5 POTENTIAL EFFECTS OF CLIMATE CHANGE ON FLOOD PEAK DISCHARGES AND FLOOD FREQUENCY ESTIMATES

Bush and Lemmen, 2019) note the following effects of climate change: (1) the frequency of temperature and precipitation extremes will change, leading to more frequent droughts and floods with stronger warming in the winter, as well as daily extreme precipitation increases along with decreases in summer precipitation; (2) decline in snow cover extent, including portions of the year with snow cover decreases and later snow onset and earlier spring melt, but that decreases/increases in snow accumulation vary from area to area; and (3) annual flows have varied with increases in annual and winter runoff and declines in summer flow, as well as with the earlier onset of spring freshet there has also been, and is predicted to be, more rain on snow events.

Dibike *et al.* (2019) comment that changes in the frequency and magnitude of peak flow events result from a temperature-induced shift in precipitation from snowfall towards rain with corresponding changes in precipitation intensity and snowmelt timing. This study also notes an overall projected increase in peak flows, especially low frequency events, and that projected changes in the 100-year peak flow events for points along the Athabasca River could range between 4% and 33% under high emission scenarios.

Appendix C contains more detailed information from both the Bush and Lemmen (2019) and Dibike *et al.* (2019).

The International Panel on Climate Change (IPCC) is the United Nations body that assesses the science related to climate change. Since it was created in 1988, it has produced a series of synthesis reports (i.e., 1990; 1995; 2001; 2007; 2014 2023). These reports use data from the most up to date General Climate Models (GCMs) which in turn

help guide policy makers around the world towards mitigation and adaptation strategies with respect to climate change (IPCC, 2023).

The previous GCM model outputs used in the IPCC assessments were based on Representative Concentration Pathways (RCPs) describing different levels of greenhouse gases and radiative forcings (i.e., RCP2.6, RCP4.5, RCP6.0 and RCP8.5 expressed in watts per meter squared). The IPCC's sixth assessment report (AR6) uses the most recent generation of climate model outputs based on the Scenario Model Intercomparison Project (ScenarioMIP) Phase 6 of the Coupled Model Intercomparison Project (CMIP6) from the World Climate Research Programme (WCRP).

The current emission scenarios are called Shared Socioeconomic Pathways (SSPs) and there are five families of SSP-based scenarios that can be categorized along two broad axes, i.e., challenges to mitigation and challenges to adaptation (Figure 7). These SSPs are scenarios of projected socioeconomic global changes up to the year 2100 and are used to derive greenhouse gas emissions scenarios with different climate policies as (Lee *et al.*, 2021; Meinshausen *et al.*, 2020), where they can be described simply as:

- **SSP1** Sustainability (Taking the Green Road)
- **SSP2** Middle of the Road
- **SSP3** Regional Rivalry (A Rocky Road)
- **SSP4** Inequality (A Road Divided)
- **SSP5** Fossil-Fueled Development (Taking the Highway)

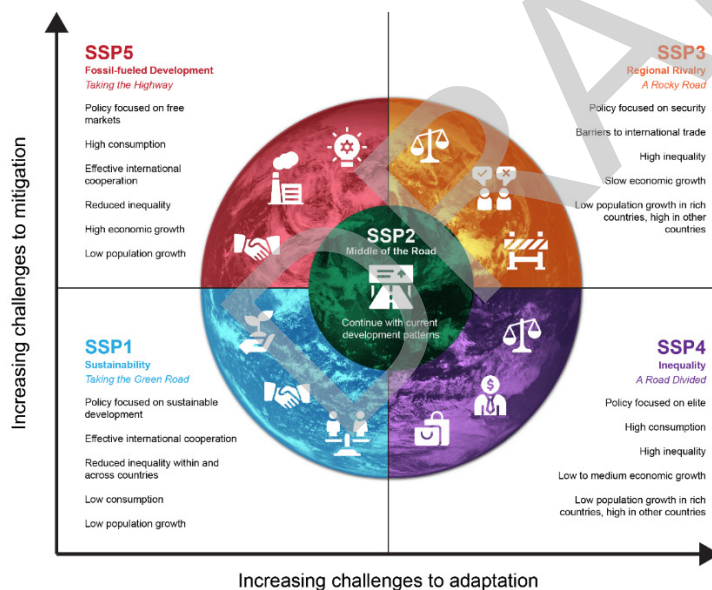


Figure 7 The Five Families of SSP-Based Scenarios Used In CMIP6

Source: <https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/>

From these five families, four individual emission scenarios for families 1, 2, 3 and 5 based on radiative forcing (in units of tenths of watts) are used, and are defined as:

- **SSP126:** this scenario mimics the RCP2.6 scenario with an anticipated radiative forcing change of 2.6 W/m² by the year 2100 using a 2°C target for development that assumes climate measures are taken.

- **SSP245**: this is an update to the RCP4.5 emission scenario that uses a radiative forcing of 4.5 W/m² by the year 2100 that represents the medium pathway of future greenhouse gas emissions that assumes climate protections measures are taken.
- **SSP370**: this is a newly introduced family that came after the RCP scenarios with the intent to close the gap between RCP6.0 and RCP8.5 and has a radiative forcing of 7 W/m² by 2100.
- **SSP585**: this scenario represents the upper bound of the GCM outputs with a radiative forcing of 8.5 W/m² by the year 2100 and is an update to the RCP8.5 from CMIP5 that now encapsulates socioeconomic conditions.

The figures below show the shared socioeconomic pathways (**Figure 8**) and anthropogenic radiative forcing in W/m² (**Figure 9**) from the CMIP6 scenarios (from O'Neill *et al.*, 2016).

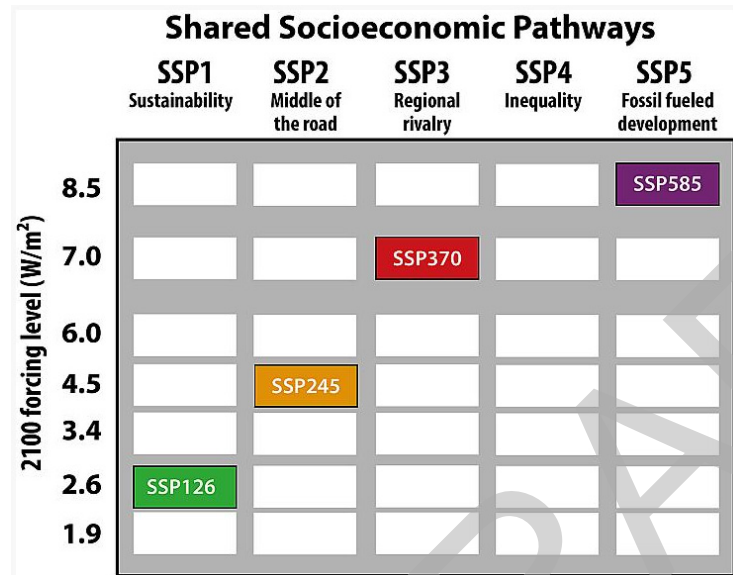


Figure 8 Shared Socioeconomic Pathways by Year 2100 Forcing Level (W/m²)

Source: O'Neill *et al.*, 2016.

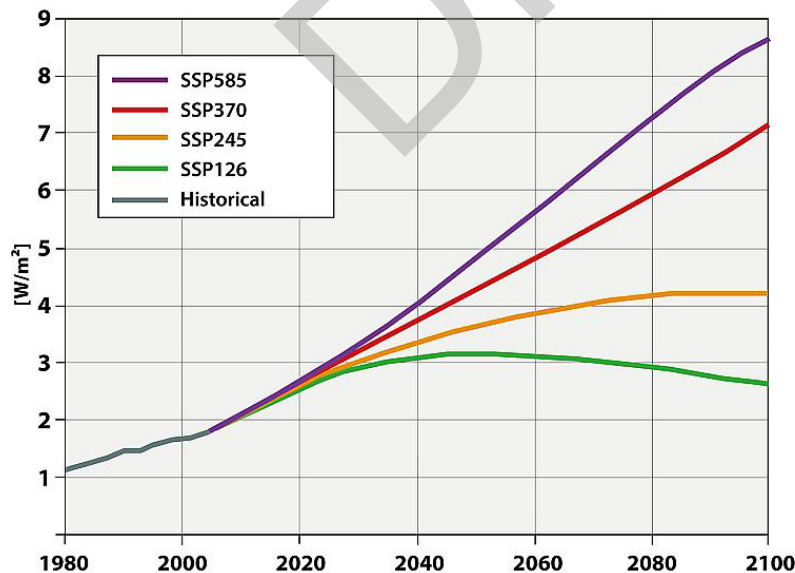


Figure 9 CMIP6 Scenarios – Anthropogenic Radiative Forcing (W/m²)

Source: O'Neill *et al.*, 2016.

WSP completed an assessment using Wang *et al.* (2016) which uses an ensemble of 13 GCMs for SSP126, SSP245, SSP370 and SSP585. Appendix D shows selected figures from these SSPs along with the baseline of 1991-2020 for the location of Paddle Prairie AB (i.e., 57° 57' 12" N; 117° 29' 09" W). The results are summarized below:

- Mean annual temperature is expected to increase between 1.4-1.5°C (2020s), 2.3-3.6°C (2050s) and 2.5-6.3°C (2080s) under the different emissions scenarios of SSP126, SSP245, SSP370 and SSP585, respectively, compared to the baseline of 0.4°C for 1991-2020 (see Figure D-4 in Appendix D).
- Mean annual precipitation is expected to increase between 441-444 mm(2020s), 458-463 mm (2050s) and 457-487 mm (2080s) under the different emissions scenarios of SSP126, SSP245, SSP370 and SSP585, respectively, compared to the baseline of 439 mm for 1991-2020 (see Figure D-5 in Appendix D).
- May to September precipitation, although expected to increase over the three time periods, shows that for the 2020s and 2050s that precipitation over these months is less than the baseline of 288 mm (1991-2020) and that by the 2080s, precipitation will be back to levels equal the baseline period used with very slight increases (see Figure D-6 in Appendix D).
- Precipitation as snow is showing that for the 2020s period that amounts will likely remain at or near the levels of the baseline period (~129 mm) and slightly decrease to between 126-128 mm for the 2050s and similarly for the 2080s decrease to 120-128 mm (see Figure D-7 in Appendix D).
- Winter mean temperatures (December; January; February (DJF)) is expected to remain around the baseline temperature of -16.6°C and ranging between -16.2 to -16.5°C for the 2020s, while it will be warming to between -13.5 to -15.2°C during the 2050s and to between -10.2 to -14.9°C during the 2080s (see Figure D-8 in Appendix D).
- Spring mean temperatures (March; April; May (MAM)) are expected to increase between 2.3 to 2.5°C (2020s), between 3.2 to 4.1°C (2050s) and between 3.3 to 6.5°C (2080s) compared to the baseline of 1.9°C (see Figure D-9 in Appendix D).
- Winter precipitation (DJF) is expected to increase between 70-71 mm (2020s), 72-75 mm (2050s) and 73 to 79 mm (2080s) compared to the baseline of 68 mm (see Figure D-10 in Appendix D).
- Spring precipitation (MAM) is expected to increase between 83-85 mm (2020s), 87 to 91 mm (2050s) and 87 to 102 mm (2080s) compared to the baseline of 72 mm (see Figure D-11 in Appendix D).

The majority of the peak flows for the Boyer River occur in the first three weeks of April (Figure 10). As the climate changes and both the frequency and magnitude of extreme events are expected to change under future climate emission scenarios, it is anticipated that the peak flows will shift to earlier in the year and that peak flows could potentially increase in the order of 4% to 33% as noted by Dibike *et al.* (2019).

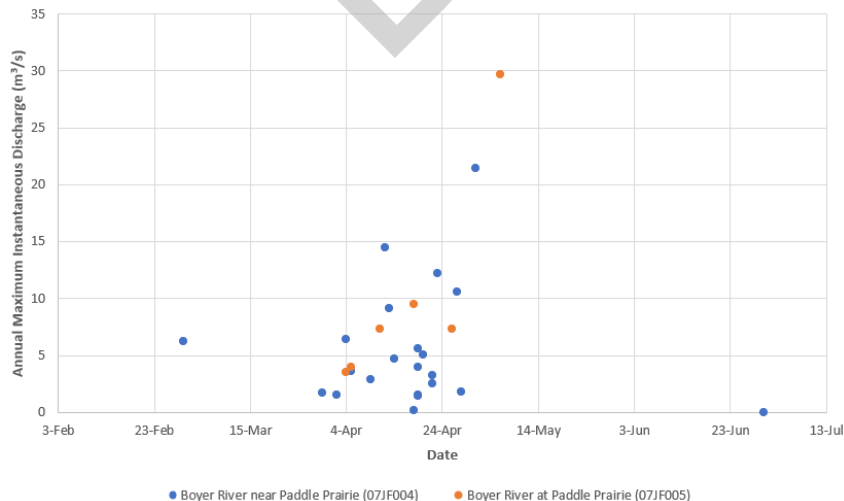


Figure 10 Timing of Boyer River Flood Peak Occurrences

6 CONCLUSIONS

The flood frequency estimates completed in this study provide the most up to date flood hydrology information for the flood mapping component of the study to assess and identify river and flood hazards along the 17 km reach of Boyer River through the Community of Paddle Prairie and PPMS. Results of the estimates are summarized for various return periods from 2 to 1,000 years with the 95% upper and lower confidence intervals in Table 2.

The length of record for the derived flood flows used in the flood frequency analysis is 44 years. As a result, there are large uncertainties (greater range between the lower and upper confidence intervals) with the flood frequency estimates for return periods greater than 50 years. The open water hydrology assessment results stated in this memorandum will be used as the flood discharges for the hydraulic modeling and open water hydraulic flood mapping task.

7 CLOSURE

WSP Canada Inc. (WSP) prepared this report solely for the use of the intended recipient, Alberta Environment and Protected Areas (EPA), 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.

Yours sincerely,

Prepared by:



Liv Hundal, M.Eng., P.Eng.
Principal Engineer Water Resources

Reviewed by:



Getu Biftu, Ph.D., P.Eng.
Principal Senior Hydrologist, Water Resources



Martin Lacroix, M.Sc., P.Geo.
Principal Hydrology Specialist, Water Resources

8 REFERENCES

- Bush, E. and Lemmen, D.S., editors (2019): Canada's Changing Climate Report; Government of Canada, Ottawa, ON. 444 p.
- Dibike, Y., Eum, H-I, Coulibaly, P. and Hartmann, J. 2019. Projected Changes in the Frequency of Peak Flows along the Athabasca River: Sensitivity of Results to Statistical Methods of Analysis. *Climate*, 2019, 7, 88; doi.org/10.3390/cli7070088
- IPCC, 2023. Intergovernmental Panel on Climate Change, Synthesis Report. <https://www.ipcc.ch/ar6-syr/>, accessed May 2023.
- Lee, J. Y. *et al.* (2021) Future Global Climate: Scenario-Based Projections and Near-Term Information. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V. et al. (eds.)]*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 553–672, doi:10.1017/9781009157896.006.
- Meinshausen *et al.* (2020). The shared socio-economic pathway (SSP) greenhouse gas concentrations and their extensions to 2500. *Geoscientific Model Development*, 13(8), 3571–3605. <https://doi.org/10.5194/gmd-13-3571-2020>.
- O'Neill *et al.* 2016: The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6, *Geosci. Model Dev.*, 9, 3461–3482, 2016, doi:10.5194/gmd-9-3461-2016
- Wang T, Hamann A, Spittlehouse D, Carroll C (2016) Locally Downscaled and Spatially Customizable Climate Data for Historical and Future Periods for North America. *PLoS ONE* 11(6): e0156720. doi:10.1371/journal.pone.0156720.

Appendix A

Summaries of Discharge Series and Flood Flow Relationships

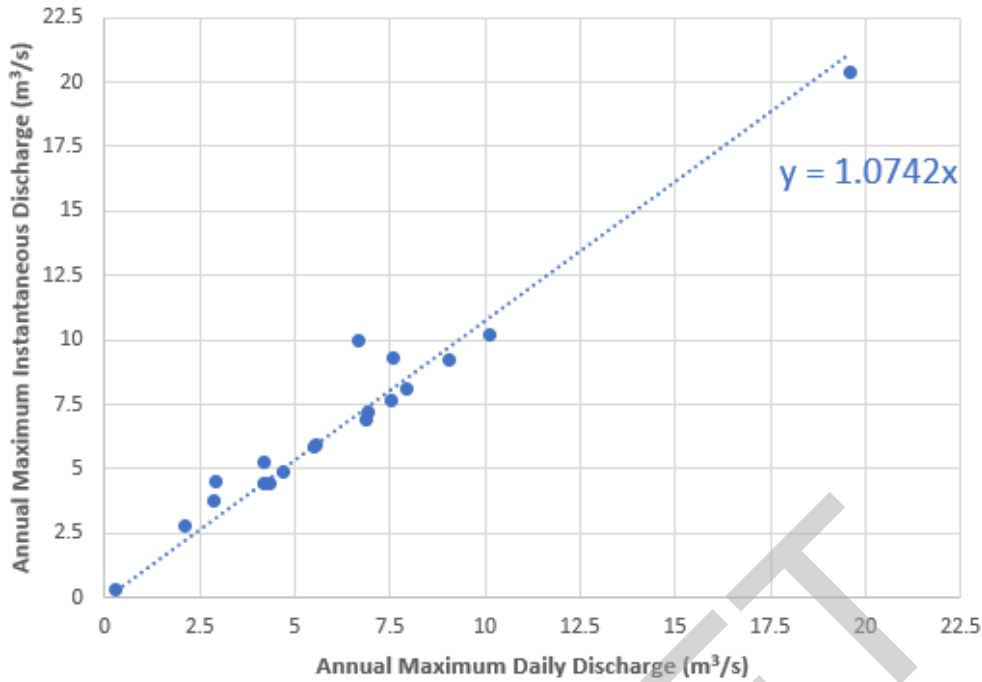


Figure A-1 Lutose Creek near Steen River (07OB006) Annual Maximum Instantaneous Discharges Vs Annual Maximum Daily Flows

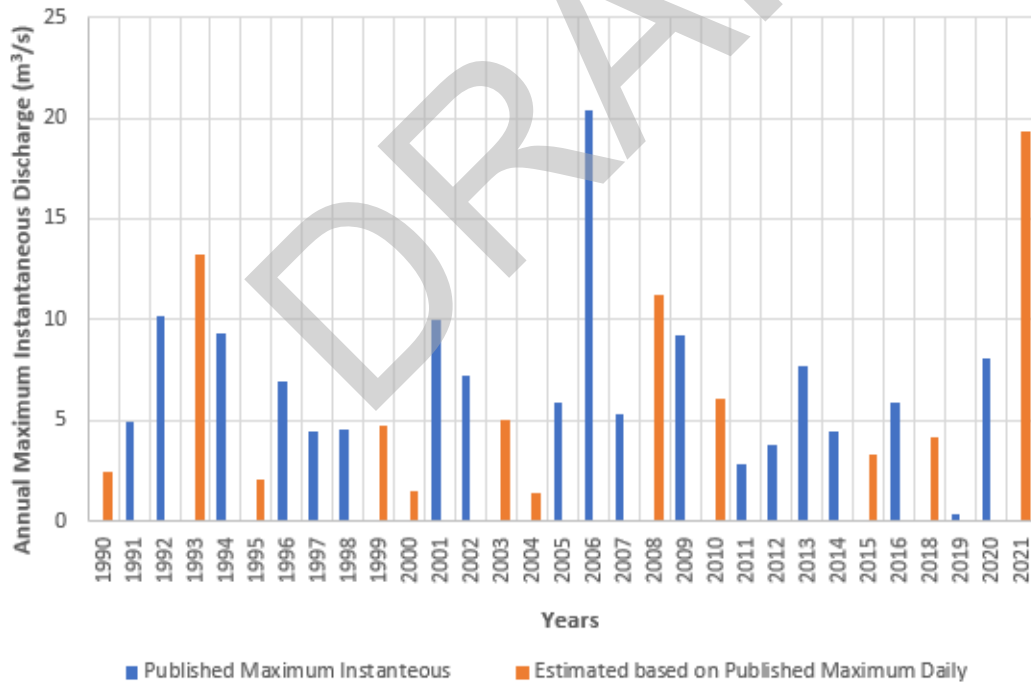


Figure A-2 Lutose Creek near Steen River (07OB006) Annual Maximum Instantaneous Discharges

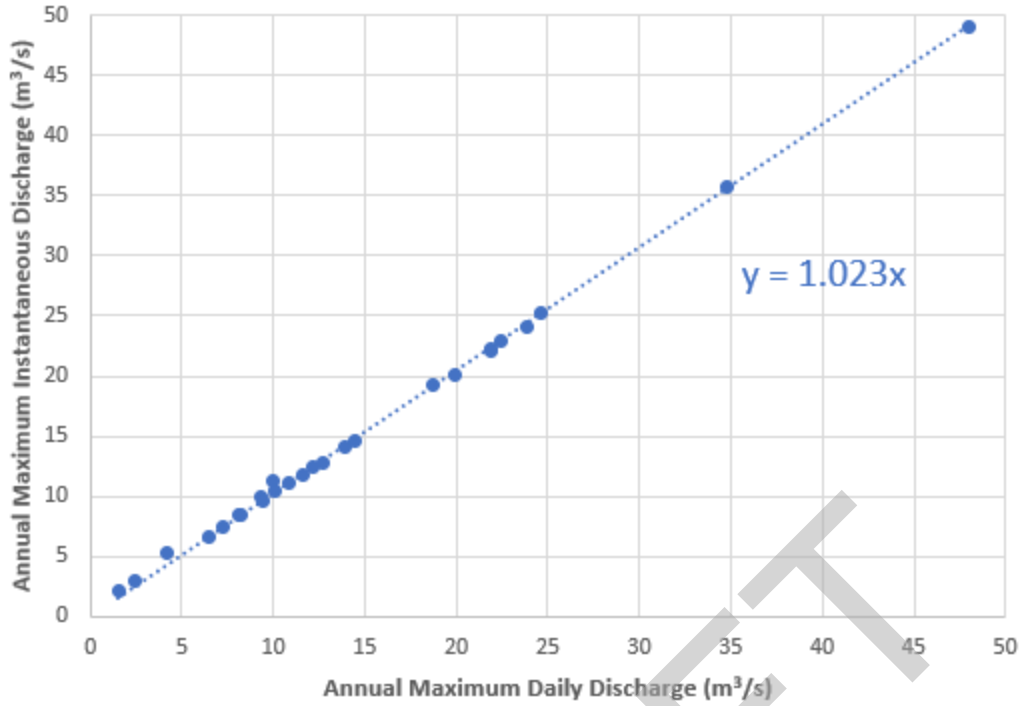


Figure A-3 Sousa Creek near High Level (07OA001) Annual Maximum Instantaneous Discharges Vs Annual Maximum Daily Flows

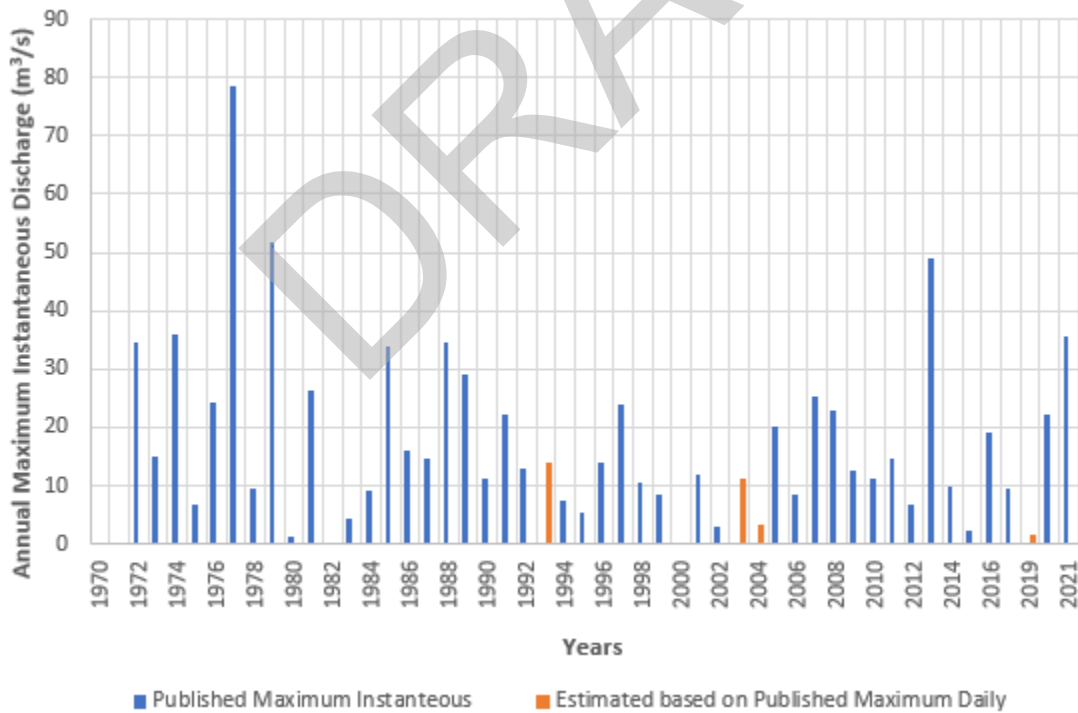


Figure A-4 Sousa Creek near High Level (07OA001) Annual Maximum Instantaneous Discharges

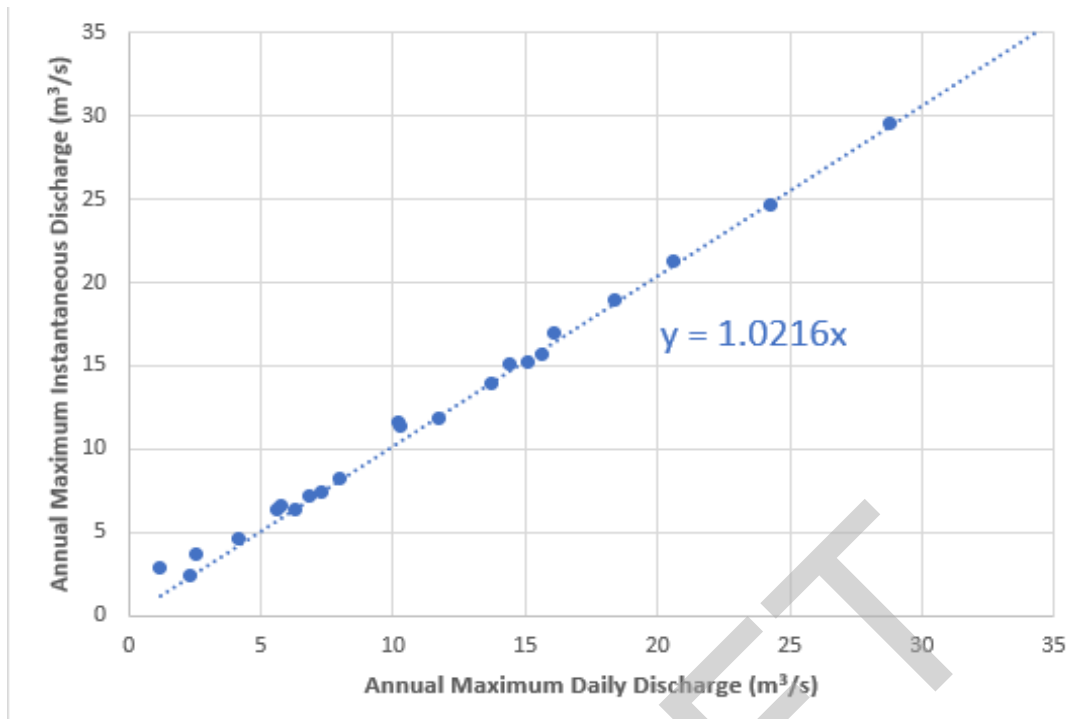


Figure A-5 Jackpine Creek at Highway No. 88 (07JD003) Annual Maximum Instantaneous Discharges Vs Annual Maximum Daily Flows

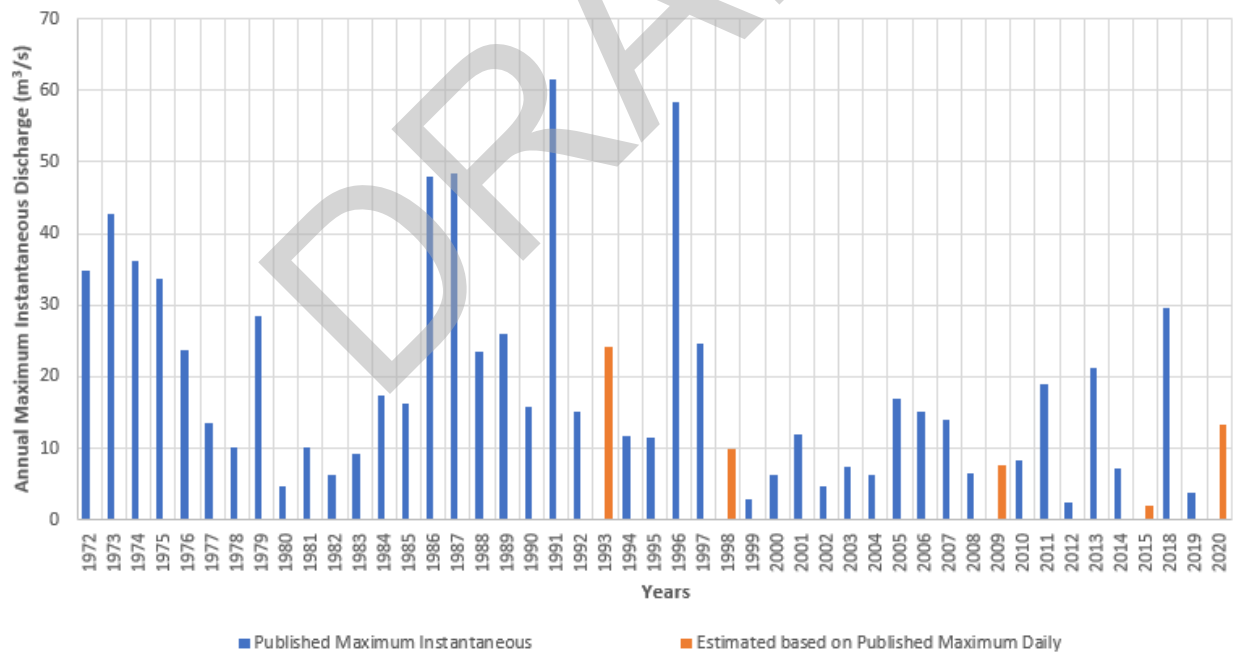


Figure A-6 Jackpine Creek at Highway No. 88 (07JD003) Annual Maximum Instantaneous Discharges

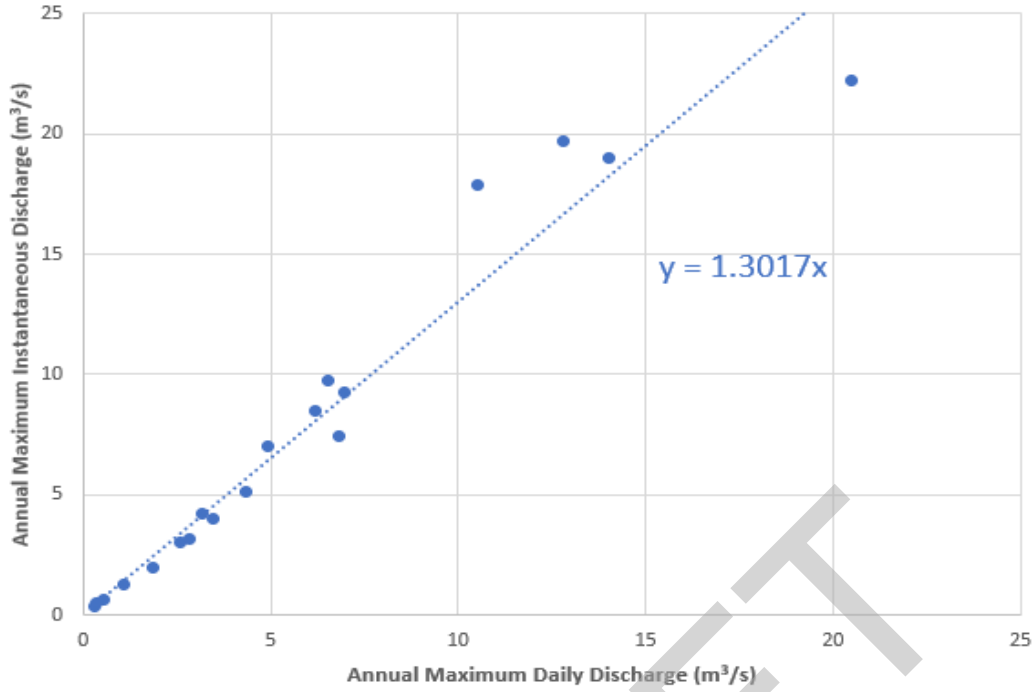


Figure A-7 Teepee Creek near La Crete (07JD004) Annual Maximum Instantaneous Discharges Vs Annual Maximum Daily Flows

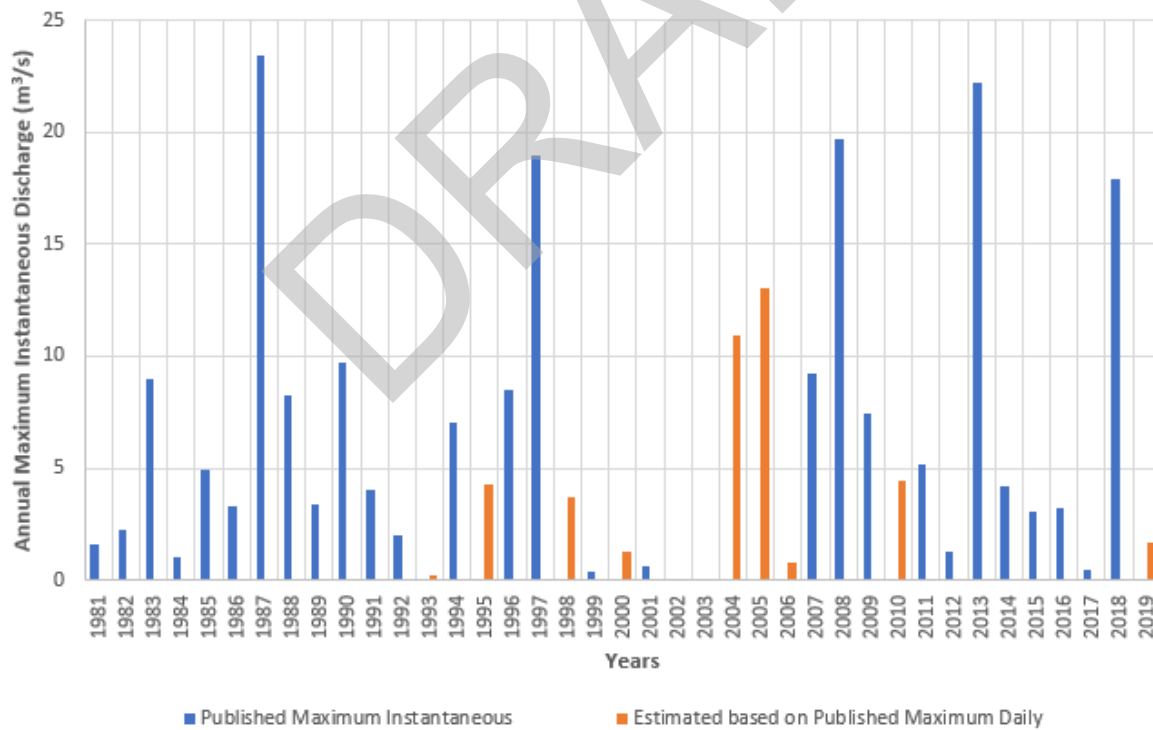


Figure A-8 Teepee Creek near La Crete (07JD004) Annual Maximum Instantaneous Discharges

Attachment B

Flood Frequency Analysis Results

DRAFT

This appendix includes flood frequency analysis results of recorded or derived annual maximum instantaneous discharges at Water Survey of Canada gauging stations used for the regional flood flow regressions and study area. For each station, the following information is provided:

- Summary of data used for the flood frequency analysis;
- Summary of statistical test results used to determine the best fitted distributions;
- Flood frequency distribution graph with all distributions;
- Flood frequency distribution graph with best of fit and confidence interval; and
- Flood frequency estimates for all distributions (best of fit colored in red).

Table B-1 Results of Statistical Tests on Annual Maximum Instantaneous Discharges and Goodness-of-Fit of Probability Distribution Functions for Hydrometric Stations

Station Name (ID)	Lutose Creek near Steen River (07OB006)	Sousa Creek near High Level (07OA001)	Jackpine Creek at Highway No. 88 (07JD003)	Teepee Creek near La Crete (07JD004)	Boyer River near Paddle Prairie (07JF004)	Boyer River at Paddle Prairie (07JF005)
Anderson-Darling Test, $A^2 = -N - S$						
3 Parameter Log-normal	0.185	0.214	0.136	0.245	0.121	0.164
Extreme Value	0.161	0.208	0.24	0.387	0.148	0.252
Log_Pearson III	0.575	0.241	0.118	0.886	1.123	0.904
Weibull	0.483	1.761	0.407	0.766	0.195	0.546
Serial Correlation Coefficient test for Independence						
S1	0.1392	-0.1608	0.2972	0.0049	-0.2375	0.0429
t	0.8778	-1.0805	2.0643	0.0295	-1.247	0.2749
t(a=0.05)	1.6849	-1.6802	1.6802	1.6883	-1.7056	1.6829
t(a=0.01)	2.4258	-2.4141	2.4141	2.4345	-2.4786	2.4208
Spearman rank order correlation coefficient test for trend						
r_s	0.0751	0.2176	0.4368	-0.0324	0.1803	0.1583
t	0.4764	1.4957	3.257	-0.1971	0.9525	1.0389
t(a=0.05)	2.0211	2.0141	2.0141	-2.0262	2.0518	2.0181
t(a=0.01)	2.7045	2.6896	2.6896	-2.7154	2.7707	2.6981
Mann-Whitney split sample test for homogeneity						
Size of earlier sample	21	24	24	20	15	22
z	-0.3899	-1.3833	-2.9582	-0.3091	-1.3093	-0.4929
z(a=0.05)	-1.6449	-1.6449	-1.6449	-1.6449		-1.6449
z(a=0.01)	-2.3263	-2.3263	-2.3263	-2.3263		-2.3263
Test of general randomness (Runs for above or below the median)						
Median	5.9	14	14	4.2	3.6	4
N1(for Q_p=Median)	21	24	24	20	15	22
N2(for Q<Median)	21	23	23	19	14	22
Run_ab	19	27	16	20	17	21
z	0.9373	0.7409	2.5051	0.1582	0.5745	0.6102
z(a=0.05)	1.96	1.96	1.96	1.96		1.96
z(a=0.01)	2.5758	2.5758	2.5758	2.5758		2.5758

Notes:

1. Selected distribution based on best statistical fit
2. Criteria for the respective statistical test were not met

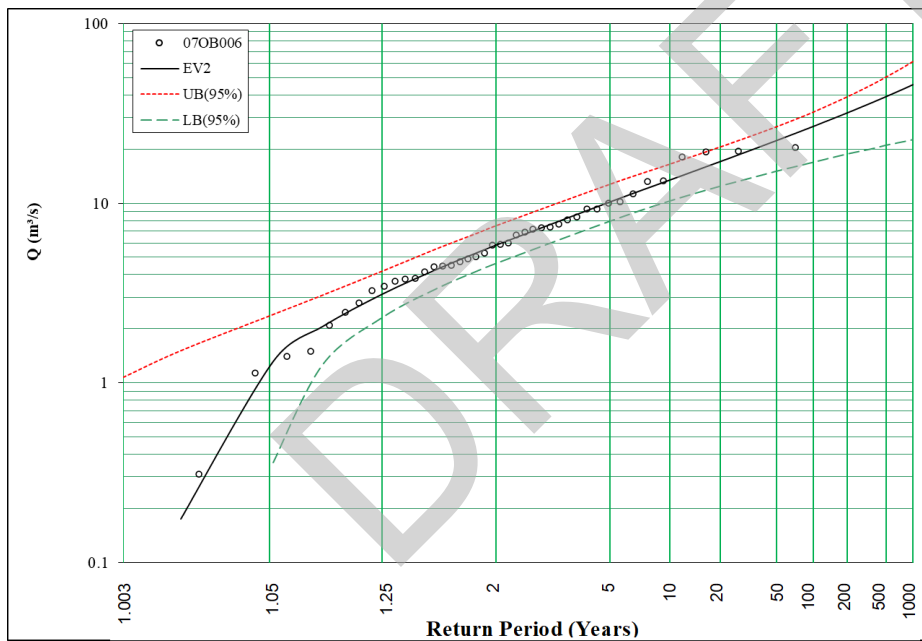
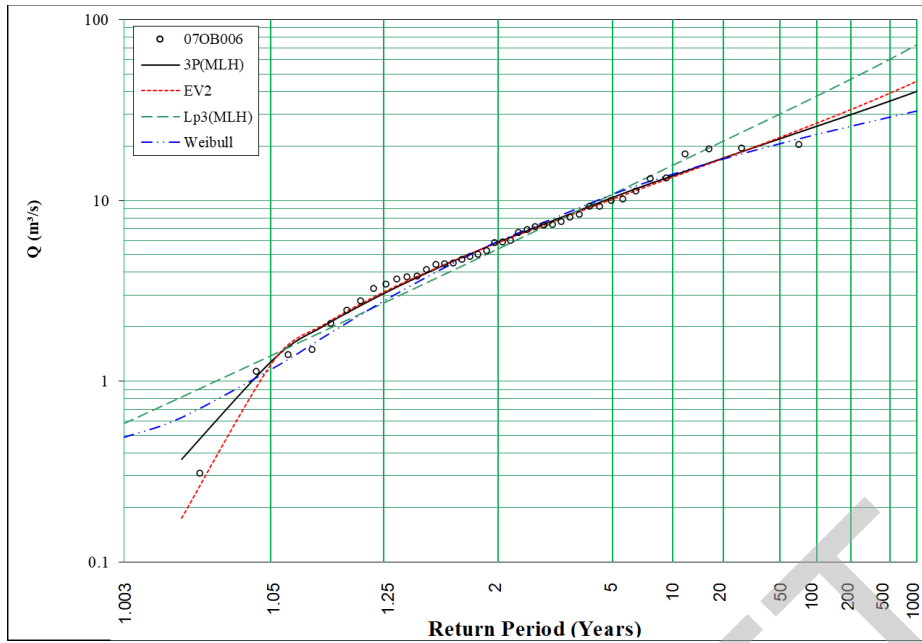


Table B-3 Recorded Maximum Daily and Maximum Instantaneous Discharges with Calculated Maximum Instantaneous Maximum Discharges for Hydrometric Stations (Part 2)

Station Name (ID)	Teepee Creek near La Crete (07JD004)						Boyer River near Paddle Prairie (07JF004)						Boyer River at Paddle Prairie (07JF005)								
	Recorded Maximum Daily			Recorded Maximum Instantaneous			Calculated	Recorded Maximum Daily			Recorded Maximum Instantaneous			Calculated	Recorded Maximum Daily			Recorded Maximum Instantaneous			Calculated
	Date		Flow	Date		Flow		Date		Flow	Date		Flow		Date		Flow	Date		Flow	
	Month	Day	(m ³ /s)	Month	Day	(m ³ /s)	(m ³ /s)	Month	Day	(m ³ /s)	Month	Day	(m ³ /s)	(m ³ /s)	Month	Day	(m ³ /s)	Month	Day	(m ³ /s)	(m ³ /s)
1979										5	1	21.4									26.82
1980										4	18	0.133									0.17
1981				4	30	1.63				4	27	10.6									13.29
1982				4	22	2.26				4	28	1.76									2.21
1983				4	19	8.96				4	20	5.07									6.36
1984				7	7	1				6	30	0.022									0.03
1985				4	2	4.94				4	4	6.41									8.03
1986				6	25	3.31				4	9	2.9									3.64
1987				4	16	23.4				4	13	9.12									11.43
1988				4	17	8.22				4	14	4.73									5.93
1989				4	13	3.38				4	12	14.5									18.18
1990	4	19	6.53	4	19	9.72		4	9	3.77	4	9	3.98								4.99
1991	4	4	3.47	4	5	3.99		4	6	2.29	4	6	3.6								4.51
1992	3	1	1.84	3	1	2.01		3	1	4.5	3	1	6.27								7.86
1993	5	8	0.14				0.183	8	12	1.84				2.23							3.04
1994	3	30	4.93	3	30	7		3	30	1.34	3	30	1.68								2.11
1995	4	23	3.25				4.24	4	24	6.69				8.12							10.05
1996	4	18	6.21	4	17	8.47		4	22	2.26	4	22	2.56								3.21
1997	4	19	14	4	19	19		4	23	10.4	4	23	12.2								15.29
1998	4	5	2.87				3.74	4	3	1				1.21							1.83
1999	4	13	0.29	4	13	0.336		4	19	1.33	4	19	1.46								1.83
2000	4	4	0.962				1.25	4	7	0.519				0.63							1.13
2001	4	15	0.553	4	14	0.627		4	19	1.48	4	19	1.54								1.93
2002	4	26	0.01				0.013	4	24	1.8				2.18							2.98
2003								4	19	4.71	4	19	5.6								7.02
2004	4	5	8.37				10.9	4	3	1.17	4	2	151								1.89
2005	4	11	10				13.04	4	22	1.65	4	22	3.2								4.01
2006	4	8	0.624				0.814	4	12	3.3				4.01							5.15
2007	4	11	6.99	4	11	3.26		4	16	5.75				6.98							8.7
2008	4	15	12.8	4	15	19.7								4	30	7.3					7.41
2009	4	15	6.82	4	14	7.44								4	18	7.97	4	18			9.49
2010	4	2	3.41				4.45							4	4	2.65	4	4			3.52
2011	4	11	4.32	4	11	5.15								4	26	6.18	4	26			7.29
2012	3	31	1.07	3	31	1.29								4	12	2.53					4.02
2013	5	5	20.5	5	5	22.2								5	7	15.2	5	6			29.7
2014	4	10	3.17	4	10	4.22								4	11	6.41	4	11			7.33
2015	4	1	2.61	4	1	3.03								4	6	2.75	4	5			4
2016	4	17	2.83	4	17	3.19															1.34
2017	4	1	0.377	4	2	0.484															0.914
2018	4	23	10.5	4	23	17.9								4	27	0.826	4	27			1.17
2019	3	28	1.26				1.64							3	27	1.08					1.21
2020	4	21	3.85	4	21	4.32								4	20	2.15					2.49
2021														4	17	1.7					1.98
2022																	5	31			17.9

Notes:

1. Values colored in red are estimated values provided by WSC.
2. Calculated values for the stations are from using the linear relationship presented in Appendix A and for 07JF005, the regional relationship was used.

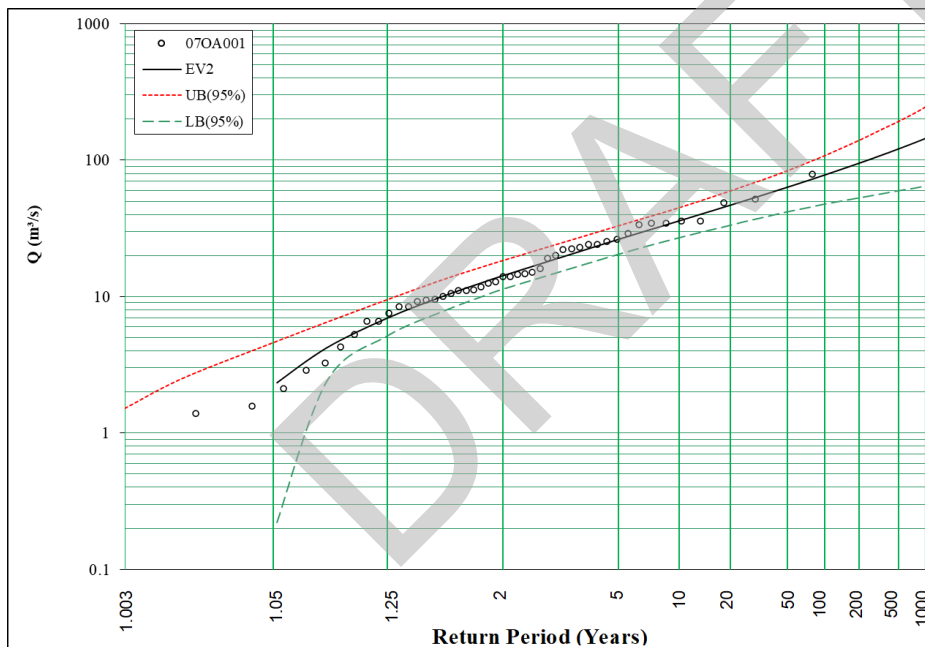
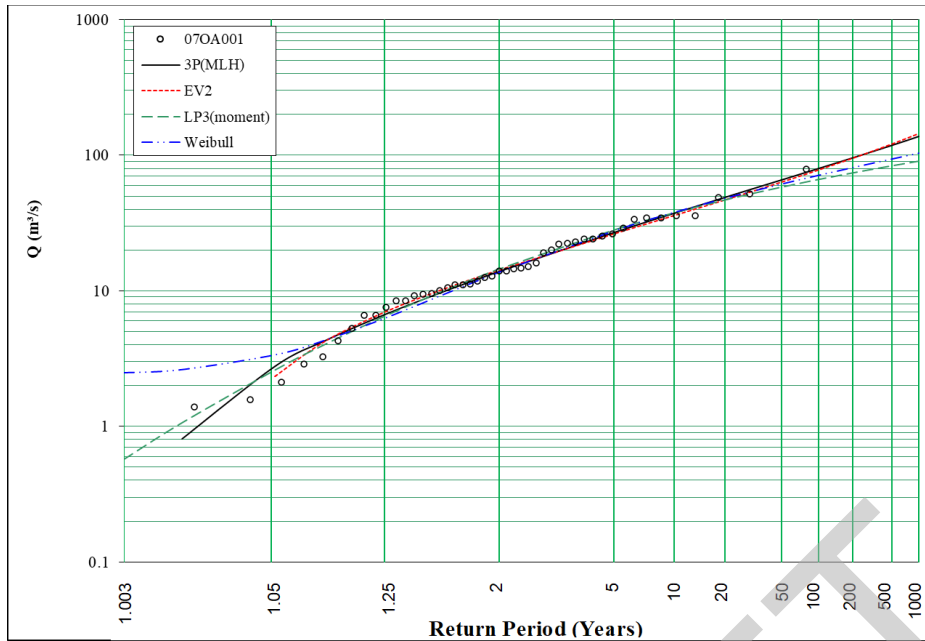


Flood Flow Series	
Years	Flow
1978	7.3
1979	19.5
1981	3.7
1982	3.5
1983	3.8
1984	1.1
1985	18.1
1986	7.4
1987	8.4
1988	13.3
1989	6.7
1990	2.5
1991	4.9
1992	10.2
1993	13.3
1994	9.3
1995	2.1
1996	6.9
1997	4.4
1998	4.5
1999	4.7
2000	1.5
2001	10.0
2002	7.2
2003	5.1
2004	1.4
2005	5.9
2006	20.4
2007	5.3
2008	11.2
2009	9.3
2010	6.0
2011	2.8
2012	3.8
2013	7.7
2014	4.5
2015	3.3
2016	5.9
2018	4.1

Flood Flow Series	
Years	Flow
2019	0.3
2020	8.1
2021	19.4

Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	5.9	5.9	5.4	6.0
5	10.4	10.2	10.8	10.8
10	13.8	13.5	15.7	14.0
20	17.2	17.0	21.2	17.0
25	18.3	18.2	23.2	17.9
35	20.1	20.1	26.4	19.2
50	22.0	22.3	30.0	20.6
75	24.2	24.8	34.4	22.2
100	25.8	26.7	37.8	23.2
200	29.9	31.7	46.7	25.8
350	33.3	36.1	54.9	27.7
500	35.6	39.2	60.5	29.0
750	38.3	42.8	67.4	30.4
1000	40.2	45.6	72.5	31.3

Figure B-1 Lutose Creek near Steen River (07OB006)

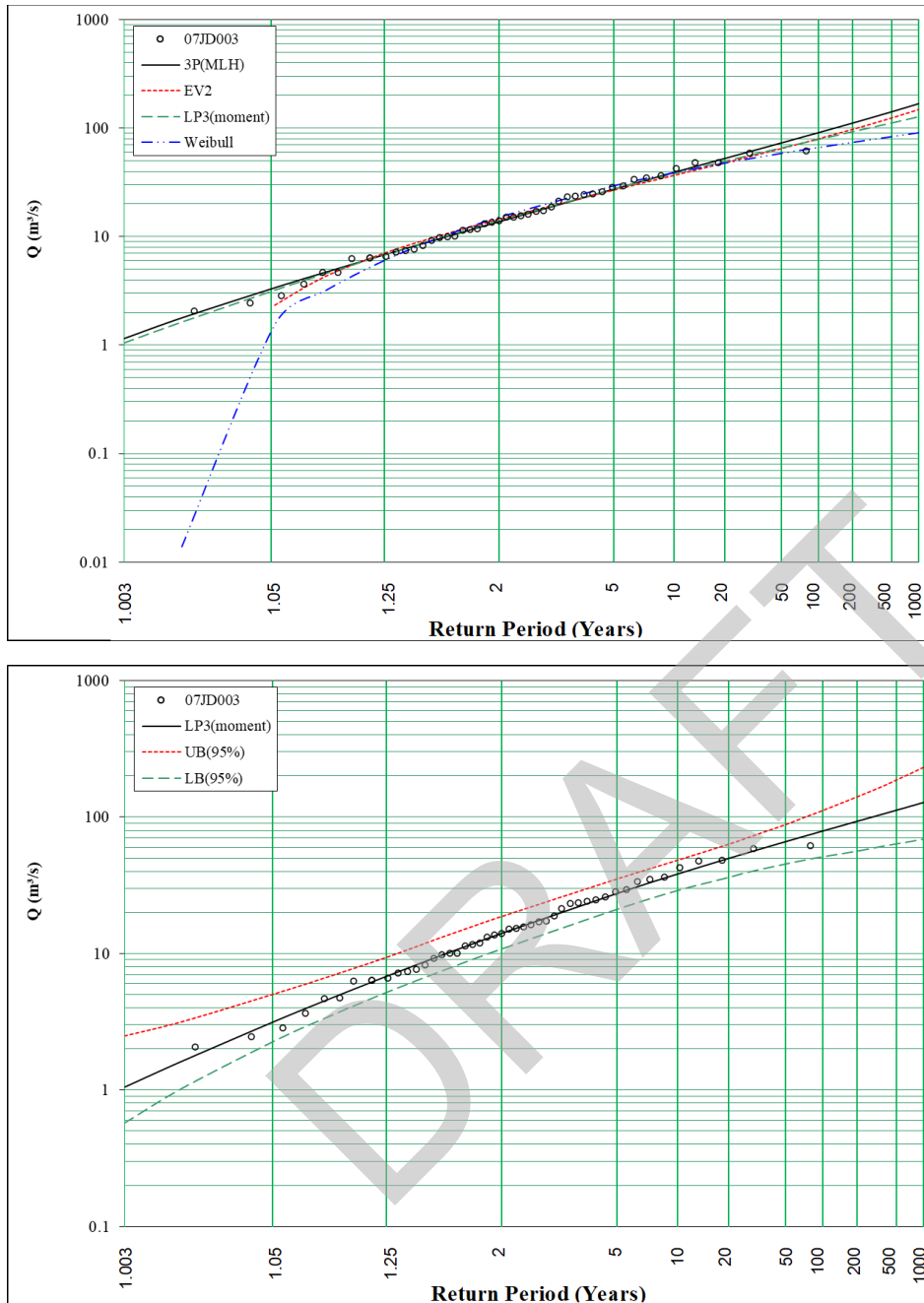


Flood Flow Series	
Years	Flow
1972	34.5
1973	15.1
1974	36.0
1975	6.6
1976	24.1
1977	78.7
1978	9.5
1979	51.7
1980	1.4
1981	26.3
1983	4.3
1984	9.3
1985	33.9
1986	16.1
1987	14.8
1988	34.7
1989	29.0
1990	11.2
1991	22.3
1992	12.8
1993	14.0
1994	7.5
1995	5.3
1996	14.1
1997	24.0
1998	10.5
1999	8.5
2001	11.8
2002	2.9
2003	11.1
2004	3.3
2005	20.1
2006	8.4

Flood Flow Series	
Years	Flow
2007	25.3
2008	22.9
2009	12.5
2010	11.1
2011	14.6
2012	6.6
2013	49.1
2014	10.0
2015	2.1
2016	19.2
2018	9.6
2019	1.6
2020	22.1
2021	35.7

Return Period	3P(MLH)	EV2	Lp3(Moment)	Weibull
2	14.0	14.3	14.5	13.8
5	27.0	26.3	28.0	27.7
10	37.6	36.0	37.5	38.0
20	49.1	46.8	46.6	48.2
25	53.0	50.6	49.4	51.4
35	59.1	56.6	53.6	56.3
50	66.0	63.4	57.9	61.4
75	74.2	71.7	62.7	67.2
100	80.2	78.1	66.0	71.3
200	95.9	94.9	73.7	81.2
350	109.6	110.4	79.6	89.1
500	118.8	121.2	83.3	94.1
750	129.9	134.5	87.3	99.8
1000	138.1	144.7	90.0	103.8

Figure B-2 Sousa Creek near High Level (07OA001)

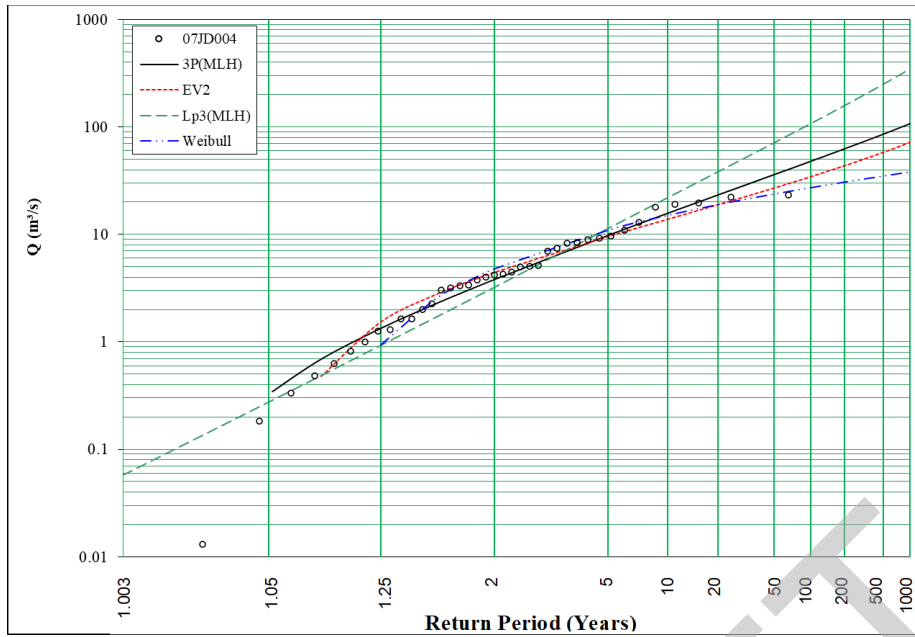


Flood Flow Series	
Years	Flow
1972	34.8
1973	42.8
1974	36.2
1975	33.7
1976	23.6
1977	13.6
1978	10.1
1979	28.5
1980	4.7
1981	10.0
1982	6.3
1983	9.2
1984	17.4
1985	16.2
1986	47.9
1987	48.3
1988	23.4
1989	26.0
1990	15.7
1991	61.5
1992	15.2
1993	24.2
1994	11.6
1995	11.4
1996	58.4
1997	24.6
1998	9.8
1999	2.8
2000	6.4
2001	11.9
2002	4.7
2003	7.4
2004	6.4
2005	17.0
2006	15.1
2007	14.0
2008	6.6
2009	7.6
2010	8.3

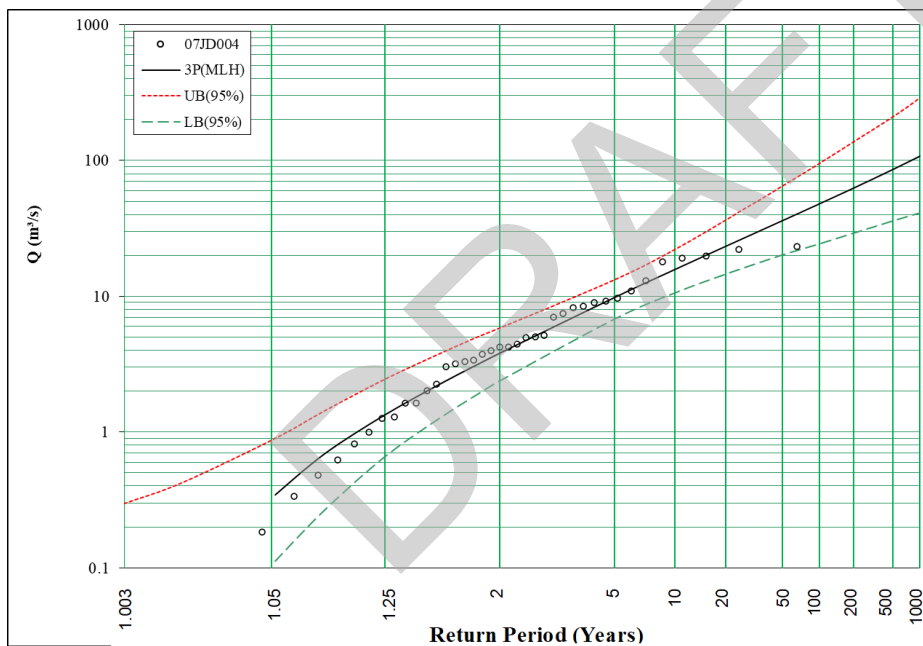
Flood Flow Series	
Years	Flow
2011	18.9
2012	2.5
2013	21.3
2014	7.2
2015	2.1
2018	29.6
2019	3.7
2020	13.2

Return Period	3P(MLH)	EV2	LP3(moment)	Weibull
2	13.7	14.5	14.1	15.1
5	27.3	28.8	27.7	29.3
10	39.0	38.7	38.4	38.6
20	52.3	47.7	49.9	47.4
25	57.0	51.6	53.7	50.1
35	64.4	57.7	59.7	54.1
50	72.7	64.7	66.1	58.2
75	82.9	73.2	73.8	62.8
100	90.5	79.7	79.3	66.0
200	110.6	96.9	93.2	73.5
350	128.6	112.8	104.9	79.4
500	141.0	123.9	112.7	83.1
750	155.9	137.5	121.7	87.2
1000	167.1	147.9	128.2	90.1

Figure B-3 Jackpine Creek at Highway No. 88 (07JD003)

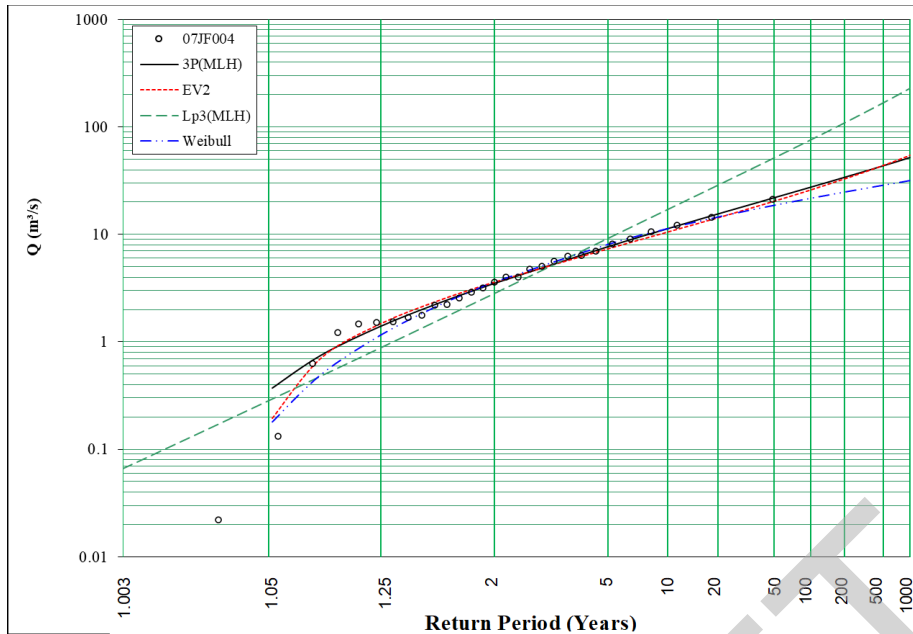


Flood Flow Series	
Years	Flow
1981	1.6
1982	2.3
1983	9.0
1984	1.0
1985	4.9
1986	3.3
1987	23.4
1988	8.2
1989	3.4
1990	9.7
1991	4.0
1992	2.0
1993	0.2
1994	7.0
1995	4.2
1996	8.5
1997	19.0
1998	3.7
1999	0.3
2000	1.3
2001	0.6
2002	0.01
2004	10.9
2005	13.0
2006	0.8
2007	9.3
2008	19.7
2009	7.4
2010	4.4
2011	5.2
2012	1.3
2013	22.2
2014	4.2
2015	3.0
2016	3.2
2017	0.5
2018	17.9
2019	1.6
2020	5.0

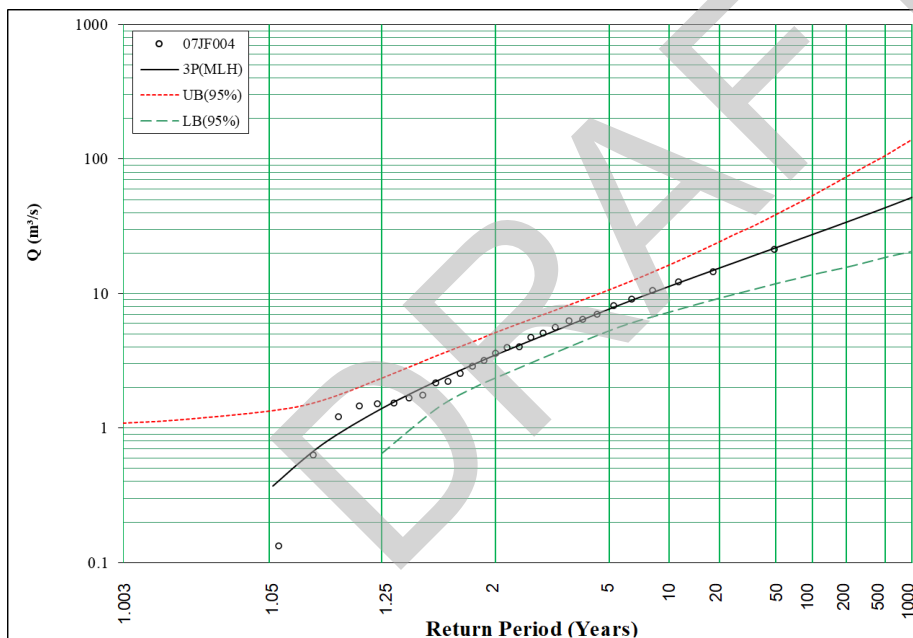


Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	3.8	4.5	3.2	4.8
5	9.8	9.8	11.3	10.9
10	15.8	13.9	22.0	15.0
20	23.4	18.9	38.0	18.9
25	26.2	20.7	44.6	20.1
35	30.7	23.6	56.2	21.9
50	36.1	27.0	70.7	23.7
75	42.9	31.2	90.5	25.8
100	48.2	34.4	107.1	27.2
200	62.7	43.4	156.7	30.6
350	76.4	51.9	208.9	33.2
500	86.2	58.0	248.9	34.9
750	98.3	65.7	301.9	36.8
1000	107.7	71.7	344.7	38.1

Figure B-4 Teepee Creek near La Crete (07JD004)

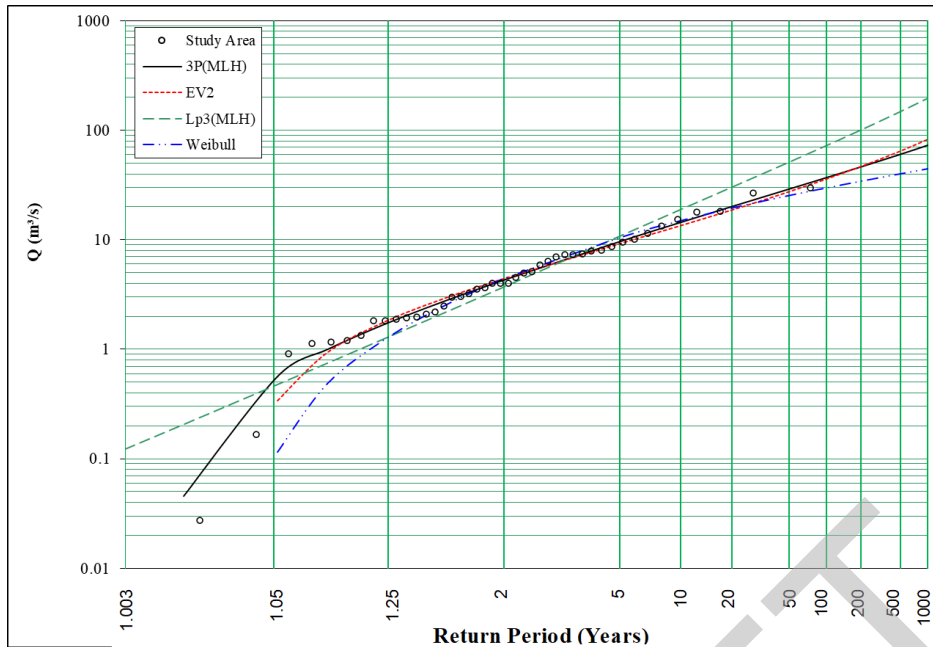


Flood Flow Series	
Years	Flow
1979	21.4
1980	0.1
1981	10.6
1982	1.8
1983	5.1
1984	0.02
1985	6.4
1986	2.9
1987	9.1
1988	4.7
1989	14.5
1990	4.0
1991	3.6
1992	6.3
1993	2.2
1994	1.7
1995	8.1
1996	2.6
1997	12.2
1998	1.2
1999	1.5
2000	0.6
2001	1.5
2002	2.2
2003	5.6
2004	1.5
2005	3.2
2006	4.0
2007	7.0



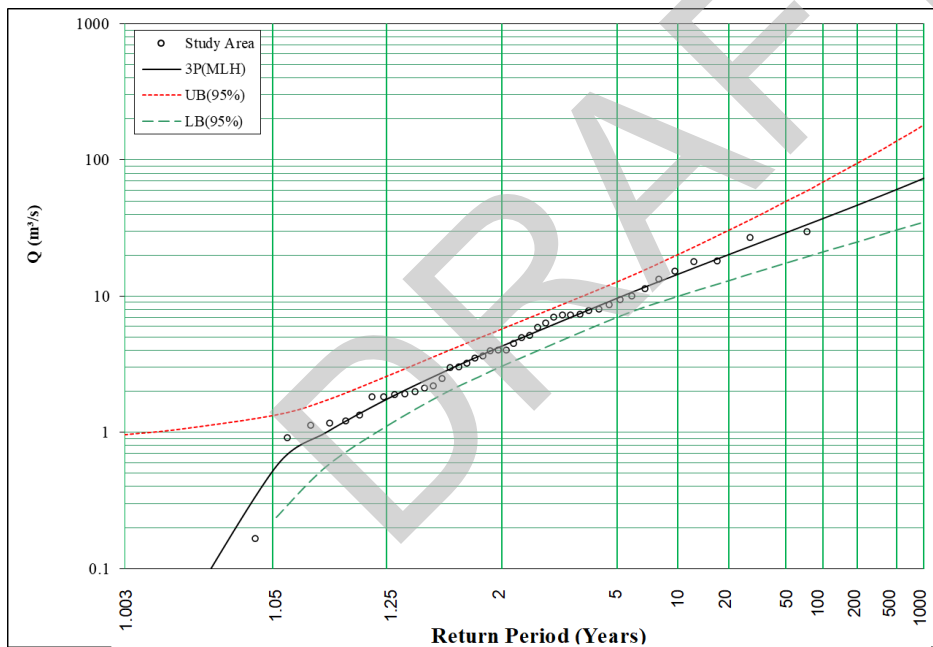
Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	3.5	3.6	2.8	3.6
5	7.7	7.4	9.2	8.1
10	11.3	10.5	17.1	11.4
20	15.5	14.3	28.7	14.6
25	16.9	16.6	33.4	15.6
35	19.2	17.8	41.4	17.2
50	21.8	20.3	51.5	18.8
75	25.0	23.5	65.0	20.6
100	27.4	28.0	76.1	21.9
200	33.8	32.8	108.9	25.0
350	39.5	39.2	142.8	27.4
500	43.4	43.9	168.5	29.0
750	48.2	49.8	202.1	30.7
1000	51.7	54.4	229.1	32.0

Figure B-5 Boyer River near Paddle Prairie (07JF004)



Flood Flow Series	
Years	Flow
1979	26.8
1980	0.2
1981	13.3
1982	2.2
1983	6.4
1984	0.03
1985	8.0
1986	3.6
1987	11.4
1988	5.9
1989	18.2
1990	5.0
1991	4.5
1992	7.9
1993	3.0
1994	2.1
1995	10.1
1996	3.2
1997	15.3
1998	1.8
1999	1.8
2000	1.1
2001	1.9
2002	3.0
2003	7.0
2004	1.9
2005	4.0
2006	5.2
2007	8.7
2008	7.4
2009	9.5
2010	3.5
2011	7.3
2012	4.0
2013	29.7
2014	7.3
2015	4.0
2016	1.3
2017	0.9

Flood Flow Series	
Years	Flow
2018	1.2
2019	1.2
2020	2.5
2021	2.0
2022	17.9



Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	4.3	4.4	3.7	4.4
5	9.6	9.2	10.9	10.5
10	14.5	13.5	19.1	15.0
20	20.1	18.7	30.4	19.8
25	22.1	20.6	34.8	21.0
35	25.4	23.7	42.3	23.2
50	29.1	27.4	51.4	25.5
75	33.6	32.1	63.4	28.1
100	37.1	35.9	73.1	30.0
200	46.3	46.3	101.0	34.5
350	54.7	56.9	128.9	38.1
500	60.6	64.6	149.8	40.4
750	67.7	74.4	176.2	43.0
1000	73.1	82.2	197.2	44.8

Figure B-6 Study Area

Attachment C

Climate Change Quotes from Recent Publications

DRAFT

The literature on climate change is quite vast and continuously being updated, but key takeaways highlighted in Bush and Lemmen (2019) are:

Changes in **Temperature and Precipitation Across Canada**

- The changing frequency of temperature and precipitation extremes can be expected to lead to a change in the likelihood of events such as wildfires, droughts, and floods. (p.119)
- To date, warming has been stronger in winter than in other seasons. Widespread changes in temperature indices and extremes associated with warming have been observed. (p. 154)
- The increase in Canadian mean temperature is about twice the rate of global mean temperature. This is the case in the historical record and also applies to future change, regardless of the emissions pathway that the earth will follow. (p. 154)
- In addition, regional climate model projections show a general increase in rain-on-snow events over the coming century. (p. 167)
- In the future, daily extreme precipitation is projected to increase (high confidence). (p. 155)
- There is medium confidence that annual mean precipitation has increased, on average, in Canada, with larger percentage increases in northern Canada. (p. 173)
- Annual and winter precipitation is projected to increase everywhere in Canada over the 21st century, with larger percentage changes in northern Canada. Summer precipitation is projected to decrease over southern Canada under a high emission scenario toward the end of the 21st century, but only small changes are projected under a low emission scenario. (p. 173)

Changes in Snow, Ice, and Permafrost Across Canada

- There is also very high confidence that snow cover extent has declined in the northern hemisphere. (p.37)
- The duration of seasonal lake ice cover has declined across Canada over the past five decades due to later ice formation in fall and earlier spring breakup (high confidence). (p.199)
- The portion of the year with snow cover decreased across most of Canada (very high confidence) as did the seasonal snow accumulation (medium confidence). Snow cover fraction decreased between 5% and 10% per decade since 1981 due to later snow onset and earlier spring melt. (p. 203)
- It is very likely that snow cover duration will decline to mid-century across Canada due to increases in surface air temperature under all emissions scenarios. Scenario-based differences in projected spring snow cover emerge by the end of the century, with stabilized snow loss for a medium emission scenario but continued snow loss under a high emission scenario (high confidence). (p.203)
- Seasonal snow accumulation decreased by a rate of 5% to 10% per decade across most of Canada (1981–2015), with the exception of southern Saskatchewan, Alberta, and British Columbia (increases of 2% to 5% per decade), driven by both temperature and precipitation changes. (p. 210)
- A reduction of 5% to 10% per decade in seasonal snow accumulation (through 2050) is projected across much of southern Canada; only small changes in snow accumulation are projected across northern regions of Canada because increases in winter precipitation are expected to offset a shorter snow accumulation period. (p. 210)

Changes in Freshwater Availability Across Canada

- Annual flows over western Canada have varied from one region to another, with both increasing and decreasing trends since approximately the 1960s and 1970s. Most declines were observed in rivers draining the eastern slopes of the central/southern Rocky Mountains, including the Athabasca, Peace, Red Deer, Elbow, and Oldman rivers. (p. 274)

- Several flows were associated with naturally occurring internal climate variability (mainly El Niño–Southern Oscillation, Pacific Decadal Oscillation [PDO], and Arctic Oscillation [AO]); particularly for western Canada during winter... (p.278)
- In general, for the mid-21st century, watersheds in British Columbia and northern Alberta are projected to have increases in annual and winter runoff, whereas some watersheds in Alberta, southwest British Columbia, and southern Ontario are projected to have declines in summer flow. (p.281)
- Athabasca River watershed (AB): projected increases in spring and winter flows, increases in minimum and maximum flows, with summer flows projected to decrease in the 2050s and 2080s; overall increase in annual runoff reaching the river mouth. (p.282)
- Several regional studies in western Canada... have also found an earlier onset of spring freshet over the past several decades. (p. 286)
- There are few studies of future streamflow timing in Canada. An earlier snowmelt peak and resulting spring freshet is projected for mid-century (2041–2070) over western Canada, particularly for northern basins, using a high emission scenario. For the majority of western Canada basins, this earlier shift was also projected for the end-of-winter low-flow events. Earlier spring freshet flows for the mid-century period (2041–2070) are also projected using several CMIP5 models under a medium (RCP4.5) and a high (RCP8.5) emission scenario. (p. 287)
- Depletion of the snowpack by mid-winter melt events are projected to lead to a major reduction in the frequency of spring ice jam flooding, but could increase the potential for mid-winter ice jam flooding in the Peace–Athabasca delta in northern Alberta. (p.291)
- The most significant observed changes in freshwater availability are in the seasonal distribution of streamflow in many snow-fed catchments: winter flows have become higher, the timing of spring peak flows has become earlier, and there has been an overall reduction in summer flows (high confidence). (p. 432)

Dibike *et al.* (2019) noted the following projected changes in the frequency of peak flows along the Athabasca River:

- Flows originating from alpine dominated cold region watersheds typically experience extended winter low flows followed by spring snowmelt and summer rainfall driven high flows. In a warmer climate, there will be a temperature-induced shift in precipitation from snowfall towards rain along with changes in precipitation intensity and snowmelt timing, resulting in alterations in the frequency and magnitude of peak flow events.
- Hydrological model projections show an overall increase in mean annual streamflow in the watershed and a corresponding shift in the freshet timing to an earlier period. The river flow is projected to experience increases during the winter and spring seasons and decreases during the summer and early fall seasons, with an overall projected increase in peak flow, especially for low frequency events.
- Both stationary and non-stationary methods of peak flow analysis, performed at multiple points along the Athabasca River, show that projected changes in the 100-year peak flow event for the high emissions scenario by the 2080s range between 4% and 33% depending on the driving climate models and the statistical method of analysis. A closer examination of the results also reveals that the sensitivity of projected changes in peak flows to the statistical method of frequency analysis is relatively small compared to that resulting from inter-climate model variability.

Attachment D

Selected Future Climate Change Model Figures for Paddle Prairie

DRAFT

SSPs are scenarios (Figure D-1) of projected socioeconomic global changes up to the year 2100 and are used to derive greenhouse gas emissions scenarios with different climate policies as (Lee *et al.*, 2021; Meinshausen *et al.*, 2020), where they can be described simply as:

- SSP1 Sustainability (Taking the Green Road)
- SSP2 Middle of the Road
- SSP3 Regional Rivalry (A Rocky Road)
- SSP4 Inequality (A Road Divided)
- SSP5 Fossil-Fueled Development (Taking the Highway)

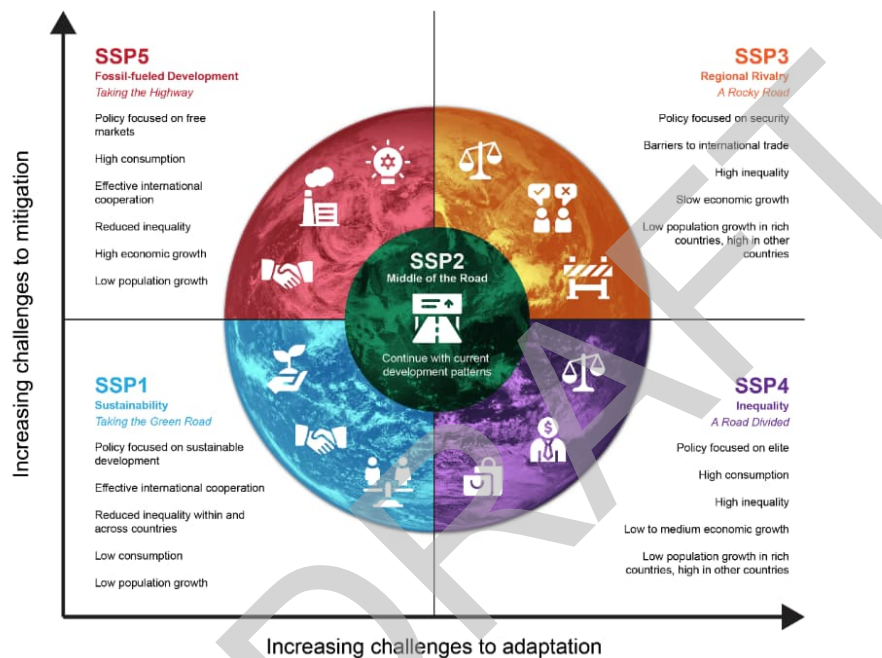


Figure D-1 The Five Families of SSP-Based Scenarios used in CMIP6

Source: <https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/>

From these five families, four individual emission scenarios for families 1, 2, 3 and 5 based on radiative forcing (in units of tenths of watts) are used, and are defined as:

- SSP126: this scenario mimics the RCP2.6 scenario with an anticipated radiative forcing change of 2.6 W/m² by the year 2100 using a 2°C target for development that assumes climate measures are taken.
- SSP245: this is an update to the RCP4.5 emission scenario that uses a radiative forcing of 4.5 W/m² by the year 2100 that represents the medium pathway of future greenhouse gas emissions that assumes climate protections measures are taken.
- SSP370: this is a newly introduced family that came after the RCP scenarios with the intent to close the gap between RCP6.0 and RCP8.5 and has a radiative forcing of 7 W/m² by 2100.
- SSP585: this scenario represents the upper bound of the GCM outputs with a radiative forcing of 8.5 W/m² by the year 2100 and is an update to the RCP8.5 from CMIP5 that now encapsulates socioeconomic conditions.

The figures below show the shared socioeconomic pathways (Figure D-2) and anthropogenic radiative forcing in W/m^2 (Figure D-3) from the CMIP6 scenarios (from O'Neill *et al.*, 2016). Figures D-4 to D-11 show temperature and precipitation under different shared socioeconomic pathways (SSPs) for various time periods.

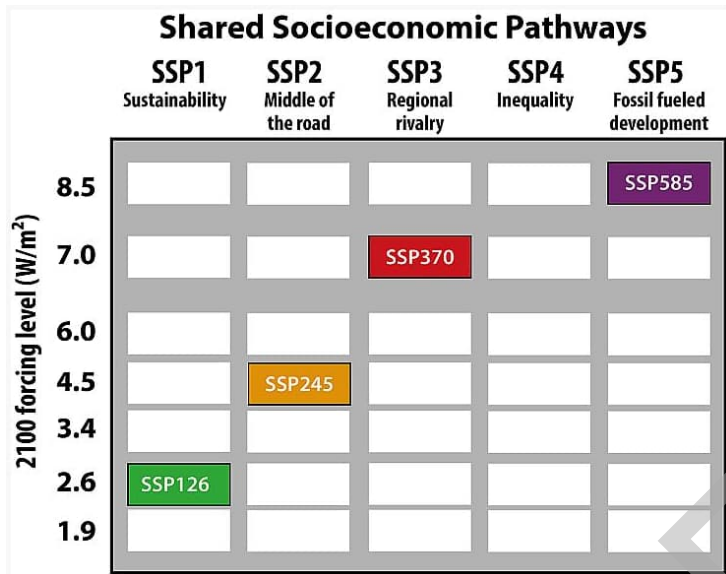


Figure D-2 Shared Socioeconomic Pathways by Year 2100 Forcing Level (W/m^2)

Source: O'Neill *et al.*, 2016.

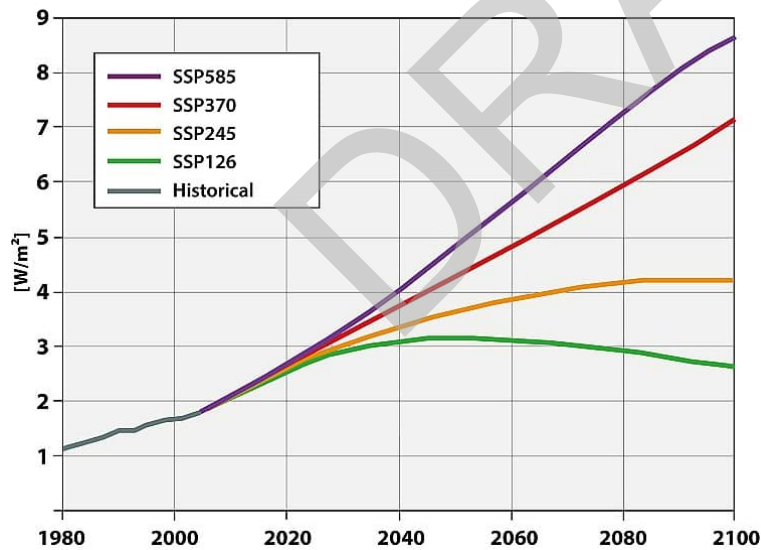


Figure D-3 CMIP6 Scenarios - Anthropogenic Radiative Forcing (W/m^2)

Source: O'Neill *et al.*, 2016.

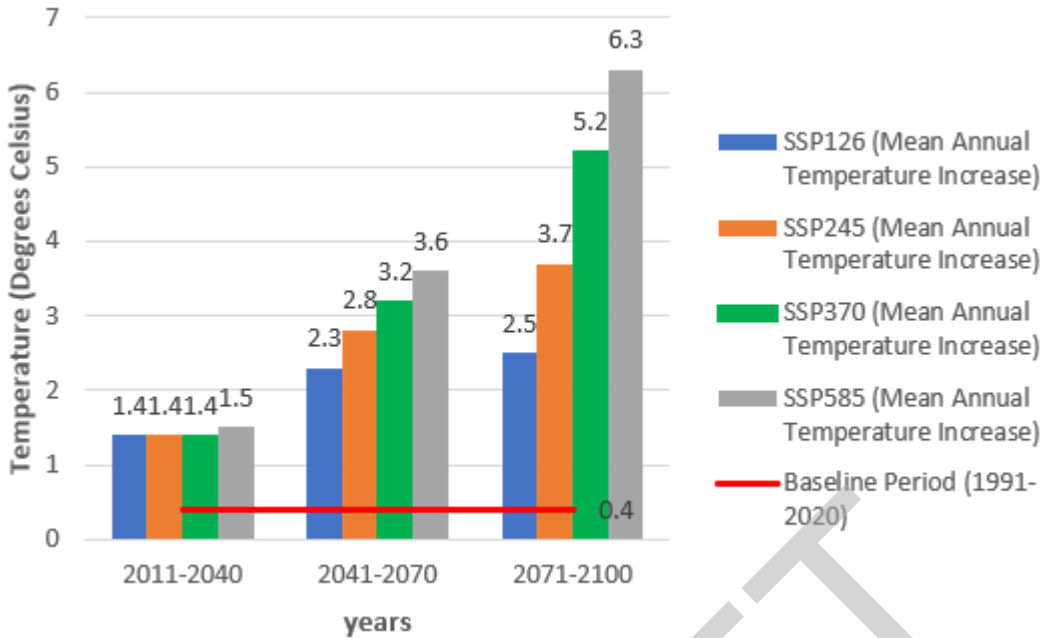


Figure D-4: Mean Annual Temperature Under Different Shared Socioeconomic Pathways (SSPs) for Various Time Periods

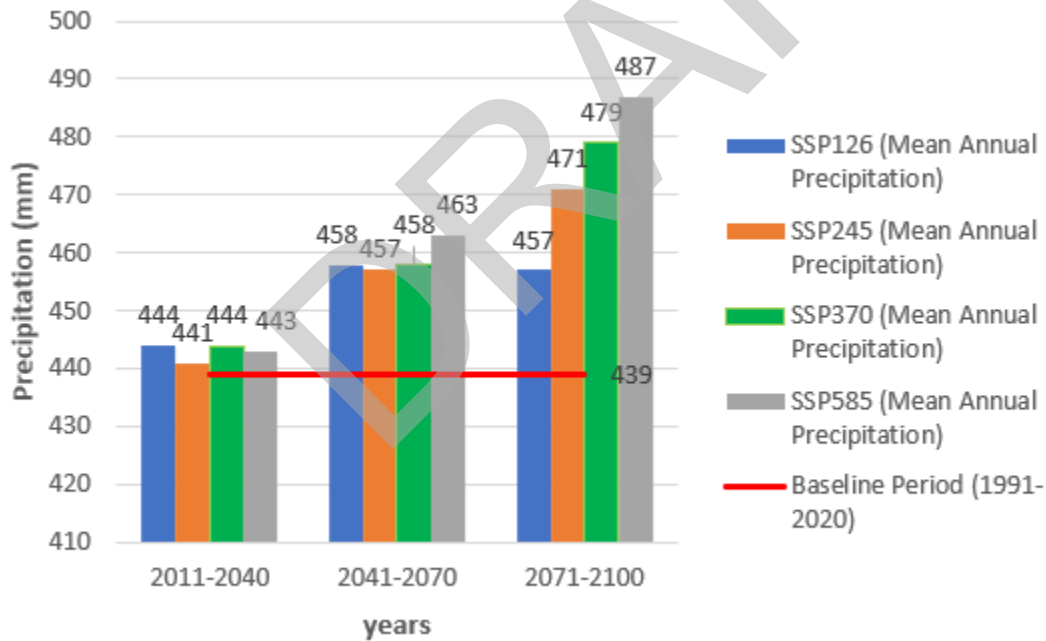


Figure D-5: Mean Annual Precipitation Under Different Shared Socioeconomic Pathways (SSPs) for Various Time Periods

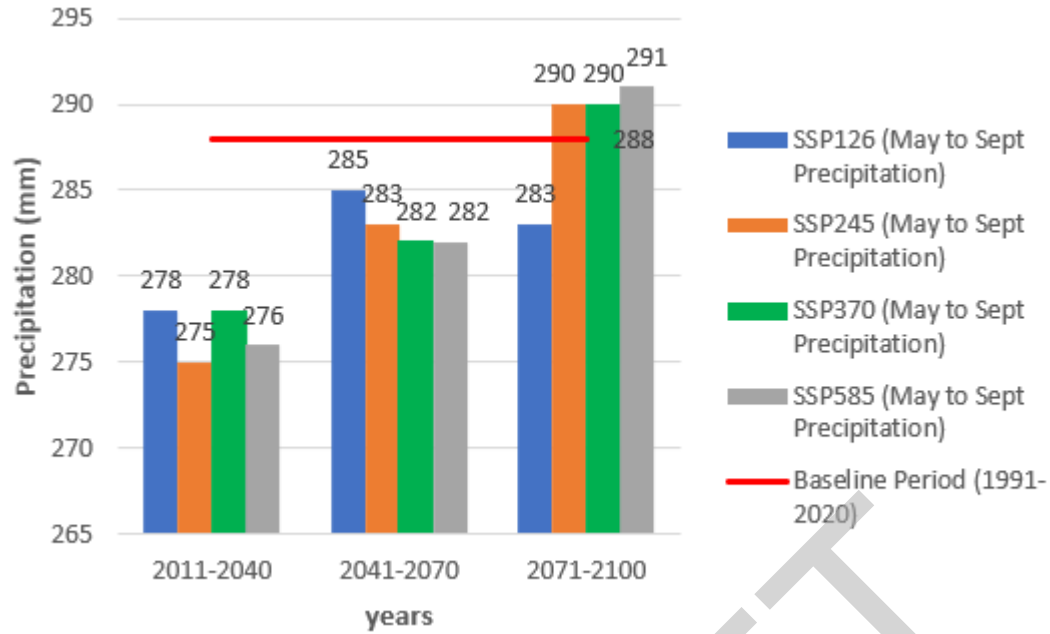


Figure D-6: May to September Precipitation Under Different Shared Socioeconomic Pathways (SSPs) for Various Time Periods

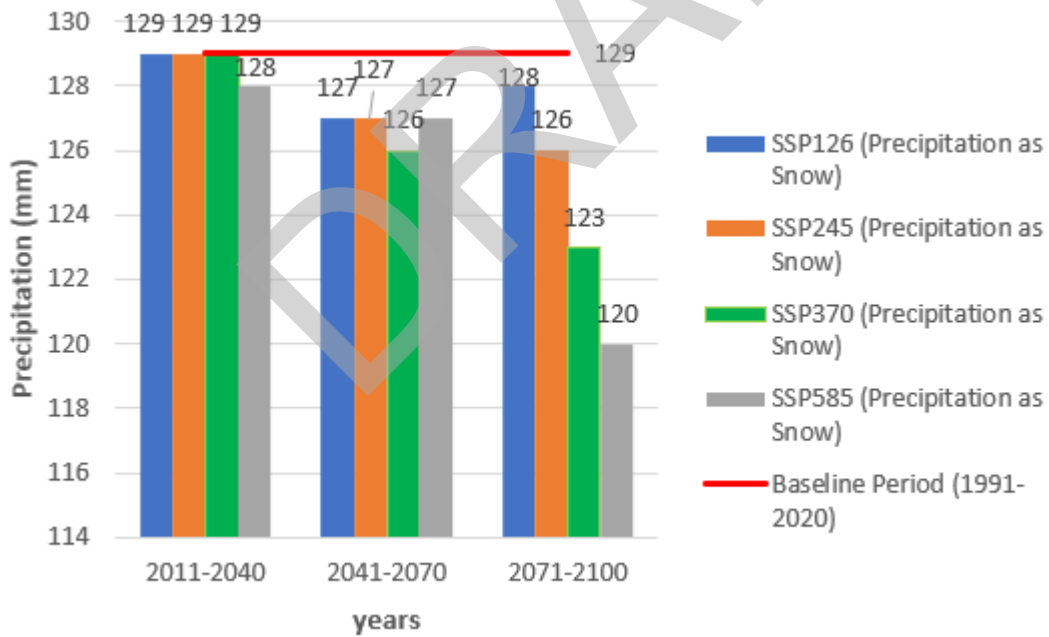


Figure D-7: Precipitation as Snow Under Different Shared Socioeconomic Pathways (SSPs) for Various Time Periods

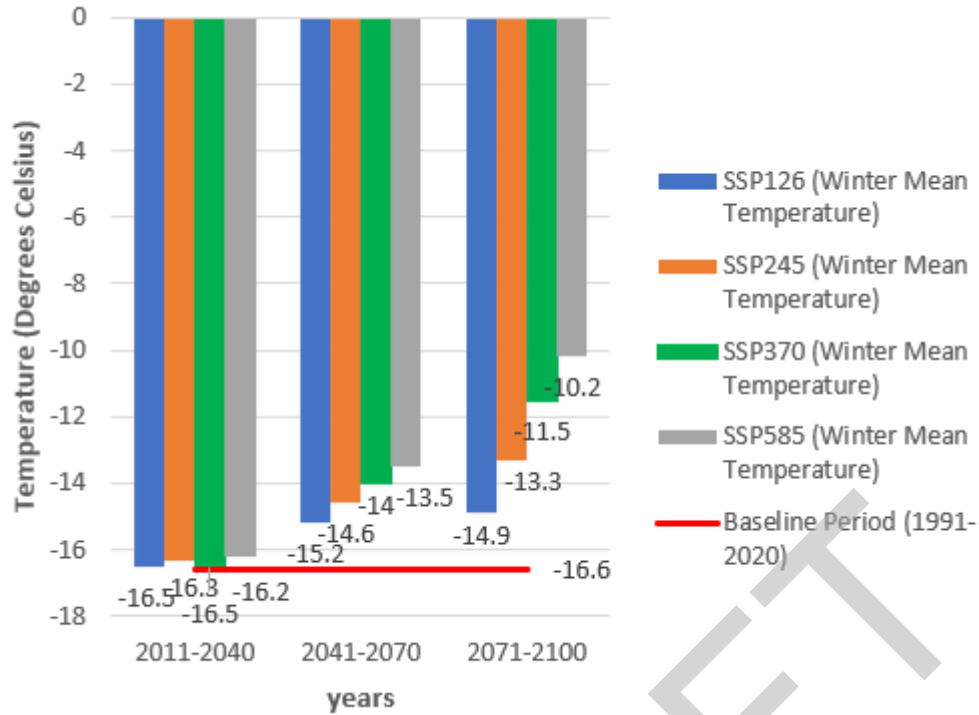


Figure D-8 Winter Mean Temperature (DJF) Under Different Shared Socioeconomic Pathways (SSPs) for Various Time Periods

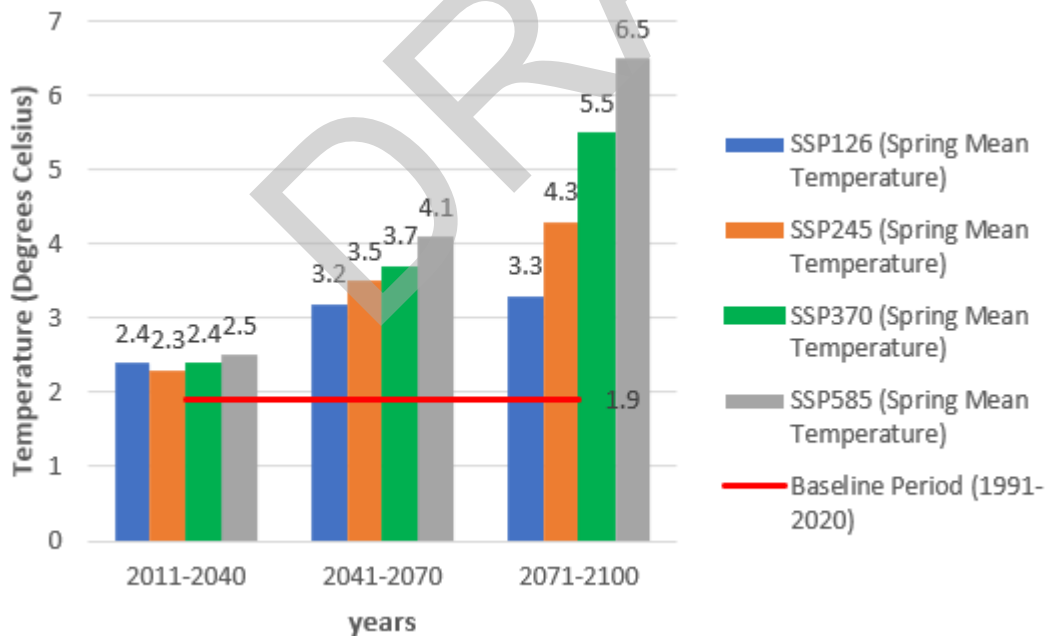


Figure D-9: Spring Mean Temperature (MAM) Under Different Shared Socioeconomic Pathways (SSPs) for Various Time Periods

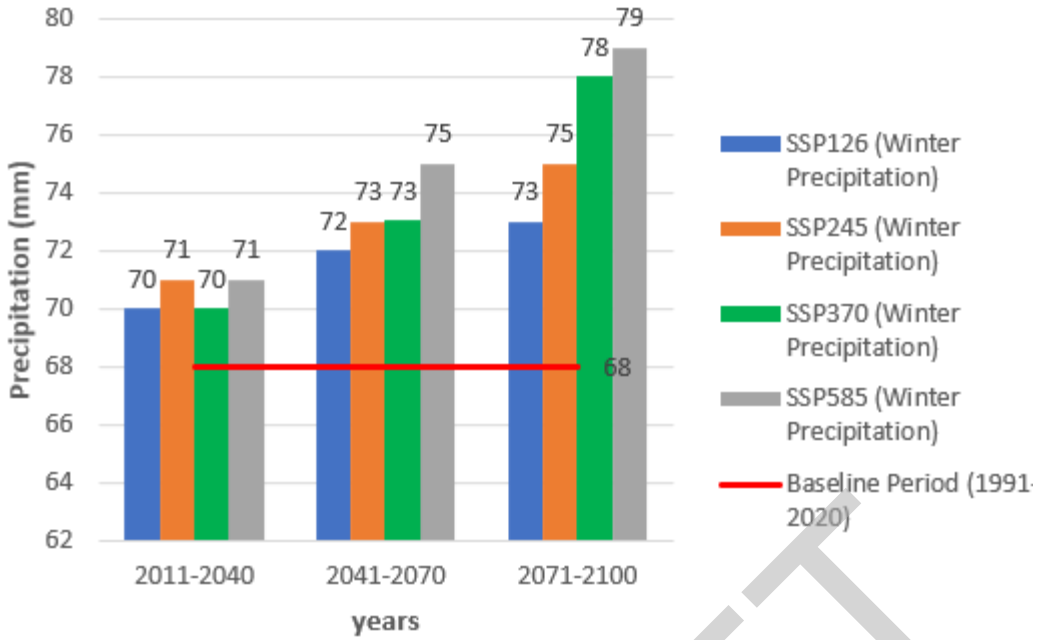


Figure D-10 Winter Precipitation (DJF) Under Different Shared Socioeconomic Pathways (SSPs) for Various Time Periods

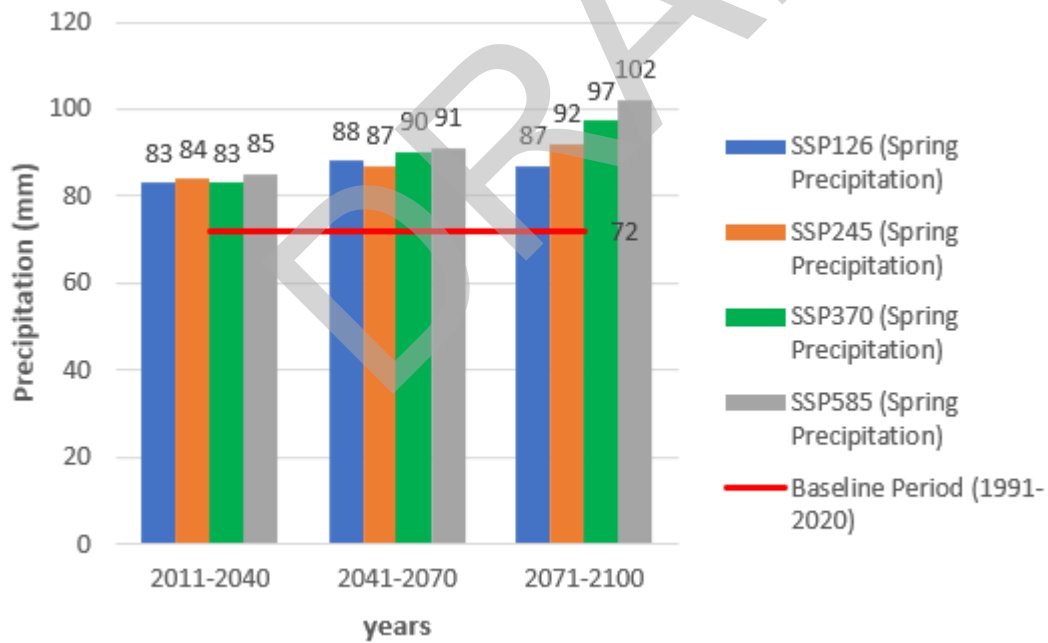


Figure D-11 Spring Precipitation (MAM) Under Different Shared Socioeconomic Pathways (SSPs) for Various Time Periods



DRAFT

APPENDIX E

Open Water Flood Profiles

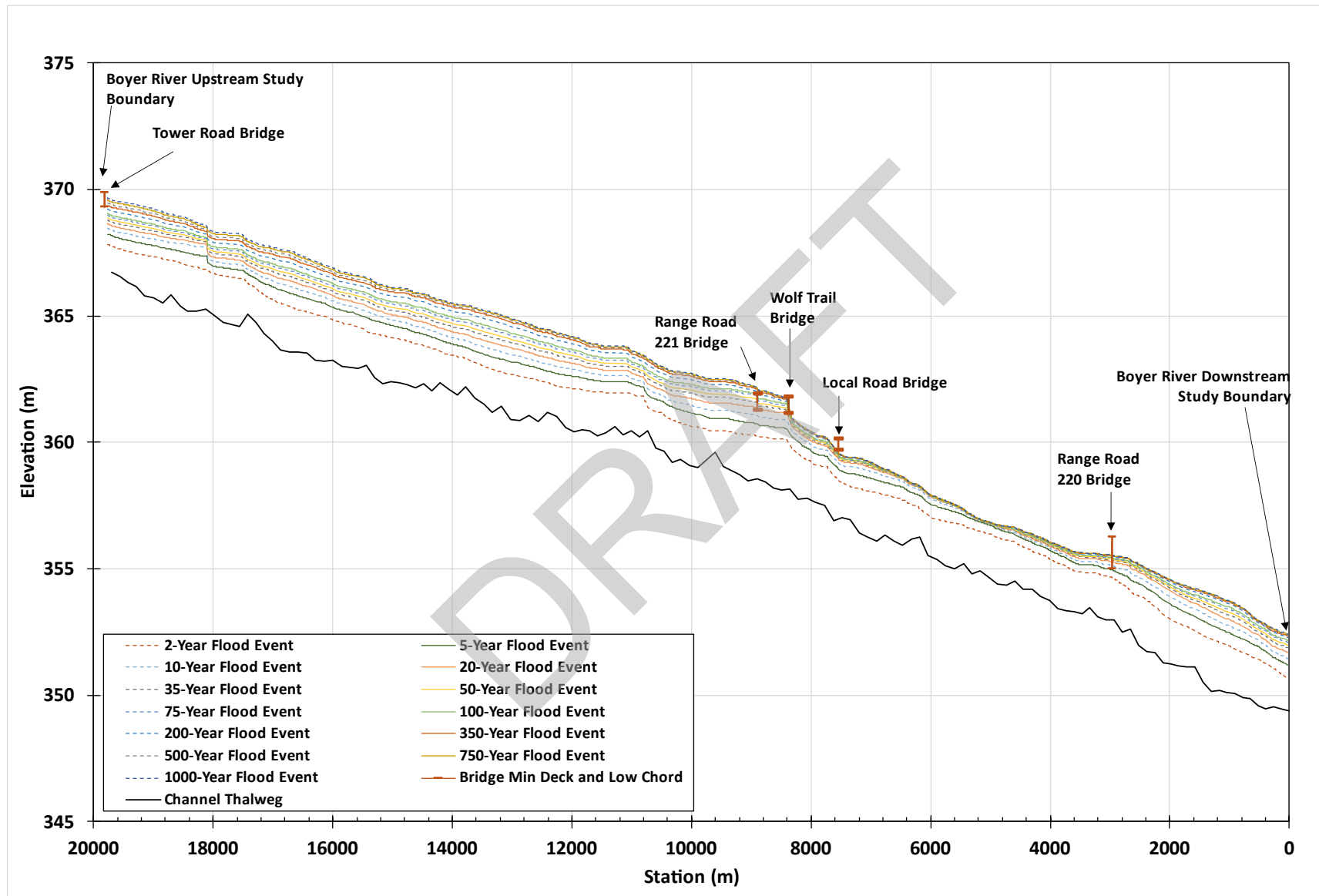


Figure E-1: Simulated Water Surface Profile along the Boyer River Study Reach

Table E-1: Boyer River Flood Profiles

River Station (m)	Channel Thalweg (m)	Simulated Water Level (m)												
		2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
19850	366.65	367.83	368.25	368.47	368.65	368.80	368.89	368.99	369.06	369.23	369.38	369.47	369.58	369.66
19350	366.22	367.52	367.96	368.20	368.39	368.54	368.63	368.73	368.80	368.99	369.14	369.24	369.35	369.43
18850	365.51	367.28	367.71	367.97	368.15	368.28	368.37	368.47	368.54	368.71	368.85	368.95	369.05	369.13
18350	365.14	366.96	367.45	367.78	367.93	368.04	368.12	368.20	368.26	368.41	368.54	368.63	368.72	368.79
17850	364.77	366.59	366.92	367.11	367.29	367.43	367.52	367.62	367.70	367.88	368.02	368.12	368.22	368.30
17350	364.85	366.19	366.56	366.76	366.93	367.08	367.17	367.27	367.34	367.53	367.68	367.77	367.88	367.95
16850	363.63	365.49	366.02	366.26	366.47	366.64	366.75	366.87	366.96	367.17	367.34	367.45	367.56	367.63
16350	363.45	365.14	365.67	365.94	366.15	366.31	366.42	366.54	366.62	366.83	367.00	367.10	367.20	367.27
15850	363.01	364.74	365.23	365.47	365.67	365.84	365.94	366.06	366.15	366.36	366.52	366.60	366.69	366.76
15350	362.58	364.32	364.85	365.10	365.32	365.49	365.60	365.73	365.82	366.05	366.21	366.30	366.39	366.45
14850	362.38	364.07	364.54	364.77	364.98	365.17	365.28	365.42	365.52	365.75	365.92	365.99	366.06	366.10
14350	362.06	363.73	364.17	364.42	364.65	364.83	364.96	365.10	365.20	365.44	365.60	365.67	365.73	365.76
13850	362.02	363.37	363.81	364.07	364.31	364.51	364.64	364.79	364.89	365.14	365.30	365.37	365.42	365.45
13350	361.14	362.94	363.43	363.72	363.98	364.20	364.33	364.49	364.60	364.86	365.03	365.10	365.16	365.18
12850	360.91	362.62	363.11	363.39	363.65	363.85	363.98	364.13	364.23	364.48	364.65	364.72	364.77	364.80
12350	361.20	362.33	362.80	363.08	363.33	363.53	363.66	363.80	363.90	364.14	364.30	364.37	364.42	364.45
11850	360.51	362.10	362.58	362.85	363.08	363.27	363.39	363.52	363.61	363.83	363.98	364.04	364.09	364.12
11350	360.55	361.97	362.41	362.65	362.86	363.03	363.14	363.26	363.34	363.55	363.69	363.75	363.79	363.82
10850	360.27	361.83	362.21	362.42	362.61	362.76	362.86	362.97	363.05	363.23	363.37	363.42	363.46	363.49
10350	359.33	360.93	361.44	361.67	361.89	362.08	362.20	362.33	362.41	362.60	362.73	362.79	362.83	362.86
9850	359.09	360.60	361.09	361.39	361.66	361.87	362.00	362.14	362.22	362.39	362.51	362.57	362.61	362.63
9350	358.89	360.41	360.93	361.25	361.54	361.76	361.89	362.02	362.11	362.26	362.37	362.42	362.46	362.48
8850	358.38	360.23	360.68	361.00	361.28	361.44	361.53	361.64	361.72	361.86	361.97	362.01	362.04	362.06
8350	358.18	359.77	360.23	360.45	360.61	360.68	360.72	360.76	360.77	360.87	360.91	360.92	360.93	360.94
7850	357.49	359.08	359.51	359.75	359.92	359.99	360.03	360.07	360.10	360.19	360.23	360.24	360.26	360.27

Table E-1: Boyer River Flood Profiles

River Station (m)	Channel Thalweg (m)	Simulated Water Level (m)												
		2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
7350	356.96	358.26	358.77	359.04	359.19	359.24	359.27	359.30	359.32	359.38	359.40	359.41	359.42	359.43
6850	356.11	357.98	358.48	358.74	358.87	358.91	358.93	358.95	358.96	359.00	359.02	359.02	359.03	359.03
6350	356.15	357.57	358.05	358.28	358.37	358.39	358.40	358.41	358.42	358.44	358.44	358.45	358.45	358.45
5850	355.29	356.93	357.43	357.63	357.71	357.73	357.73	357.74	357.75	357.77	357.77	357.78	357.78	357.78
5350	355.19	356.62	357.01	357.11	357.15	357.16	357.16	357.17	357.17	357.18	357.19	357.19	357.19	357.19
4850	354.40	356.23	356.57	356.62	356.66	356.67	356.68	356.69	356.70	356.72	356.73	356.73	356.74	356.74
4350	354.26	355.78	356.10	356.19	356.26	356.29	356.32	356.34	356.35	356.39	356.41	356.41	356.42	356.42
3850	353.40	355.21	355.55	355.66	355.74	355.79	355.81	355.84	355.86	355.90	355.91	355.92	355.93	355.93
3350	353.44	354.85	355.15	355.28	355.40	355.46	355.49	355.52	355.54	355.59	355.61	355.61	355.62	355.62
2850	352.69	354.48	354.83	355.04	355.21	355.29	355.33	355.36	355.39	355.44	355.47	355.48	355.49	355.49
2350	351.89	353.71	354.18	354.44	354.64	354.72	354.77	354.81	354.84	354.91	354.95	354.96	354.97	354.98
1850	351.14	352.82	353.40	353.70	353.92	354.03	354.09	354.15	354.20	354.30	354.36	354.39	354.40	354.42
1350	350.26	352.26	352.83	353.12	353.37	353.53	353.62	353.72	353.78	353.92	353.99	354.01	354.03	354.04
850	349.83	351.76	352.30	352.58	352.83	353.01	353.11	353.23	353.31	353.45	353.51	353.53	353.55	353.56
350	349.54	351.21	351.67	351.91	352.11	352.27	352.36	352.46	352.53	352.63	352.68	352.70	352.73	352.74



DRAFT

APPENDIX F

Open Water Sensitivity Analysis

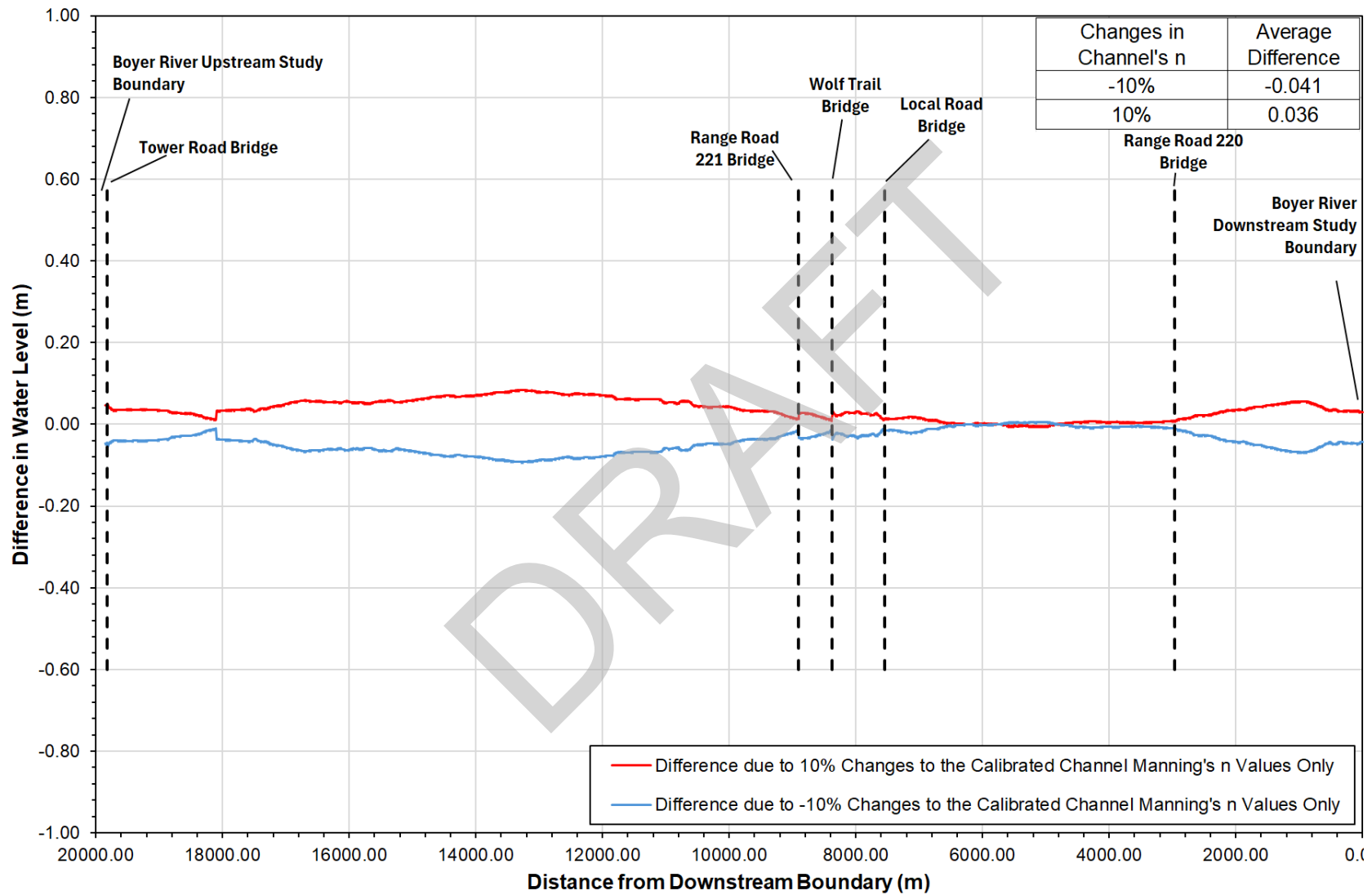


Figure F-1: Sensitivity of Simulated Water Level along the Boyer River Study Reach for the 100-Year Flood Event (Channel Manning's n Only)

Paddle Prairie Flood Study
Main Report

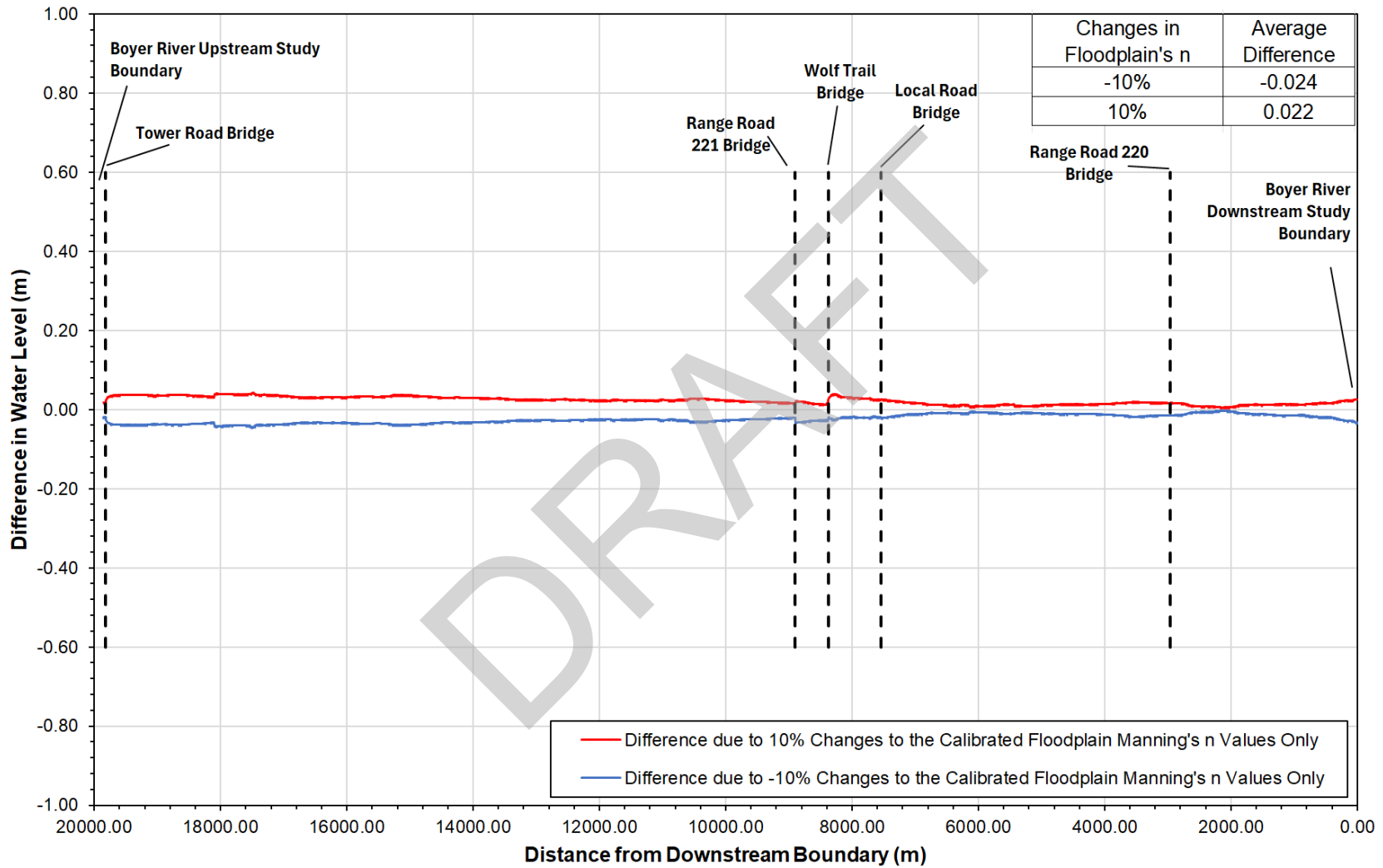


Figure F-2: Sensitivity of Simulated Water Level along the Boyer River Study Reach for the 100-Year Flood Event (Floodplain Manning's n Only)

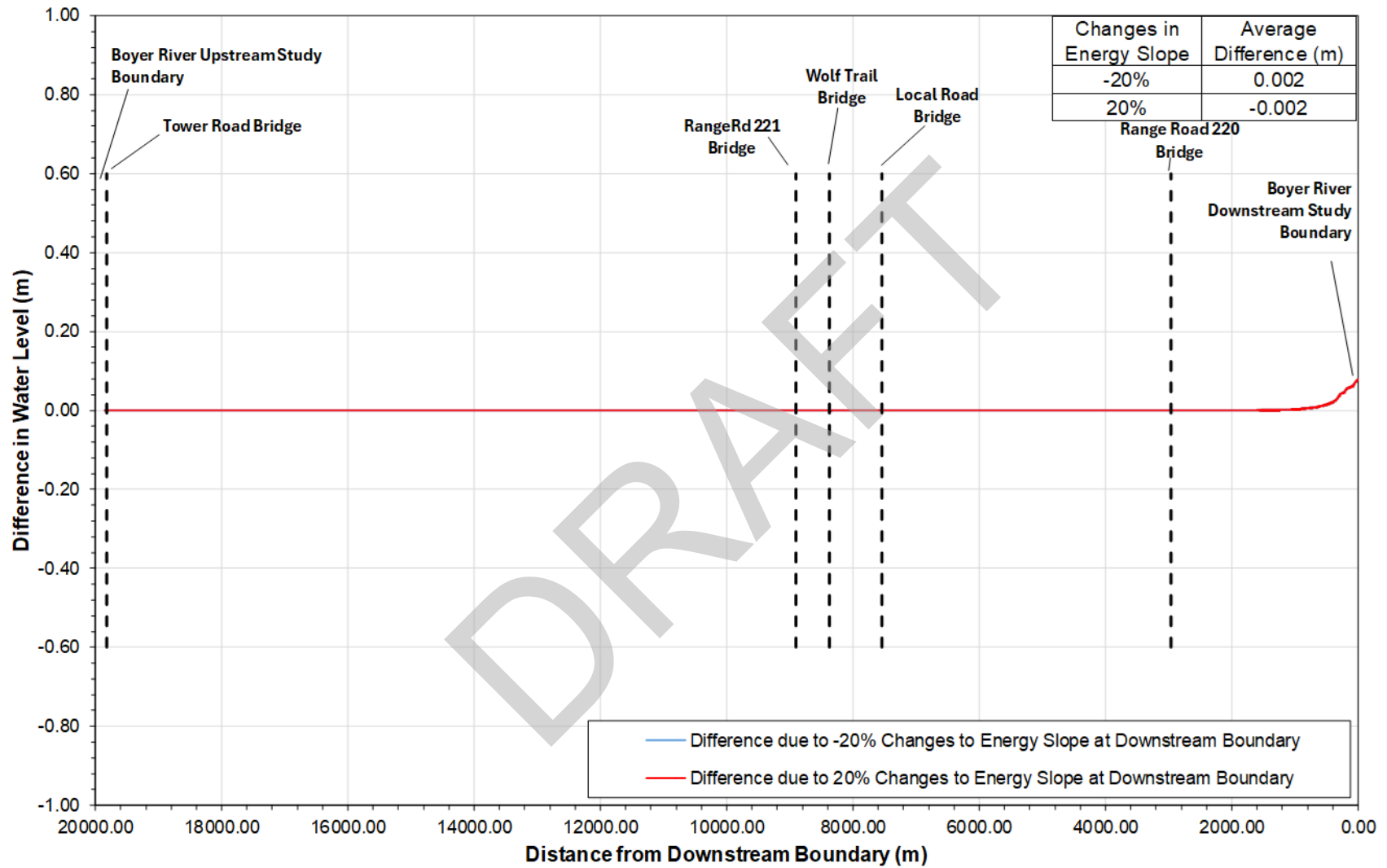


Figure F-3: Sensitivity of Simulated Water Level along the Boyer River Study Reach for the 100-Year Flood Event (Downstream Boundary)

APPENDIX G

Open Water Inundation Maps

TO BE PROVIDED SEPARATELY IN THE MAP LIBRARY

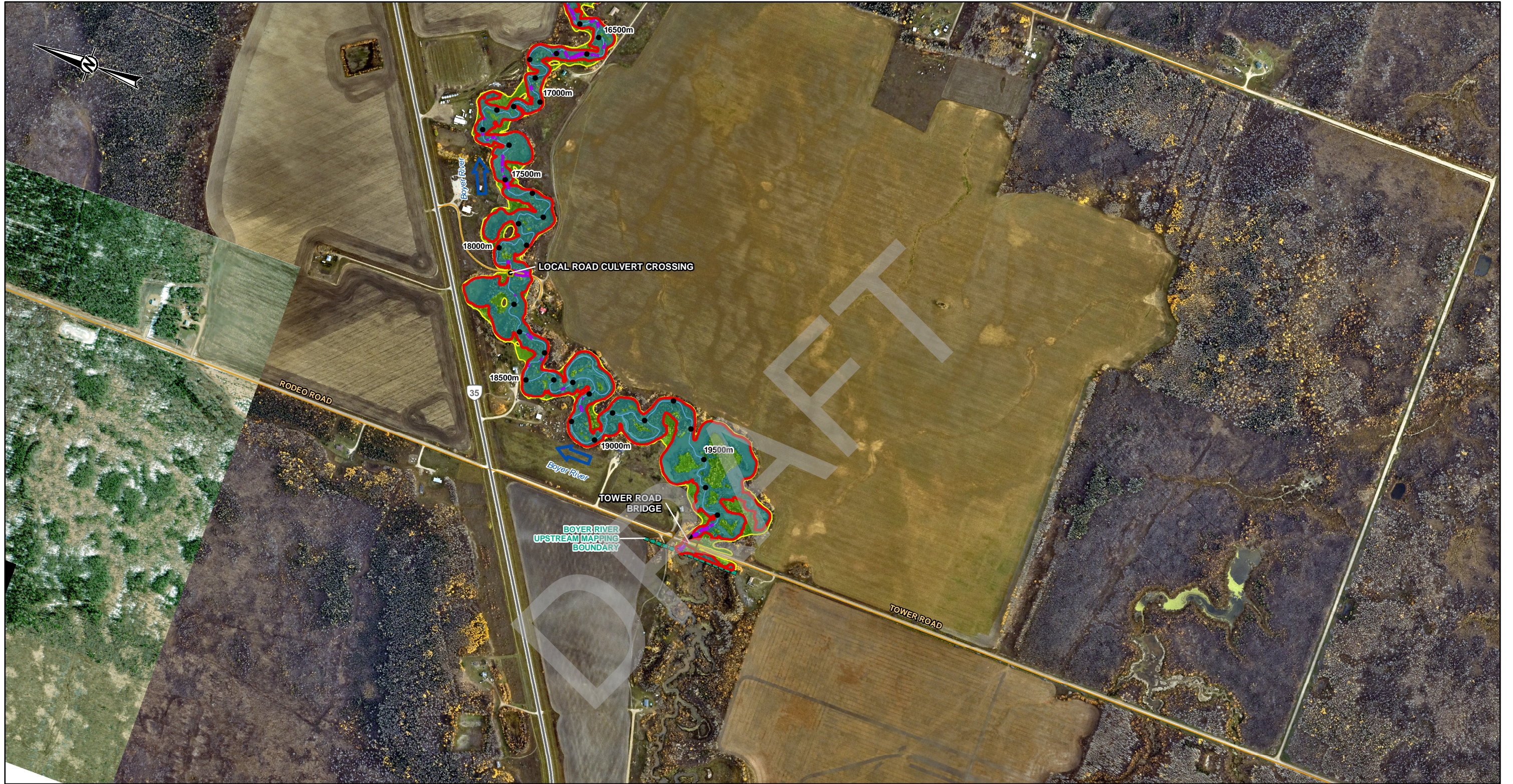
DRAFT



DRAFT

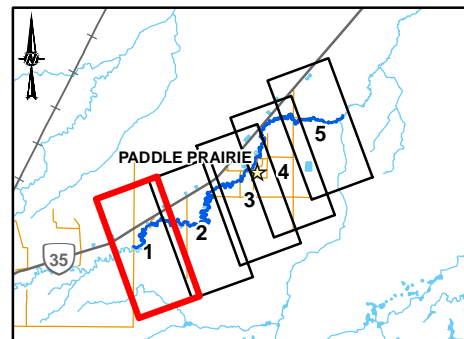
APPENDIX H

**Floodway Criteria Maps and Flood
Hazard Maps**



LEGEND

- PROFILE STATION
 - ▬ MAPPING BOUNDARY
 - ➔ FLOW DIRECTION
 - PRIMARY HIGHWAY
 - SECONDARY ROAD
 - LOCAL ROAD
 - CHANNEL CENTRELINE
 - ★ HYDROMETRIC GAUGING STATION
- | | |
|--|---|
| <p>HYDRAULIC STRUCTURES</p> <ul style="list-style-type: none"> ◻ CULVERT ▬ BRIDGE | <ul style="list-style-type: none"> — PROPOSED FLOODWAY BOUNDARY — DEPTH ≥ 1 M — 100-YEAR DESIGN FLOOD EXTENT — VELOCITY ≥ 1 M/S <p>DESIGN DISCHARGE
BOYER RIVER = 37.1 M³/S</p> |
|--|---|



CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



CONSULTANT



YYYY-MM-DD	2025-03-21
DESIGNED	LH
PREPARED	BS
REVIEWED	AL
APPROVED	LH

REFERENCE(S)

ROADS AND WATERBODIES OBTAINED FROM GEOGRATIS. © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED OR ALTALIS LTD. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA. OTHER IMAGERY COPYRIGHT © 20170409 ESRI AND ITS LICENSORS. SOURCE: MAXAR. USED UNDER LICENSE. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

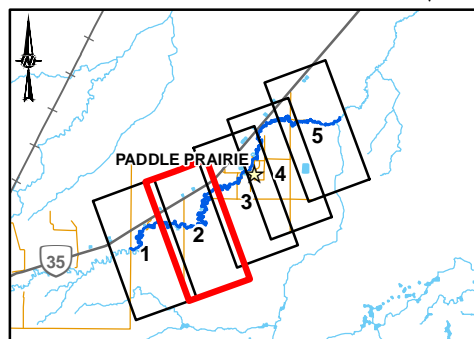
PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
FLOODWAY CRITERIA MAP

PROJECT NO.	CONTROL	REV.	FIGURE
23592570	5000	0	1 OF 5



- LEGEND**
- PROFILE STATION
 - MAPPING BOUNDARY
 - ➔ FLOW DIRECTION
 - PRIMARY HIGHWAY
 - SECONDARY ROAD
 - LOCAL ROAD
 - CHANNEL CENTRELINE
 - ★ HYDROMETRIC GAUGING STATION
- HYDRAULIC STRUCTURES**
- ◻ CULVERT
 - ▬ BRIDGE
- PROPOSED FLOODWAY BOUNDARY
 - DEPTH ≥ 1 M
 - 100-YEAR DESIGN FLOOD EXTENT
 - VELOCITY ≥ 1 M/S
- DESIGN DISCHARGE
BOYER RIVER = 37.1 M³/S



CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



CONSULTANT

YYYY-MM-DD	2025-03-21
DESIGNED	LH
PREPARED	BS
REVIEWED	AL
APPROVED	LH

REFERENCE(S)
ROADS AND WATERBODIES OBTAINED FROM GEOGRATIS. © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED OR ALTALIS LTD. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA. OTHER IMAGERY COPYRIGHT © 20170409 ESRI AND ITS LICENSORS. SOURCE: MAXAR. USED UNDER LICENSE. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

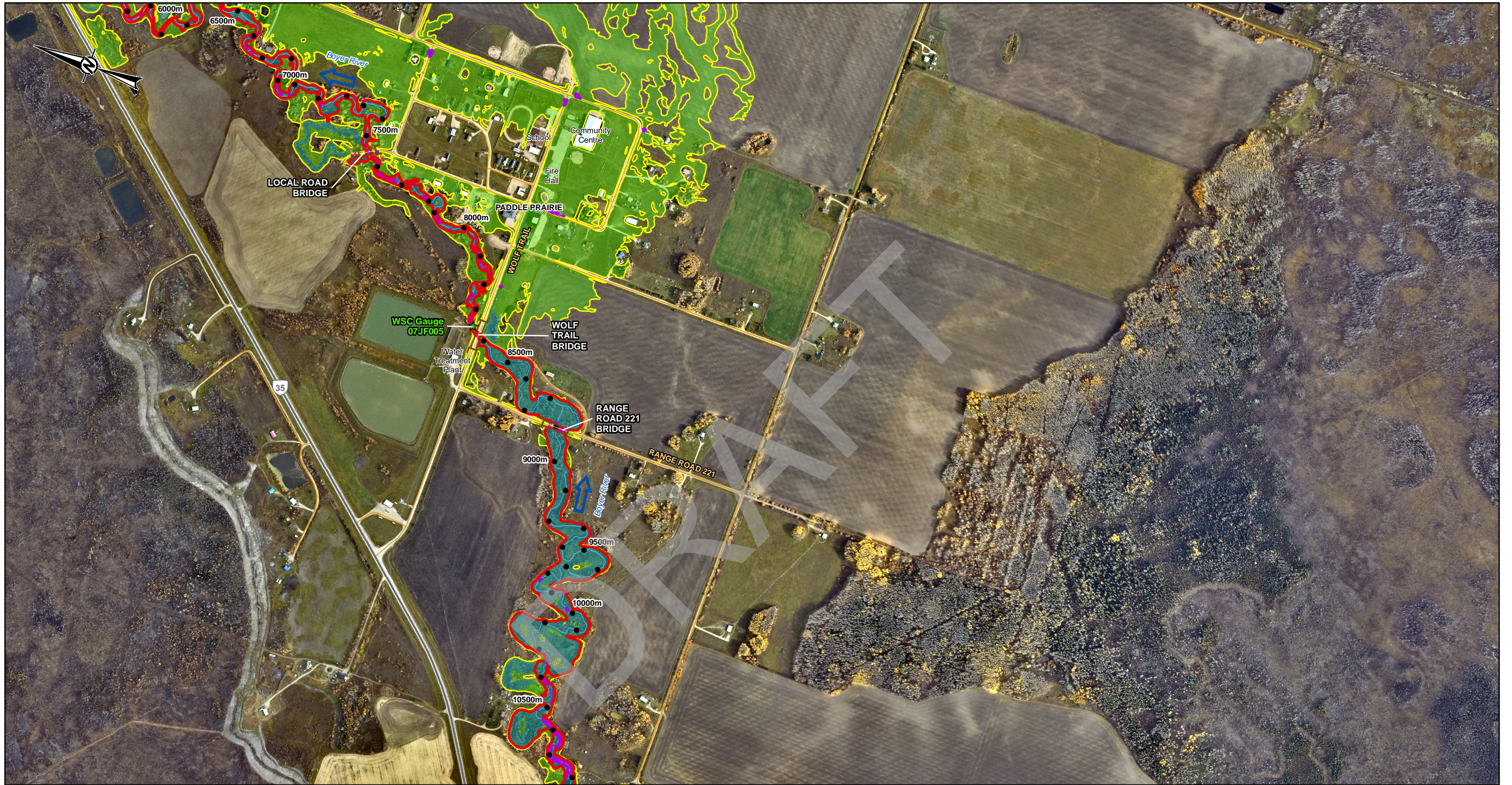
PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
FLOODWAY CRITERIA MAP

PROJECT NO.	CONTROL	REV.	FIGURE
23592570	5000	0	2 OF 5

I:\CLIENTS\GOVERNMENT_OF_ALBERTA\23592570_Paddle_Prairie\FloodwayCriteriaMap\Hydro\05_Design_Flood_Hazard_Mapping\23592570_FloodwayCriteria_Rev0.mxd PRINTED ON: 2025-03-21 AT: 2:15:49 PM

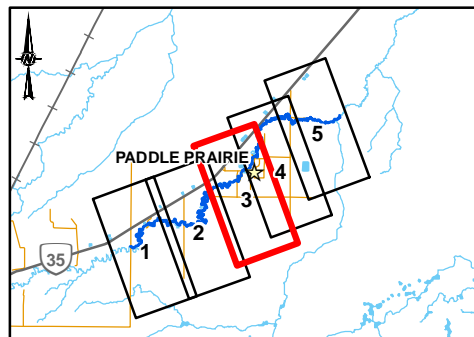
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B 26mm



LEGEND

● PROFILE STATION	HYDRAULIC STRUCTURES	— PROPOSED FLOODWAY BOUNDARY
▬ MAPPING BOUNDARY	◻ CULVERT	■ DEPTH ≥ 1 M
➔ FLOW DIRECTION	▬ BRIDGE	■ 100-YEAR DESIGN FLOOD EXTENT
— PRIMARY HIGHWAY		■ VELOCITY ≥ 1 M/S
— SECONDARY ROAD		
— LOCAL ROAD		
— CHANNEL CENTRELINE		
★ HYDROMETRIC GAUGING STATION		

DESIGN DISCHARGE
BOYER RIVER = 37.1 M³/S



CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



CONSULTANT

YYYY-MM-DD	2025-03-21
DESIGNED	LH
PREPARED	BS
REVIEWED	AL
APPROVED	LH

REFERENCE(S)
ROADS AND WATERBODIES OBTAINED FROM GEOGRATIS. © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED OR ALTALIS LTD. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA. OTHER IMAGERY COPYRIGHT © 20170409 ESRI AND ITS LICENSORS. SOURCE: MAXAR. USED UNDER LICENSE. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

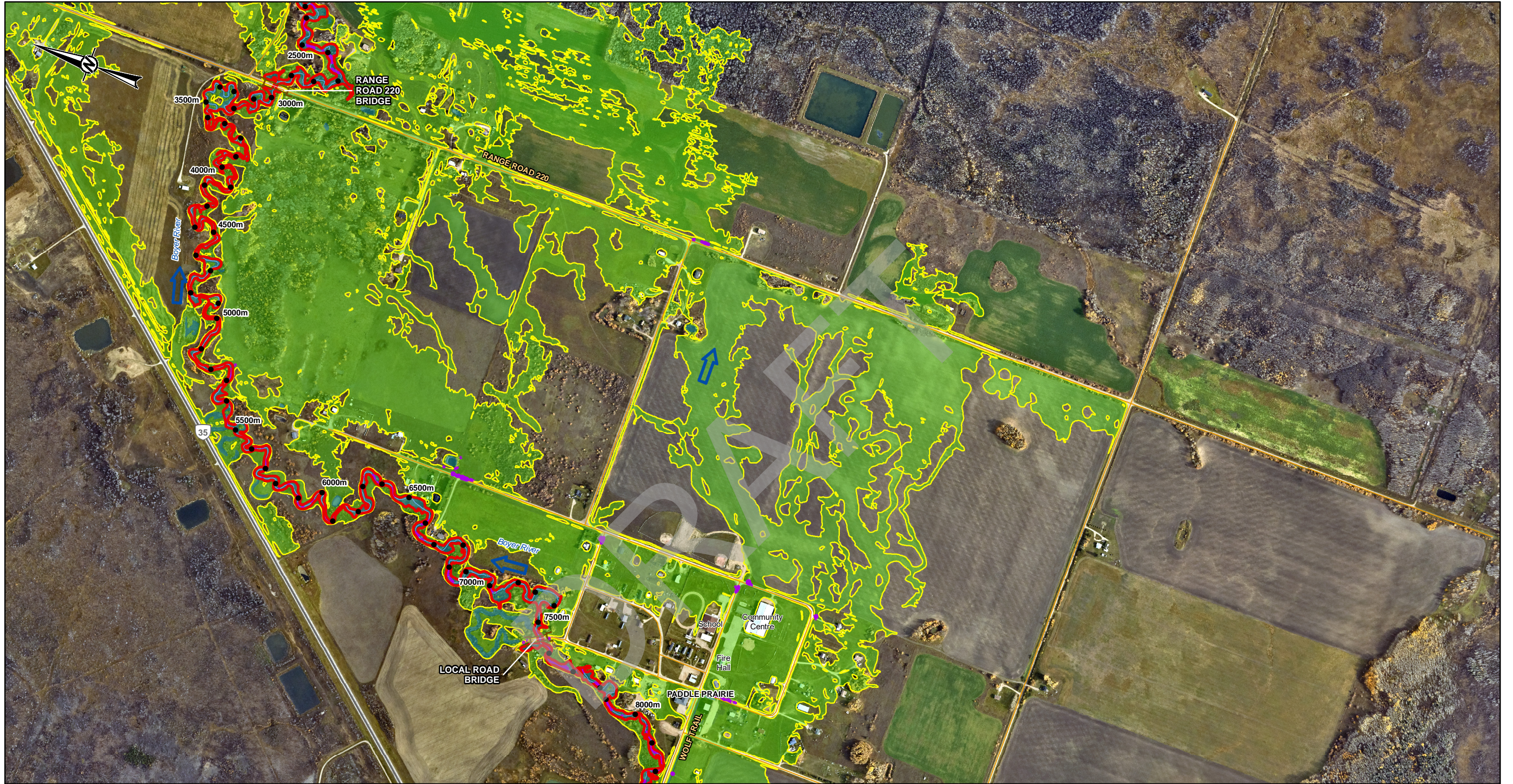
PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
FLOODWAY CRITERIA MAP

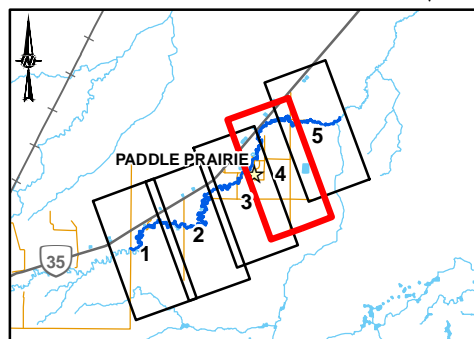
PROJECT NO.	CONTROL	REV.	FIGURE
23592570	5000	0	3 OF 5

C:\CLIENTS\GOVERNMENT_OF_ALBERTA\23592570_Paddle_Prairie\FloodwayCriteriaMap\Hydrology\05_Design_Flood_Hazard_Mapping\23592570_FloodwayCriteria_Rev0.mxd PRINTED ON: 2025-03-21 AT: 2:16:27 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B 26mm



- LEGEND**
- PROFILE STATION
 - ▬ MAPPING BOUNDARY
 - ➔ FLOW DIRECTION
 - PRIMARY HIGHWAY
 - SECONDARY ROAD
 - LOCAL ROAD
 - CHANNEL CENTRELINE
 - ★ HYDROMETRIC GAUGING STATION
- HYDRAULIC STRUCTURES**
- ◻ CULVERT
 - ▬ BRIDGE
- PROPOSED FLOODWAY BOUNDARY
- DEPTH ≥ 1 M
 - 100-YEAR DESIGN FLOOD EXTENT
 - VELOCITY ≥ 1 M/S
- DESIGN DISCHARGE**
BOYER RIVER = 37.1 M³/S



CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



CONSULTANT

YYYY-MM-DD	2025-03-21
DESIGNED	LH
PREPARED	BS
REVIEWED	AL
APPROVED	LH

REFERENCE(S)
ROADS AND WATERBODIES OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED OR ALTALIS LTD. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA. OTHER IMAGERY COPYRIGHT © 20170409 ESRI AND ITS LICENSORS. SOURCE: MAXAR. USED UNDER LICENSE. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

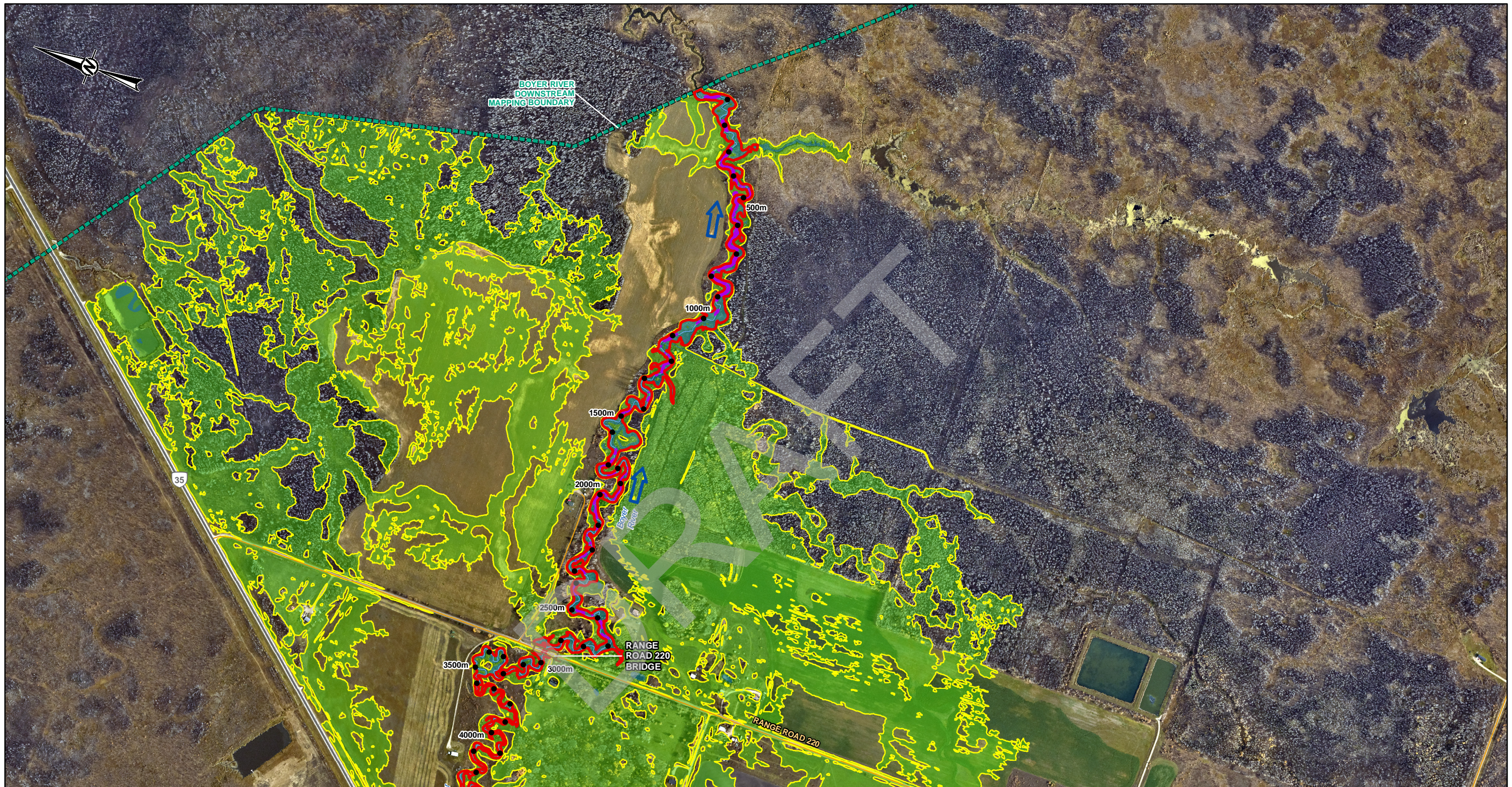
PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
FLOODWAY CRITERIA MAP

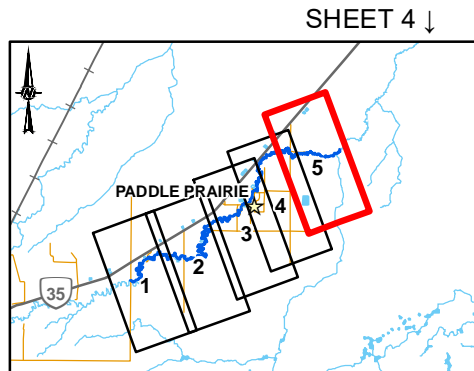
PROJECT NO.	CONTROL	REV.	FIGURE
23592570	5000	0	4 OF 5

I:\CLIENTS\GOVERNMENT_OF_ALBERTA\23592570_Paddle_Prairie\FloodwayCriteriaMap\05_Design_Flood_Hazard_Mapping\23592570_FloodwayCriteria_Rev0.mxd PRINTED ON: 2025-03-21 AT: 2:17:05 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B



- LEGEND**
- PROFILE STATION
 - ▬ MAPPING BOUNDARY
 - ➔ FLOW DIRECTION
 - PRIMARY HIGHWAY
 - SECONDARY ROAD
 - LOCAL ROAD
 - CHANNEL CENTRELINE
 - ★ HYDROMETRIC GAUGING STATION
- HYDRAULIC STRUCTURES**
- ◻ CULVERT
 - ▬ BRIDGE
- PROPOSED FLOODWAY BOUNDARY
 - DEPTH ≥ 1 M
 - 100-YEAR DESIGN FLOOD EXTENT
 - VELOCITY ≥ 1 M/S
- DESIGN DISCHARGE
BOYER RIVER = 37.1 M³/S



CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



CONSULTANT

YYYY-MM-DD	2025-03-21
DESIGNED	LH
PREPARED	BS
REVIEWED	AL
APPROVED	LH

REFERENCE(S)
ROADS AND WATERBODIES OBTAINED FROM GEOGRATIS. © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED OR ALTALIS LTD. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA. OTHER IMAGERY COPYRIGHT © 20170409 ESRI AND ITS LICENSORS. SOURCE: MAXAR. USED UNDER LICENSE. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

PROJECT
PADDLE PRAIRIE FLOOD STUDY

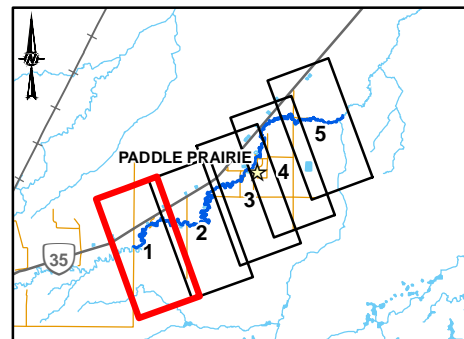
TITLE
FLOODWAY CRITERIA MAP

PROJECT NO.	CONTROL	REV.	FIGURE
23592570	5000	0	5 OF 5



LEGEND

- | | | | |
|---|-----------------------------|--|--------------------------|
| ● | PROFILE STATION | | FLOODWAY |
| | MAPPING BOUNDARY | | HIGH HAZARD FLOOD FRINGE |
| | FLOW DIRECTION | | FLOOD FRINGE |
| | PRIMARY HIGHWAY | | 200-YEAR FLOOD EXTENT |
| | SECONDARY ROAD | | 500-YEAR FLOOD EXTENT |
| | LOCAL ROAD | | |
| | CHANNEL CENTRELINE | | |
| ★ | HYDROMETRIC GAUGING STATION | | |
-
- | | |
|-----------------------------|---------|
| HYDRAULIC STRUCTURES | |
| | CULVERT |
| | BRIDGE |
-
- DESIGN DISCHARGE**
BOYER RIVER = 37.1 M³/S



CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



CONSULTANT



YYYY-MM-DD	2025-03-21
DESIGNED	LH
PREPARED	BS
REVIEWED	AL
APPROVED	LH

REFERENCE(S)

ROADS AND WATERBODIES OBTAINED FROM GEOGRATIS. © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED OR ALTALIS LTD. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA. OTHER IMAGERY COPYRIGHT © 20170409 ESRI AND ITS LICENSORS. SOURCE: MAXAR. USED UNDER LICENSE. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

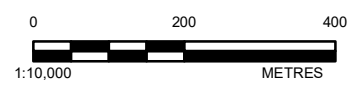
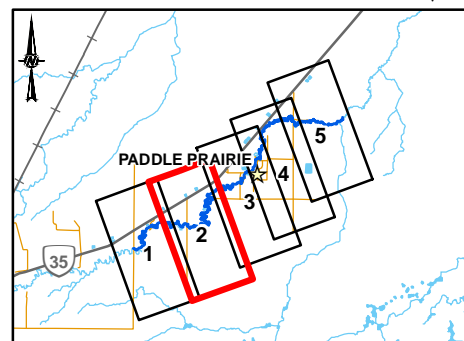
PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
FLOOD HAZARD MAP

PROJECT NO.	CONTROL	REV.	FIGURE
23592570	4000	0	1 OF 5



LEGEND	
●	PROFILE STATION
▬	MAPPING BOUNDARY
➔	FLOW DIRECTION
—	PRIMARY HIGHWAY
—	SECONDARY ROAD
—	LOCAL ROAD
—	CHANNEL CENTRELINE
★	HYDROMETRIC GAUGING STATION
HYDRAULIC STRUCTURES	
◻	CULVERT
—	BRIDGE
▬	FLOODWAY
▬	HIGH HAZARD FLOOD FRINGE
▬	FLOOD FRINGE
▬	200-YEAR FLOOD EXTENT
▬	500-YEAR FLOOD EXTENT
DESIGN DISCHARGE BOYER RIVER = 37.1 M ³ /S	



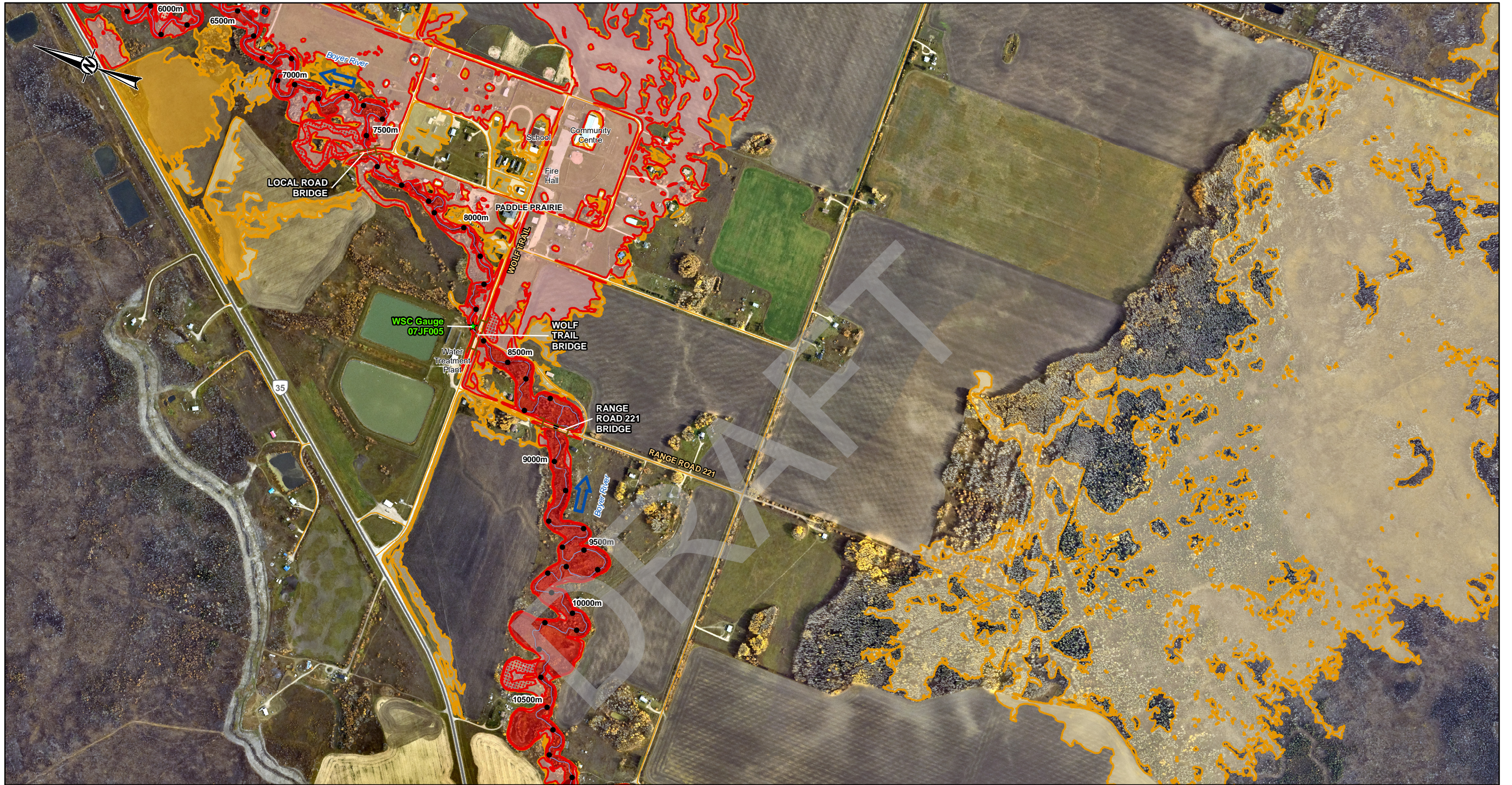
CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



CONSULTANT	YYYY-MM-DD	2025-03-21
DESIGNED	LH	
PREPARED	BS	
REVIEWED	AL	
APPROVED	LH	

REFERENCE(S)
ROADS AND WATERBODIES OBTAINED FROM GEOGRATIS. © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED OR ALTALIS LTD. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA. OTHER IMAGERY COPYRIGHT © 20170409 ESRI AND ITS LICENSORS. SOURCE: MAXAR. USED UNDER LICENSE. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

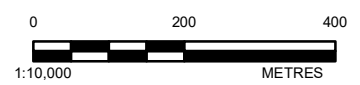
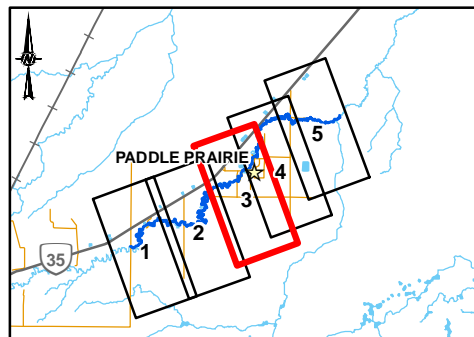
PROJECT		TITLE	
PADDLE PRAIRIE FLOOD STUDY		FLOOD HAZARD MAP	
PROJECT NO.	CONTROL	REV.	FIGURE
23592570	4000	0	2 OF 5



LEGEND

●	PROFILE STATION	HYDRAULIC STRUCTURES	■	FLOWWAY
▬	MAPPING BOUNDARY	◻	■	HIGH HAZARD FLOOD FRINGE
➔	FLOW DIRECTION	▬	▬	FLOOD FRINGE
▬	PRIMARY HIGHWAY	▬	▬	200-YEAR FLOOD EXTENT
▬	SECONDARY ROAD	▬	▬	500-YEAR FLOOD EXTENT
▬	LOCAL ROAD	▬	▬	
▬	CHANNEL CENTRELINE			
★	HYDROMETRIC GAUGING STATION			

DESIGN DISCHARGE
BOYER RIVER = 37.1 M³/S



CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



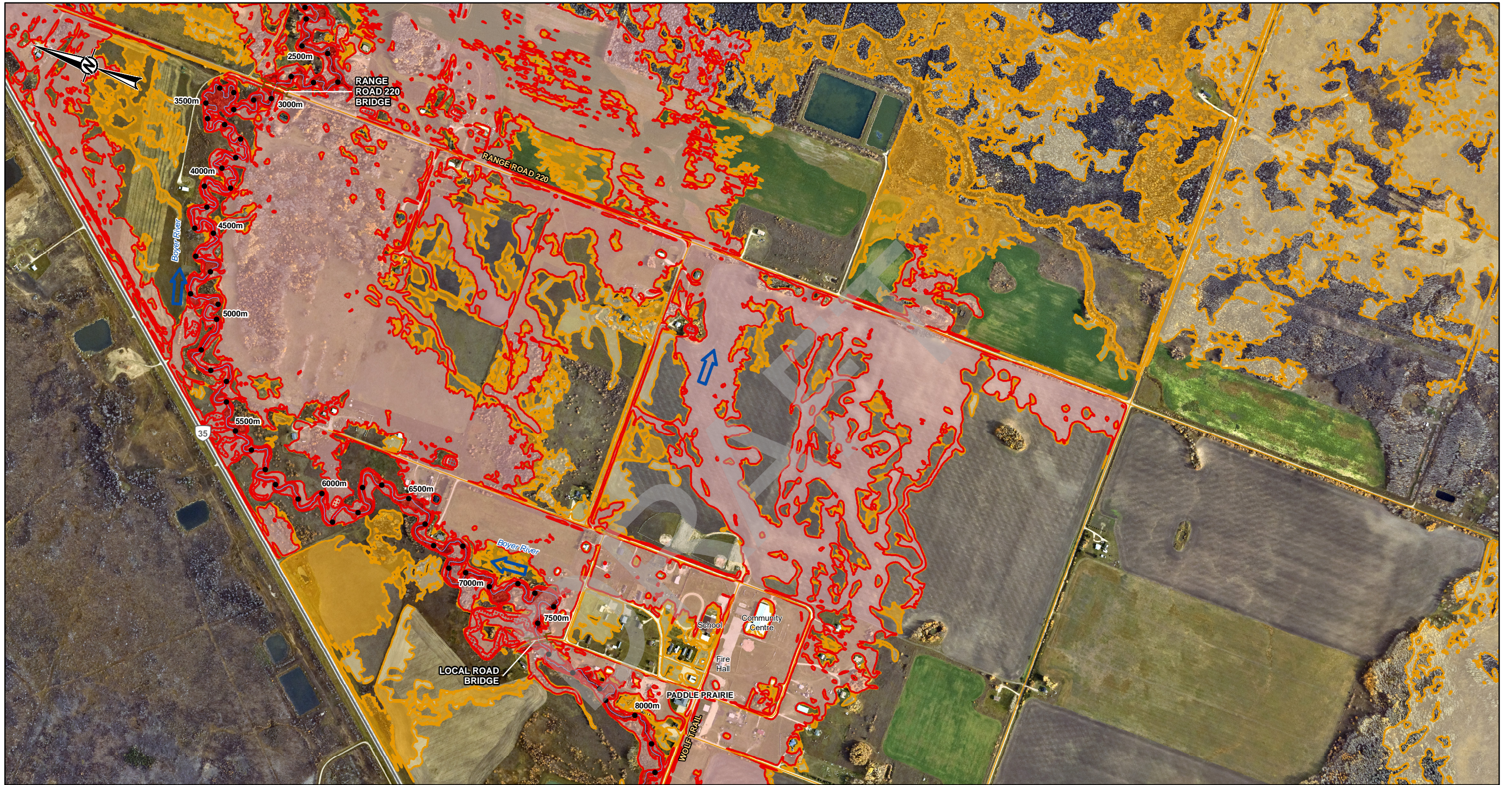
CONSULTANT



YYYY-MM-DD	2025-03-21
DESIGNED	LH
PREPARED	BS
REVIEWED	AL
APPROVED	LH

REFERENCE(S)
ROADS AND WATERBODIES OBTAINED FROM GEOGRATIS. © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED OR ALTALIS LTD. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA. OTHER IMAGERY COPYRIGHT © 20170409 ESRI AND ITS LICENSORS. SOURCE: MAXAR. USED UNDER LICENSE. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

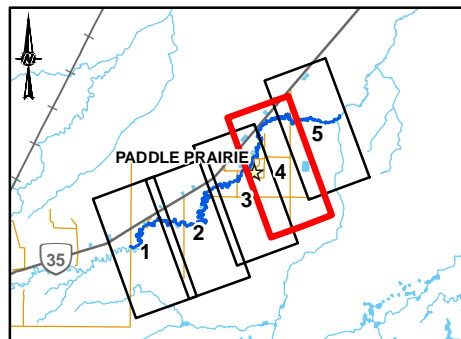
PROJECT PADDLE PRAIRIE FLOOD STUDY			
TITLE FLOOD HAZARD MAP			
PROJECT NO.	CONTROL	REV.	FIGURE
23592570	4000	0	3 OF 5



LEGEND

- | | | | | |
|---|-----------------------------|----------------------|---|--------------------------|
| ● | PROFILE STATION | HYDRAULIC STRUCTURES | ▭ | FLOODWAY |
| ▭ | MAPPING BOUNDARY | ○ | ▭ | HIGH HAZARD FLOOD FRINGE |
| ➔ | FLOW DIRECTION | ▭ | ▭ | FLOOD FRINGE |
| — | PRIMARY HIGHWAY | ▭ | ▭ | 200-YEAR FLOOD EXTENT |
| — | SECONDARY ROAD | ▭ | ▭ | 500-YEAR FLOOD EXTENT |
| — | LOCAL ROAD | | | |
| — | CHANNEL CENTRELINE | | | |
| ★ | HYDROMETRIC GAUGING STATION | | | |

DESIGN DISCHARGE
BOYER RIVER = 37.1 M³/S



CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



CONSULTANT



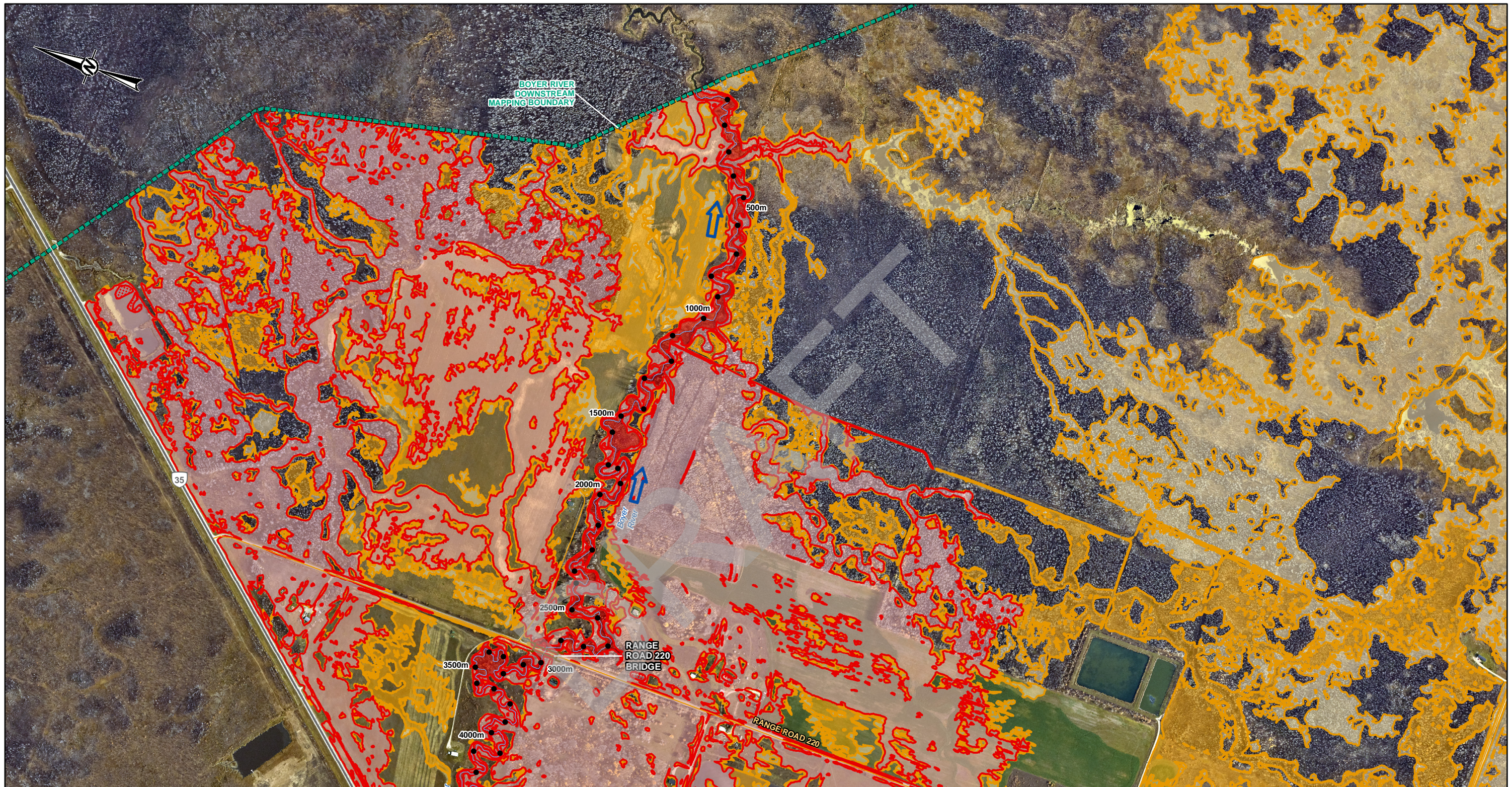
YYYY-MM-DD	2025-03-21
DESIGNED	LH
PREPARED	BS
REVIEWED	AL
APPROVED	LH

REFERENCE(S)
ROADS AND WATERBODIES OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED OR ALTALIS LTD. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA. OTHER IMAGERY COPYRIGHT © 20170409 ESRI AND ITS LICENSORS. SOURCE: MAXAR. USED UNDER LICENSE. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
FLOOD HAZARD MAP

PROJECT NO.	CONTROL	REV.	FIGURE
23592570	4000	0	4 OF 5



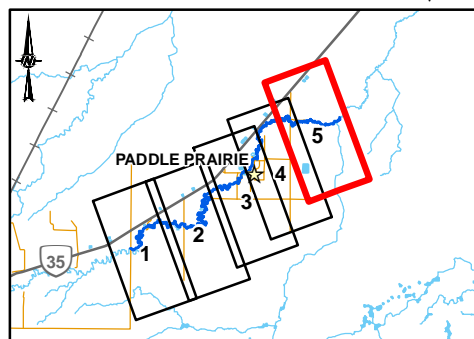
- LEGEND**
- PROFILE STATION
 - MAPPING BOUNDARY
 - ➔ FLOW DIRECTION
 - PRIMARY HIGHWAY
 - SECONDARY ROAD
 - LOCAL ROAD
 - CHANNEL CENTRELINE
 - ★ HYDROMETRIC GAUGING STATION

- HYDRAULIC STRUCTURES**
- CULVERT
 - BRIDGE

- FLOODWAY
- HIGH HAZARD FLOOD FRINGE
- FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

DESIGN DISCHARGE
BOYER RIVER = 37.1 M³/S

SHEET 4 ↓



CLIENT
ALBERTA ENVIRONMENT AND
PROTECTED AREAS



CONSULTANT



YYYY-MM-DD	2025-03-21
DESIGNED	LH
PREPARED	BS
REVIEWED	AL
APPROVED	LH

REFERENCE(S)
ROADS AND WATERBODIES OBTAINED FROM GEOGRATIS. © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED OR ALTALIS LTD. © GOVERNMENT OF ALBERTA 2023. ALL RIGHTS RESERVED. PROJECT IMAGERY CAPTURED OCTOBER 2023 BY OGL ENGINEERING FOR THE GOVERNMENT OF ALBERTA. OTHER IMAGERY COPYRIGHT © 20170409 ESRI AND ITS LICENSORS. SOURCE: MAXAR. USED UNDER LICENSE. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 117

PROJECT
PADDLE PRAIRIE FLOOD STUDY

TITLE
FLOOD HAZARD MAP

PROJECT NO.	CONTROL	REV.	FIGURE
23592570	4000	0	5 OF 5

I:\CLIENTS\GOVERNMENT_OF_ALBERTA\23592570_Paddle_Prairie\Flood_Hazard_Mapping\23592570_GoverningFloodHazard_Rev0.mxd PRINTED ON: 2025-03-21 AT: 2:44:34 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B



DRAFT

APPENDIX I

Climate Change Flood Profiles

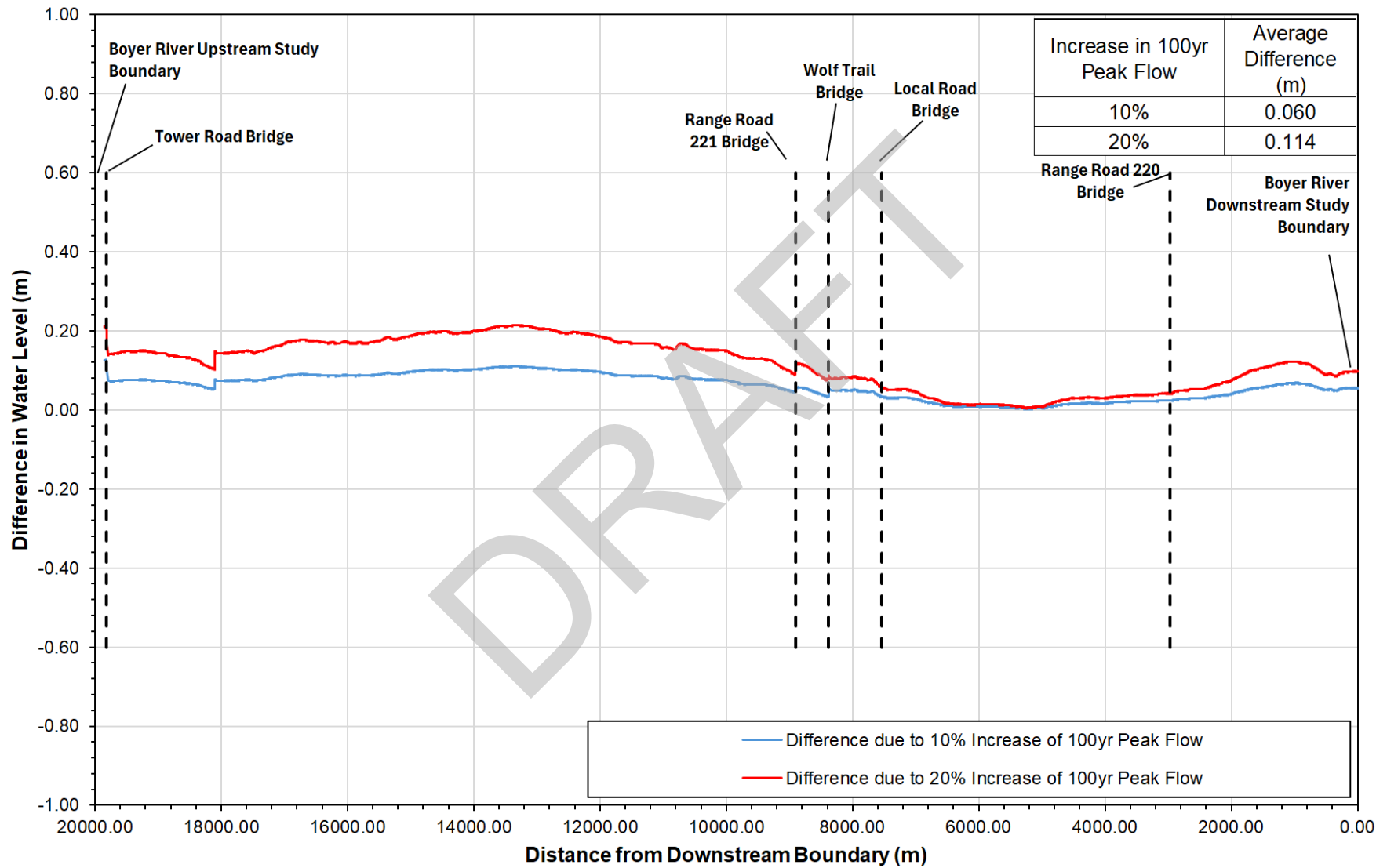


Figure I-1: Simulated Water Surface Profile along the Boyer River Study Reach Due to Climate Change

Table I-1: Water Level Difference along the Boyer River Study Reach due to Climate Change

River	River Station (m)	Water Level for 100-Year Peak Flow (Base Case) (m)	Water Level for 10% Increase in Peak Flow (m)	Water Level for 20% Increase in Peak Flow (m)	Difference due to 10% increase in Peak Flow (m)	Difference due to 20% increase in Peak Flow (m)
Boyer River	19850	369.61	369.74	369.82	0.13	0.21
Boyer River	19350	368.80	368.88	368.95	0.08	0.15
Boyer River	18850	368.54	368.61	368.68	0.07	0.14
Boyer River	18350	368.26	368.33	368.39	0.06	0.12
Boyer River	17850	367.70	367.77	367.84	0.07	0.14
Boyer River	17350	367.34	367.42	367.49	0.08	0.15
Boyer River	16850	366.96	367.05	367.13	0.09	0.17
Boyer River	16350	366.58	366.67	366.75	0.09	0.17
Boyer River	15850	366.15	366.24	366.32	0.09	0.17
Boyer River	15350	365.82	365.92	366.01	0.09	0.18
Boyer River	14850	365.52	365.62	365.71	0.10	0.19
Boyer River	14350	365.20	365.30	365.39	0.10	0.20
Boyer River	13850	364.89	364.99	365.09	0.10	0.20
Boyer River	13350	364.58	364.69	364.79	0.11	0.21
Boyer River	12850	364.23	364.34	364.44	0.11	0.21
Boyer River	12350	363.90	364.00	364.10	0.10	0.20
Boyer River	11850	363.59	363.68	363.77	0.09	0.18
Boyer River	11350	363.34	363.43	363.51	0.09	0.17
Boyer River	10850	363.05	363.12	363.20	0.08	0.15
Boyer River	10350	362.41	362.49	362.57	0.08	0.15
Boyer River	9850	362.21	362.28	362.35	0.07	0.14
Boyer River	9350	362.11	362.17	362.23	0.06	0.13
Boyer River	8850	361.72	361.78	361.84	0.06	0.12
Boyer River	8350	360.94	360.99	361.02	0.05	0.09
Boyer River	7850	360.10	360.14	360.18	0.05	0.08

Table I-1: Water Level Difference along the Boyer River Study Reach due to Climate Change

River	River Station (m)	Water Level for 100-Year Peak Flow (Base Case) (m)	Water Level for 10% Increase in Peak Flow (m)	Water Level for 20% Increase in Peak Flow (m)	Difference due to 10% increase in Peak Flow (m)	Difference due to 20% increase in Peak Flow (m)
Boyer River	7350	359.32	359.35	359.37	0.03	0.05
Boyer River	6850	358.96	358.98	359.00	0.02	0.03
Boyer River	6350	358.42	358.43	358.43	0.01	0.02
Boyer River	5850	357.75	357.76	357.76	0.01	0.01
Boyer River	5350	357.17	357.18	357.18	0.00	0.01
Boyer River	4850	356.70	356.71	356.72	0.01	0.02
Boyer River	4350	356.35	356.37	356.38	0.02	0.03
Boyer River	3850	355.86	355.88	355.89	0.02	0.03
Boyer River	3350	355.54	355.56	355.58	0.02	0.04
Boyer River	2850	355.39	355.41	355.44	0.03	0.05
Boyer River	2350	354.84	354.88	354.90	0.03	0.06
Boyer River	1850	354.21	354.26	354.30	0.05	0.09
Boyer River	1350	353.78	353.85	353.90	0.06	0.11
Boyer River	850	353.31	353.37	353.43	0.07	0.12
Boyer River	350	352.51	352.56	352.60	0.05	0.09
Boyer River	0	352.15	352.20	352.25	0.06	0.10



DRAFT

